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Thermal Load Analysis for IVR-ERVC Evaluation in SMART

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1. Introduction

IVR (In-Vessel corium Retention) through 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. 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 SMART (System-integrated Modular Advanced ReacTor)[1], as a design feature for severe accident management. Thermal load analysis from the corium pool to the outer reactor vessel in the lower plenum of the reactor vessel has been performed to evaluate IVR-ERVC for the SMART.

2. Initial Condition for Thermal Load Analysis

Fig.1 shows the corium pool formation in the lower plenum of the reactor vessel. In this analysis, all core material is melted and relocated to the lower plenum during a severe accident.

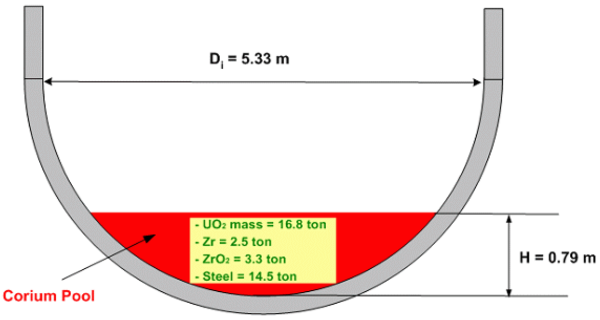

Fig. 1. Corium pool formation in the lower plenum of the reactor vessel.

Fig. 2 shows an input model for the thermal load analysis of the SMART under IVR-ERVC conditions. In this analysis, a two-layer formation of the corium pool is assumed in the lower plenum of the reactor vessel, which is an oxidic layer of UO_2, ZrO_2, and a metallic layer of Zr and stainless steel. The lower oxidic layer thickness is determined by 16.8 tons of UO_2 and 3.3 tons of ZrO_2, and the upper oxidic layer thickness is determined by 2.5 tons of Zr and 14.5 tons of steel. The height of the oxidic and metallic layers is 0.54 m and 0.25 m, respectively.

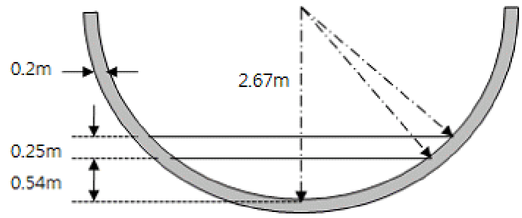

Fig. 2. Two layer formation of the corium pool in the lower plenum of the reactor vessel.

The thermal load analysis is concentrated on the heat flux distribution in consideration of a focusing effect in the thin metallic layer. This effect of the metallic layer is mainly determined by the molten pool configuration in the lower plenum of the reactor vessel. The melt pool configurations inside the lower plenum affect the initial thermal load to the outer reactor vessel and play a key role in determining the integrity of the reactor vessel. As shown in Fig. 3, a numerical model has been developed for a thermal load response to the outer RPV during a severe accident[2]. The model is based on a simple mechanistic model using an energy balance equation. The governing equations were solved using a non-linear Newton-Raphson method.

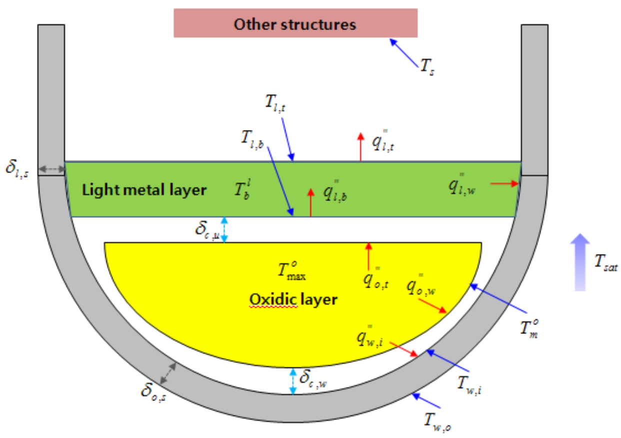

Fig. 3. Simple numerical model of thermal load analysis for the SMART.

Fig. 4 shows the crust thickness of the oxdic corium pool as a function of the angle in the lower plenum of the reactor vessel. Angle 0 ˚ indicates the bottom of the lower plenum of the reactor vessel. The maximum crust thickness of the oxidic pool is approximately 11 cm at the bottom, and the minimum crust thickness is approximately 2 cm at the top of the oxdic corium, which results from the natural convection heat transfer in the oxidic corium pool.

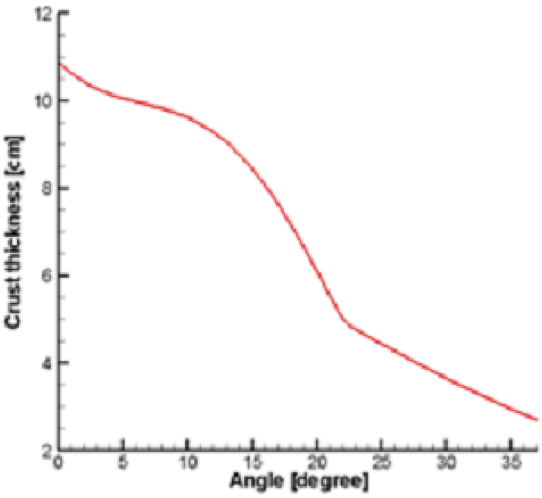

Fig. 4. Simple analysis results of the crust thickness as a function of angle in the corium pool.

Fig. 5 shows simple analysis result of the reactor vessel thickness as a function of angle in the corium pool. The reactor vessel thickness of the integral reactor is 20 cm. The reactor vessel, which is in contact with the oxdic corium pool, is not melted, but in contact with the metallic pool is melted. Finally, the reactor vessel thickness in contact with the metallic pool is 18.6 cm.

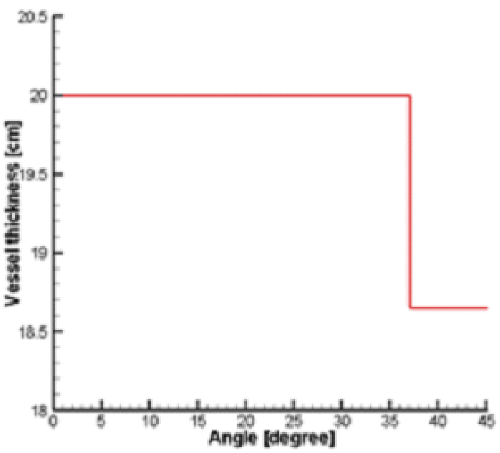

Fig. 5. Simple analysis results of the reactor vessel thickness as a function of angle in the corium pool.

Fig. 6 shows simple analysis results of the heat flux distribution as a function of angle in the corium pool. The maximum heat flux from the corium pool to the outer reactor vessel is approximately 0.25 MW/m^2 in the metallic layer, owing to the focusing effect. This value is very small than other plants, because of small thermal power and large reactor vessel geometry in the SMART.

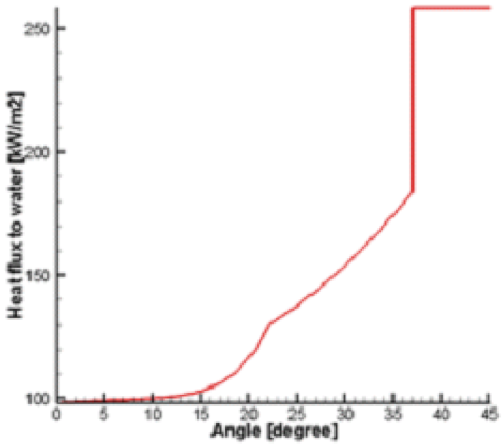

Fig. 6. Simple analysis results of the heat flux distribution as a function of angle in the corium pool.

3. Conclusion

Thermal load analysis from the corium pool to the outer reactor vessel in the lower plenum of the reactor vessel has been performed to evaluate IVR-ERVC for SMART. The maximum heat flux from the corium pool to the outer reactor vessel is approximately 0.25 MW/m^2 in the metallic layer, owing to the focusing effect. It is necessary to evaluate the thermal margin for success of the IVR-ERVC during a severe accident in the SMART by a comparison of the thermal load with the maximum heat removal rate of the CHF on the outer reactor vessel wall

ACKNOWLEDGMENTS

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[1] The SMART Development Team, The SMART Standard Safety Analysis Report, KAERI Report, 2010.
[2] J. R. Lee, R. J. Park and S. W. Hong, “Analysis on Thermal Load Response for the In-Vessel Retention during a Severe Accident,” NURETH-14, Toronto, Ontario, Canada, 2011.