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Numerical Calculation of Pressure Loss Coefficients in External Reactor Vessel Cooling Channel

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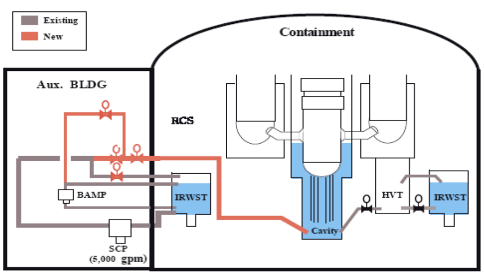
1. Introduction

The hypothetical scenario of a severe accident with core meltdown and formation of a melt pool in the lower plenum of the reactor pressure vessel (RPV) can result in the failure of the RPV and the discharging of the melt to the containment. One accident management strategy could be the stabilization of the RPV by cooling the outside vessel wall with water. This is the concept of In-Vessel Retention External Reactor Vessel Cooling (IVR-ERVC) (Fig. 1).

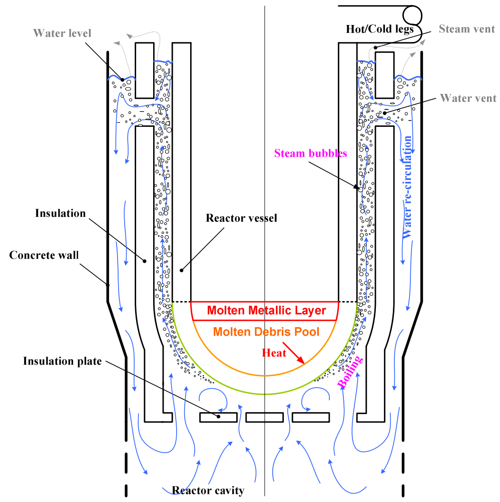
To simulate the severe accident progression and to estimate overall performance of the In-Vessel Retention strategy when external reactor vessel cooing, natural circulation flow rate is the key role because the natural convection heat transfer rate is depend on the natural circulation flow rate, dominantly. To calculate the natural circulation flow rate more accurately, We need geometrical properties of the cooling channel such as the cross sectional areas, pressure loss coefficient caused by obstacles, sudden changes in flow direction and sudden changes of the cross sectional area.

While geometrical properties can be obtained from design documents related to the reactor vessel, experimental studies or numerical studies must be carried out to obtain the pressure loss coefficient.

A few studies have been applied the pressure loss coefficient to simulate a severe accident including the In-Vessel Retention strategy with the external cooling. In the present study, pressure loss coefficients for single phase flow in the cooling channel are calculated using a computational fluid dynamics(CFD).



(a) Cavity flooding strategy for IVR-ERVC



(b) General flow pattern

Fig. 1 Schematic diagram of IVR-ERVC

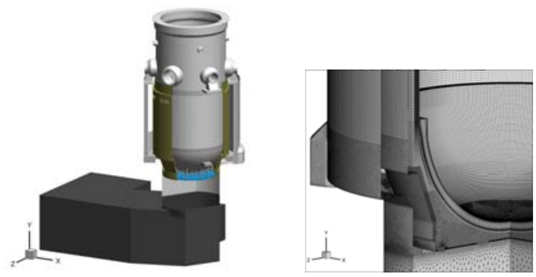


Fig. 2 3D Configuration for the numerical analysis.

2. Numerical Methods

Pressure loss coefficients in the external cooling channel in APR1400 are calculated using a computational fluid dynamics (CFD) technique. A three-dimensional geometric model for numerical simulation based on the current design drawings is generated as shown in Fig. 2. For a numerical calculation based on finite volume formation, a three-dimensional mesh system is generated with about 14,000,000 cells which consisted of hexahedral and tetrahedral cells. Several conservation equations are numerically solved to obtain sing phase flow fields.

Pressure loss coefficients, K, is described from the Darcy equation as follows

$$\Delta P = K \frac{1}{2} \rho V^2 \qquad K = \frac{2\Delta P}{\rho V^2}$$

V is the average upstream velocity at the inlet of the IVR-ERVC.

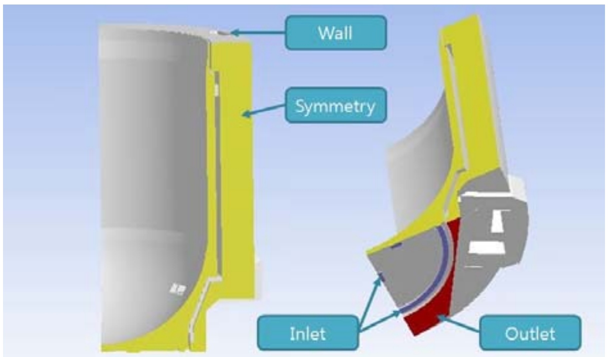


Fig. 3 Boundary conditions for the numerical analysis.

Using the above equations, this study try to calculate the pressure loss coefficients in the case of 10, 50, 250, 500, 1000 and 1500 kg/s mass flow rate of the inlet.

3. Results

Fig. 4 shows the pressure fields at the cross section away 10 degrees from the symmetry surface have a range of 4300 to 5600 Pa in upward flow. The pressure fields have low values in descending flow. There are large pressure drops near the water vent and the lower head due to sudden changes of flow areas. The velocity fields are shown in Fig. 5. The lower part and water vent part have larger values of velocity than the other parts particularly at the water vent part and the water vent part has a range of 1.2 to 1.6 m/s. On the contrary, descending flow has the low velocity. Similar results are obtained in the case of 10, 50, 250, 1000 and 1500 kg/s mass flow rate.

Fig. 6 shows the calculated pressure loss coefficients with different mass flow rates. Pressure loss coefficients have a range of 7.9 to 9.4. The pressure loss coefficients show a sudden change until 250 kg/s, but show a gradual change over 250kg/s.

4. Conclusions

To calculate the natural circulation flow rate more accurately in the external cooling using 1D severe accident system code, pressure loss coefficients in the cooling channel are calculated using a CFD. The calculated pressure loss coefficients can be used to increase accuracy of severe accident analysis including IVR strategy using 1D system code.

Acknowledgement

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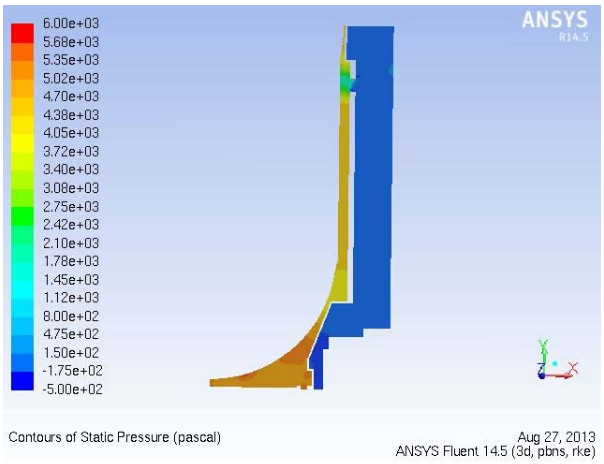

Fig. 4 Pressure contours at the cross section away 10 degrees from the symmetry surface (mass flow rate 500kg/s).

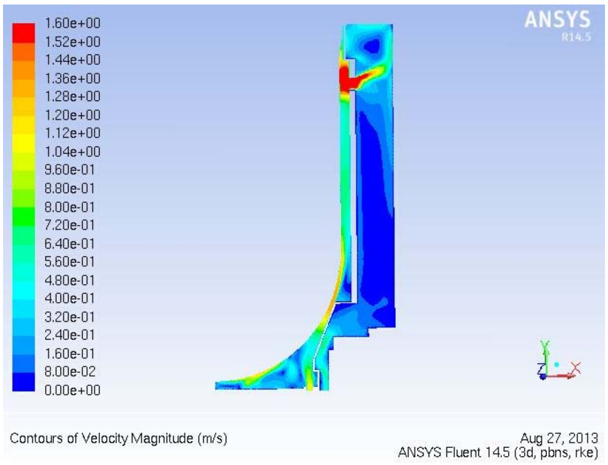

Fig. 5 Velocity contours at the cross section away 10 degrees from the symmetry surface (mass flow rate 500kg/s).

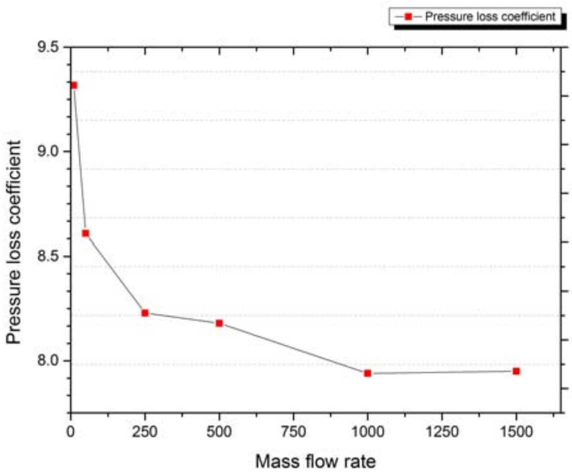

Fig. 6 Pressure loss coefficients in the external cooling channel in APR1400.