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Thermal-Fluid and Safety Analysis of the TRU Deep-Burn MHR Core

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1. Introduction

The DB-MHR (Deep Burn-Modular Helium Reactor) concept was proposed by GA to achieve a very high burnup of the LWR TRU fuel. To increase the TRU discharge burnup, the original GT-MHR of GA [1] was modified for the DB-MHR core: a 5-fuel-ring configuration was adopted instead of the original 3-fuel-ring concept [2].

This paper describes the GAMMA+ [3] thermal-fluid analysis of the 600MW_{th} DB-MHR system at the steady state and the transient condition of LPCC (Low Pressure Conduction Cooling) event. The objective of this study is to characterize the DB-MHR core in terms of the fuel temperature during the nominal and LPCC conditions.

2. Modeling of DB-MHR Core

Figure 1 shows the schematic configuration of the candidate DB-MHR core with 5 fuel rings. Forty eight control rods (CR) are placed in the reflector region and 12 reserved shutdown channels (RSC) are located in the active core. The cooling system of the DB-MHR is composed of the RCS (Reactor Cooling System), the VCS (Vessel Cooling System) and the air-cooled RCCS (Reactor Cavity Cooling System).

The DB-MHR core has the thermal power of 600 MW_{th} , the coolant inlet/outlet temperatures of 490/850 ^oC and the active core height of 7.93 m. The fuel type of $TRUO_2$ kernel is composed of the Pu, U, Np, Am, and Cm isotopes [2]. Compared to the UO_2 kernel diameter of 350～500 μm, a relatively small TRU kernel diameter of 200 μm is designed to reduce the fuel self-shielding and accommodate a very high fuel burnup by considering the current fuel fabrication technologies. On the other hand, the thickness of buffer layer is increased from 100 to 120 μm. The volumetric packing fraction of TRISO particles in a fuel compact is 27%. TRU kernel is coated with four successive layers of buffer, inner PyC, SiC and outer PyC.

The GAMMA+ model of the DB-MHR core accounts for the geometric factors of the main core components and the physical properties of the TRU kernel for the thermal-fluid and safety analysis of the core.

The core flow network model simulates the inlet riser, core coolant channels, FA (Fuel Assembly) gap bypasses, and RSC/CR channels. The gap flow channels are interconnected to each other and also interconnected to the FA coolant flow channels and RSC/CR flow channels through cross-flow junctions.

The solid region in a reactor core is divided into two zones: the fuel region and the non-fuel region (the graphite). One-dimensional heat conduction is used in the fuel region for TRISO particle or fuel compact rod. In the non-fuel region, the multi-dimensional heat conduction is modeled by a continuous porous medium approach. The radiation heat transfer in the core zone is considered by the effective thermal conductivity including the contact conductance, gas conductance and void radiation.

The properties of TRU kernel are assumed to be identical to those of PuO_2 material because the TRU kernel is mainly composed of the Pu isotopes. The TRU fuel of the DB-MHR provides different core power distribution and decay power curve from the UO_2 fuel. The decay power curve is calculated by McCARD and ORIGEN codes. As shown in Figure 2, the decay power of TRU fuel after 2 hours remains substantially higher than that of UO_2 fuel. The decay power level of TRU fuel [4] is 76% higher than that of UO_2 fuel at 500 hours.

3. Results of the Steady State

In the active core, the flow rate changes at the axial location due to the cross flow through the gap between fuel blocks. The maximum bypass flow occurs at the middle of the core, where total RCS flow distributes to the fuel channel (88.7%), the CR/RSC hole (7.1%) and the FA bypass gap (4.2%).

Figure 3 shows the maximum fuel temperature at each fuel ring. The hottest point is observed at the 3rd layer from the bottom of the outer-most ring fuel block, where the peak fuel temperature of 1040 ^oC is less than the normal operation limit of 1250 ^oC of TRISO fuel.

4. Results of LPCC

Figure 4 shows the peak temperature behavior of the main core components during the LPCC event. The peak fuel temperature is 2011 ^oC at 123 hours, which is much higher than the fuel failure limit of 1600 ^oC. The peak RPV temperature of 600 ^oC at 142 hours is also beyond the off-normal operation limits of RPV of SA508 steel (538 ^oC).

This is obviously caused by the lack of the heat absorber due to the reduction of 70% volume in the central reflector as well as by the increased decay power due to TRU fuel compositions of the DB-MHR, compared to the 5-ring central reflector and the UO_2 fuel decay power of the reference GT-MHR.

The heat conduction in the core is dominantly determined by the graphite material because the graphite thermal conductivity and the volume fraction of the graphite in the core are much higher than those of fuel kernel. Based on the sensitivity calculations, it is confirmed that the difference of the thermophysical properties between PuO_2 and UO_2 kernel hardly affects the temperature distributions of core, fuel and TRISO particle.

5. Conclusions

The key design characteristics of the candidate DB-MHR core are the followings;

- At the steady state, the maximum fuel and RPV temperatures are less than the normal operation limits.
- But, 70% reduced central reflector provides the lack of the heat absorber during LPCC.
- A deeply-burned TRU fuel produces a higher decay power, compared to UO_2 fuel.

Thus, the peak fuel and RPV temperatures exceed the generic safety limits during LPCC. In order to guarantee the passive safety, power level reduction or core design change is required for the DB-MHR core loaded with the conventional TRISO particles.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Potter and A. Shenoy, "Gas Turbine-Modular Helium Reactor (GT-MHR) Conceptual Design Description Report", GA Report 910720, Revision 1, General Atomics, July 1996

[2] Yonghee Kim, Francesco Venneri, "Optimization of TRU Burnup in Modular Helium Reactor", Proceedings of ICAPP 2007 Nice, France, May 13-18, 2007.

[3] Hong Sik Lim, Hee Cheon No, "GAMMA Multidimensional Multicomponent Mixture Analysis to Predict Air Ingress Phenomena in an HTGR", Nuclear Science and Engineering 152 (2006) 1-11, 2006

[4] Hyun Chul Lee, Chang Keun Jo, Yonghee Kim, Jae Man Noh, "Decay Heat Analysis of a TRU-fueled Deepburn VHTR Core," Transactions of the Korean Nuclear Society Autumn Meeting Gyeongju, Korea, October 29-30, 2009

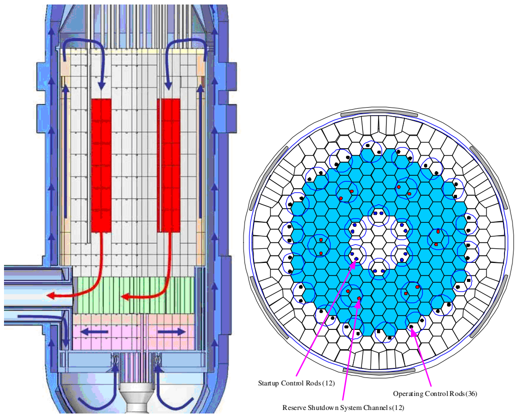

Fig. 1 DB-MHR Core Design Configuration

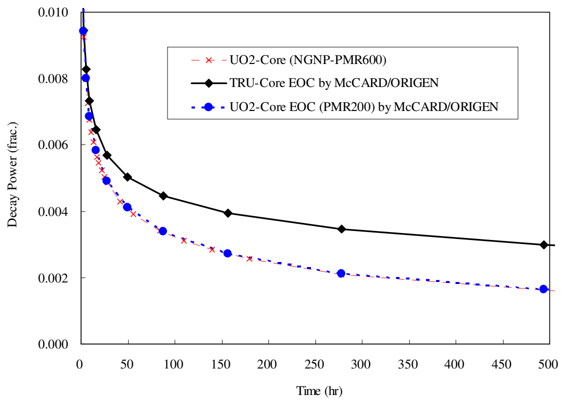

Fig. 2 Decay Power Curve of TRU Fuel Core

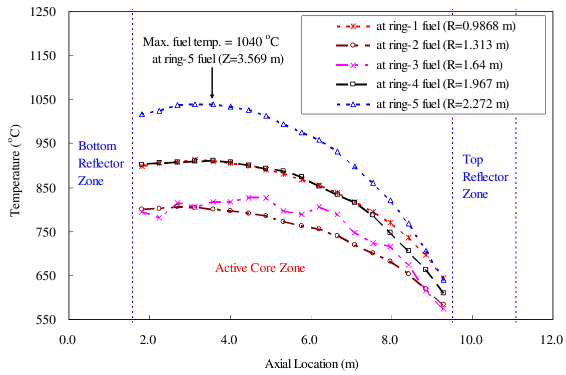

Fig. 3 Maximum Fuel Temperature

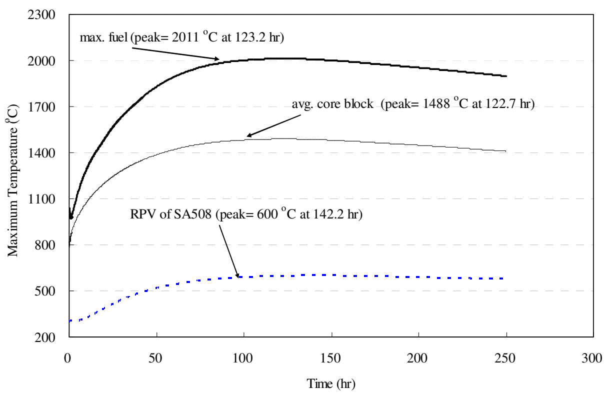

Fig. 4 Peak Temperature Transients during LPCC