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The Steady State Performance and Limiting Accident Analysis for a PMR 200MWth Prototype Reactor

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1. Introduction

We have performed the steady state and limiting accident analysis of a PMR 200MWth, which is one of the scale-down prototype reactor models for an NHDD (Nuclear Hydrogen Development and Demonstration). The system configurations of the core and the air-cooled RCCS are referred to the PMR 600MWth GT-MHR design [1]. The GAMMA code [2] is applied for the steady state, HPCC and LPCC analysis. The analysis provides the key design parameters of the steady state conditions such as the peak fuel temperatures, RPV temperature, RCS flow rate, CR bypass flow and heat loss to the RCCS. Then, it also provides the HPCC and LPCC transient behaviors of the main components to confirm the natural circulation cooling function of the RCCS for the feasibility of the PMR 200MWth reactor as a scale-down prototype reactor model.

2. Analysis Method

Based on the PMR 600MWth GT-MHR design [1], the PMR 200MWth is designed as a candidate prototype reactor for an NHDD with the annular core of a prismatic modular fuel assembly. The prismatic core [3] is composed of three annular rings with 48 fuel assemblies and 7 axial fuel block layers at each fuel assembly. The core is surrounded by the inner, outer, bottom and top reflectors. The startup and operating control rod (CR) holes are located at the inner fuel ring (6 holes) and the outer reflector (12 holes), respectively. Fuel assemblies in the outer and the middle rings have eight reserved shutdown channels (RSC). There are 102 large holes and 6 small holes of the helium coolant channels at each standard fuel assembly. 88 large holes and 7 small holes are also located at each CR/RSC fuel assembly. The 83 kg/s of the primary helium reactor cooling flow (RCS) comes from the outer annular pipe of the cross vessel with a pressure of 7.0 MPa and an inlet temperature of 490℃. The coolant goes up to the top plenum through the annular riser channel between the core barrel (CB) and the reactor pressure vessel (RPV). The heated coolant going down through the holes in the fuel assembly gathers at the outlet plenum, and then goes to the power conversion unit with an outlet temperature of 950℃ through the inner pipe of the cross vessel. The air-cooled RCCS system has 219 rectangular panels for removing the decay heat during an accident by a natural circulation cooling.

Figure 1 shows the fluid and solid parts model of the reactor and the RCCS system for the GAMMA code [2]. The prismatic core is modeled as three solid blocks of the inner, middle and outer fuel assembly rings. The bypass flows of the CR/RSC holes are modeled to pass through the inner and outer reflectors. The scenarios of the HPCC and LPCC accidents are assumed as follows; (i) In the case of the HPCC (High Pressure Conduction Cooling) accident, after the reactor scrammed at 0 second, the core power switches to the decay heat curve and the inlet flow rapidly decreases to zero during 60 seconds. The outlet pressure slowly decreases from 7.0 to 5.03 MPa during 8 hours. (ii) In the case of the LPCC (Low Pressure Conduction Cooling), the inlet flow is set to zero at 0 second. The outlet pressure rapidly decreases from 7.0 to 0.1 MPa during 10 seconds. The decay power reduces to 5% of the total power after 10 second and to below 1% of the total power after 3 hours.

3. Results and Discussions

The results of the steady state indicate that the flow rates of the RCS, RCCS and CR bypasses are 82.985, 12.9 and 9.5 kg/s, respectively. The RCS flow rate is adjusted for the outlet temperature of 950 ℃. Total bypass is predicted at 11% of the RCS flow rate. The peak fuel temperature of 1165 ℃ occurs just above the bottom of the inner fuel assembly, and is a less than the fuel operating limit of 1250 ℃. The peak RPV temperature of 477 ℃ is less than the operating criteria (495 ℃) of the modified 9Cr-Mo material. The temperatures of the fuel assembly and graphite reflectors show an increasing trend along the helium flow direction to the core exit. The unheated zones of the inner and outer reflectors are considerably cooled by a bypass flow, when compared to the heated fuel assembly zone. The heat loss to the RCCS is estimated as 1.88 MW.

In the cases of HPCC and LPCC, the decay heat is partially removed by the natural circulation in the core at a high pressure condition, and most of the heat is transferred by a heat conduction of the core components and it is finally removed by the RCCS. The decay power is greater than the RCCS heat removal during 20 hours after the accidents occur. Thus, the peak temperatures of the main components increase at the initial period of the accident and then slowly decrease when the RCCS stably removes the decay heat. Figure 2 shows that the peak fuel temperatures of the HPCC and LPCC are about 1242 ℃ at 23 hours and 1440 ℃ at 31 hours, respectively. These temperatures are less than the fuel failure criteria of 1600 ℃. In addition, the transient behaviors of the HPCC and LPCC indicate that the peak temperatures of the graphite reflectors, fuel rings and main wall components (CB, RPV) are slowly decreasing by the natural circulation cooling function of the RCCS. Based on the results of the steady state, the HPCC and LPCC transient analysis, the PMR 200MWth can be considered as one of the scale-down prototype reactor models.

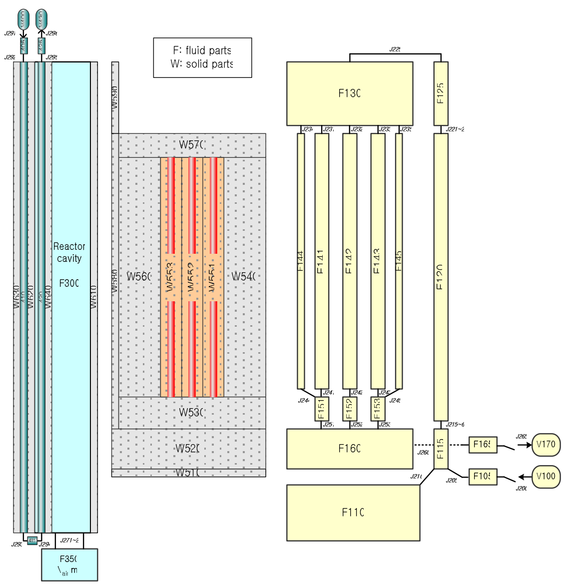
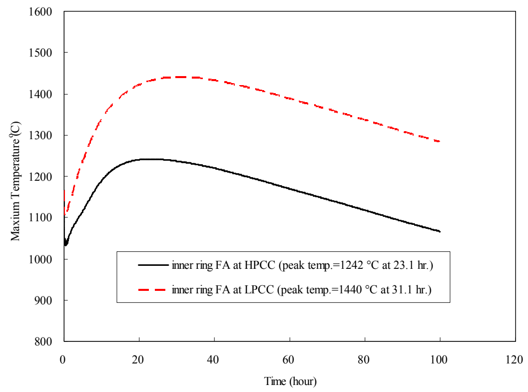
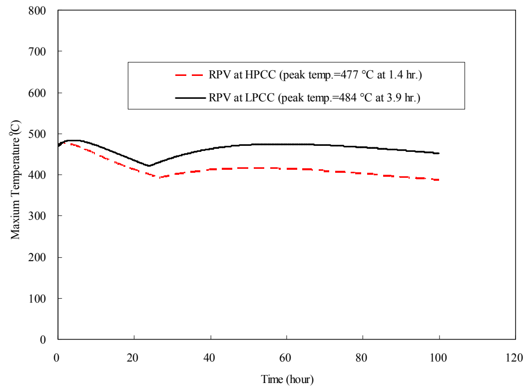


Fig.1 Fluid and Solid Parts Model of PMR 200MWth for GAMMA Code



(a) Fuel Compact Assembly



(b) RPV

Fig.2 Peak Temperatures of Fuel Compact Assembly and RPV

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