Decay Heat Impact on the Maximum Transient Fuel Temperature of the various TRU Compositions in a Deep-Burn MHR Core

Ji Su Jun[a]*, Hong Sik Lim[a], Chang Keun Jo[a], Francesco Venneri[b]
[a]*Korea Atomic Energy Research Institute, P.O.Box105, Yuseong, Daejeon, Korea 305-600*
[b]*Logos Technologies, U.S.A*
[*]*Corresponding author: junjisu@kaeri.re.kr*

1. Introduction

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

This study intends to characterize the decay heat impact on the maximum transient fuel temperature of the various TRU compositions. The volumetric packing fractions (PF) of 4.9%, 5.9% and 6.9% are applied for the TRISO of ($0.2\%UO_2$+$99.8\%(PuO_{1.8}+NpO_2)$+ 0.6mole SiC getter) and the PFs of 7.0% and 8.0% are used for the TRISO of ($30\%UO_2$+$70\%(PuO_{1.8}+NpO_2)$+ 0.6mole SiC getter), respectively, with the kernel diameter of 350 μm and the buffer layer thickness of 100 μm.

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.

For the TRISO of $100\%(PuO_2+NpO_2+Am)$ with the kernel diameter of 200 μm, the buffer layer thickness of 120 μm and the volumetric packing fraction of 27%, the peak fuel temperature during the LPCC (Low Pressure Conduction Cooling) event was evaluated as 2011 °C [3], which was much higher than the nominal transient fuel design limit of 1600 °C. That was 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, respectively.

Thus, the various TRU fuel compositions are considered to reduce the decay power by removing the initial Am isotopes and reducing the volumetric packing fraction of TRISO particles.

The decay power curves [4,5] are calculated by McCARD and ORIGEN codes. As shown in Figure 2, the decay power of a 27% PF TRU is much higher than that of UO_2 fuel, but the reduced PF of TRU with removing the initial Am isotopes can provide lower decay power than that of UO_2 fuel. The decay power of a $30\%UO_2$ mixed TRU is less than that of a $0.2\%UO_2$ mixed TRU [5]. The normal core power distribution is based on the hybrid (using both the axial and the radial shuffling) scheme and the use of B_4C burnable poison.

The GAMMA+ code [6] 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, FB (Fuel Block) gap bypasses, and RSC/CR channels. The gap flow channels are interconnected to each other and also interconnected to the FB 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. 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.

As shown in Figure 3, the TRU kernel is contained with 0.6mole (24% vol. of kernel) SiC getter to prevent the potential kernel migration due to the production of noble fission gases and CO for high burnup fuel and is coated with four successive layers of buffer, inner PyC, SiC and outer PyC. The thermal conductivity of SiC (16.0 W/mK) is much higher than that PuO_2 (2.91 W/mK at 1000 ^oC). Thus, the properties of a TRU kernel are assumed to be volume-averaged values of those of PuO_2 and SiC.

3. Peak Fuel Temperature during LPCC

Figure 4 shows the peak fuel temperature behavior of the various TRU fuel compositions during the LPCC event. For a $0.2\%UO_2$ mixed TRU, the peak fuel temperatures are 1580 ^oC (PF=4.9%), 1644 ^oC (PF=5.9%) and 1685 ^oC (PF=6.9%) at near 80 hours. For a $30\%UO_2$ mixed TRU, the peak fuel temperatures are 1617 ^oC (PF=7.0%) and 1647 ^oC (PF=8.0%), which are relatively low due to a small decay power by the

reduced amount of ($PuO_{1.8}$+NpO_2), compared to a 0.2%UO_2 mixed TRU.

It is noted that these results are based on the annealing effect assumption of H-451 graphite thermal conductivity. It assumes that the degraded thermal conductivity by the irradiation starts to increase at 1300 K and recovers to the unirradiation value at 1600 K due to the annealing effect. For a 0.2%UO_2 mixed TRU (PF=4.9%), if annealing effect is not used, the peak fuel temperature becomes 1749 ^oC instead of 1580 ^oC. The thermophysical properties of the SiC getter hardly affect the temperature distributions of the core, fuel and the TRISO particle, because the heat conduction in the core is dominantly determined by the graphite material.

In spite of the reduced decay power effects, most of the peak fuel temperatures are still higher than the transient fuel design limit of 1600 ^oC due to the lack of heat absorber volume in the central reflector.

4. Conclusions

For a 0.2%UO_2 mixed or a 30%UO_2 mixed TRU, the decay power could be reduced by removing the initial Am isotopes and reducing the volumetric packing fraction of TRISO particles.

For the PF range of 4.9%~8.0%, the peak fuel temperatures during an LPCC event in a 600 MW_{th} DB-MHR core are evaluated as the range of 1580 ^oC ~1685 ^oC, which is still higher than the transient fuel design limit of 1600 ^oC due to the lack of heat absorber volume in the central reflector.

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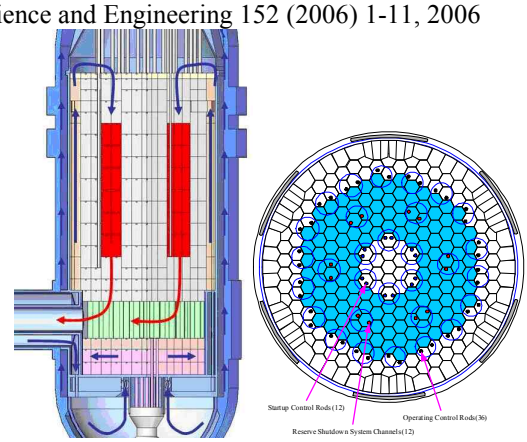

Fig. 1 DB-MHR Core Design Configuration

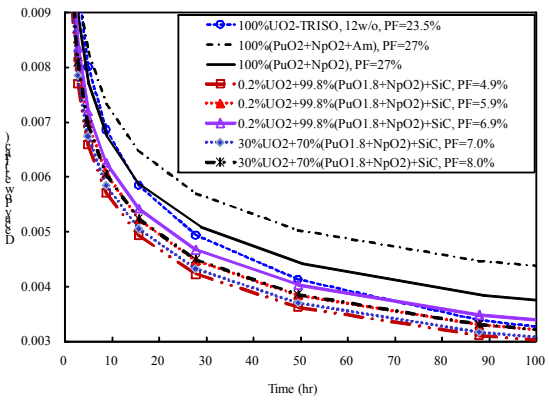

Fig. 2 Decay Power of the TRU Fuel Compositions

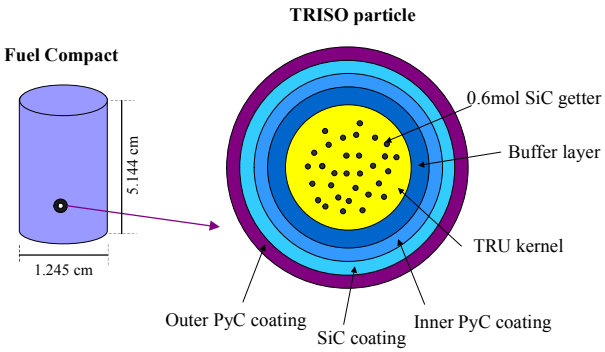

Fig. 3 TRISO Fuel Particle with SiC getter

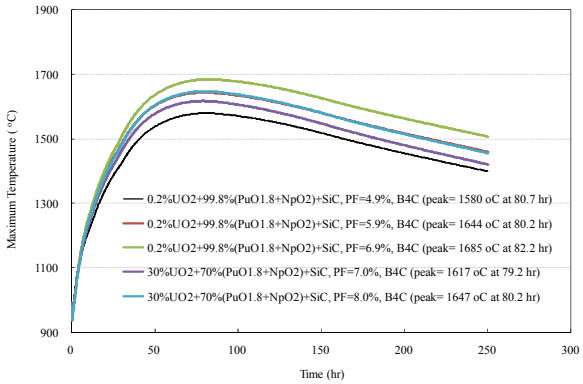

Fig. 4 Peak Fuel Temperature Transients during LPCC