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STRUCTURAL ANALYSIS OF SMART RPV LOWER HEAD UNDER ERVC CONDITIONS DURING A SEVERE ACCIDENT

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ABSTRACT

An IVR-ERVC (In-Vessel corium Retention through External Reactor Vessel Cooling) is known to be an effective means for maintaining the reactor vessel integrity during a severe accident, especially for low- and medium-power nuclear power plants such as AP600 and AP1000. This measure has been also adopted for the high-power reactors of APR(Advanced Power Reactor)1400 and APR+ as an accident management strategy, and a SMART (System-integrated Modular Advanced ReacTor) as well. Despite low thermal power, the size of SMART RPV (Reactor Pressure Vessel) is relatively large and thick compared to the existing LWRs (Light Water Reactors) because the main components of the steam generators, pressurizer, and reactor coolant pumps are located in the reactor vessel. In addition, it has no penetration tubes at the lower head. Because of these structural characteristics, the thermo-mechanical behaviour during a severe accident should be different from the typical LWRs.

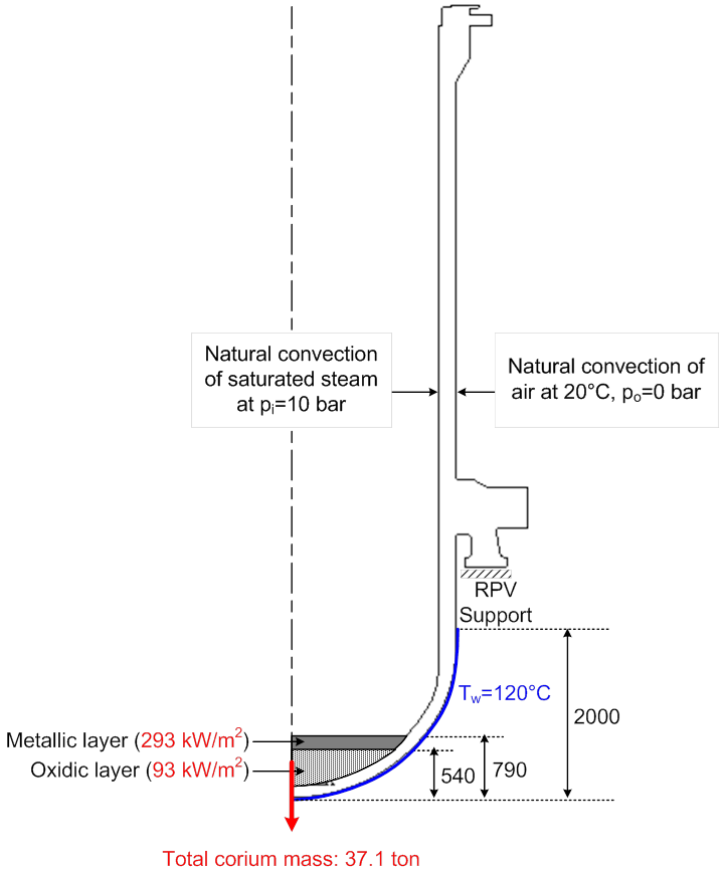

Figure 1. 2D axisymmetric model with initial and boundary conditions.

This paper addresses a preliminary thermo-mechanical analysis to investigate the structural integrity of SMART RPV lower head during a severe accident. A transient coupled thermo-mechanical creep analysis of the SMART RPV lower head under the ERVC conditions was performed for a postulated accident scenario using a commercial code ANSYS 18.0, taking into account both the thermal and integral mechanical loads. A simplified computational domain of an axisymmetric 2D model with the initial and boundary conditions is shown in Fig. 1. The 37.1 tons of corium pool located in the lower head was provided by MELCOR 1.8.6 code analysis, and the fluxes from two (oxdic and metallic) melt layers to the RPV lower head were evaluated by SIMPLE (Severe In-vessel Melt Progression in Lower plenum Environment) code. It was assumed that the RPV is depressurized down to 10 bar and heat transfer occurs at the inner wall by natural convection of saturated steam. The lower head near the bottom was assumed to maintain 120℃ by ERVC and the vertical outer wall is exposed to the ambient air. The weight of RPV and corium pool is supported at a RPV support.

An ‘element-birth-and-death’ technique was implemented in ANSYS 18.0 to deactivate of the elements higher than the vessel melting temperature (1501℃). This technique enables to reflect the erosion of the vessel wall (i.e., vessel wall thickness change). Similarly, the conductivity and specific heat are set to infinity and zero for the deactivated elements. However, additional mass from the melted vessel is not taken into account in total corium mass, and the lower head deformation by erosion and creep is assumed to have negligible effect on the melt pool heat transfer.

The element type used is QuadPlane223 which is a 2D 8-node coupled-field (structural -thermal) solid. Thermo-mechanical properties of the SMART RPV (SA508, Grade 3, Class 1) were taken by ASME (American Society of Mechanical Engineers) code and KAERI material database for high temperature range.

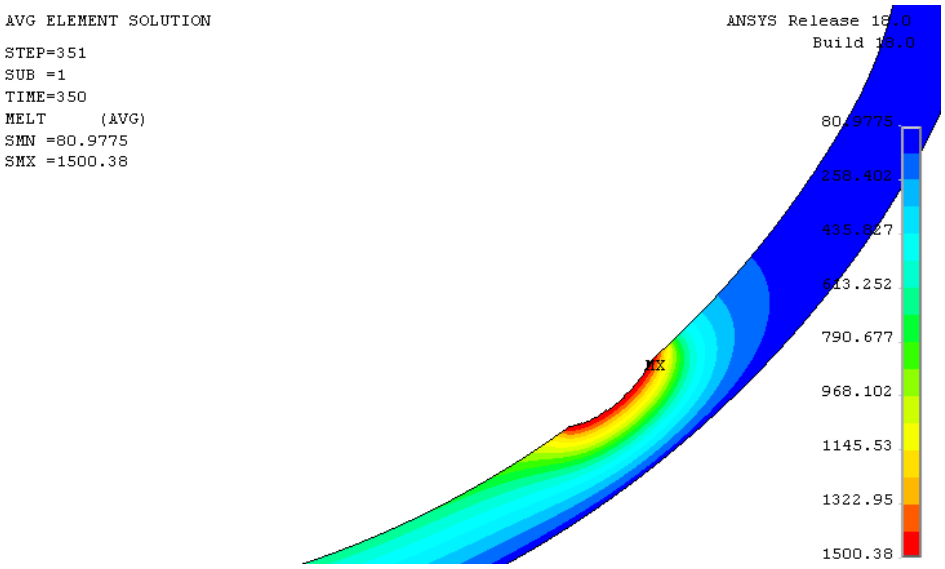

Figure 2. Temperature distribution of the SMART RPV lower head.

Figure 2 shows the temperature distribution of the RPV lower head at the steady state. It was found that that the inner wall of the RPV lower head is eroded partially by high heat flux of the metallic melt but the structural integrity is retained by ERVC. The lower head deformation and stress distributions by corium weight, internal pressure and thermal expansion showed that large stress and deformation at the bottom of the lower head. However, ERVC was also turned out a very effective means to retard the vessel creep and subsequently prevent the global vessel failure. Further analysis is necessary to investigate the structural integrity of the RPV lower head for various accident scenarios.