Deep-Burn MHR Neutronic Analysis with a SiC-Gettered TRU Kernel

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1. Introduction

This paper is focused on the nuclear core design of a DB-MHR (Deep Burn-Modular Helium Reactor) [1] core loaded with a SiC-gettered TRU fuel. The SiC oxygen getter is added to reduce the CO pressure in the buffer zone of TRISO. In the paper, the cycle length, reactivity swing, discharged burnup, and the burning rate of plutonium were calculated for the DB-MHR. Also, impacts of uranium addition to the TRU kernel were investigated. Recently, the decay heat of TRU fueled DB core was found to be highly dependent on the TRU loading: the higher the loading, the higher the decay heat. The high decay heat of TRU fuel may lead to unacceptably high peak fuel temperature during an LPCC (Low Pressure Conduction Cooling) accident. Thus, we tried to minimize the decay heat of the core for a minimal peak fuel temperature during LPCC.

2. Core Model and Methodologies

Figure 1 shows a 5-ring core model comprised of 144 fuel columns, which was derived the 3-ring GT-MHR[2]. Each fuel column is comprised of 9 fuel blocks. The fuel block design is identical to that of GT-MHR. The active core height is 7.93m and the core is reflected by 120cm-thick top/bottom graphite reflectors. The coolant inlet and outlet temperatures are 490°C and 850°C, respectively.

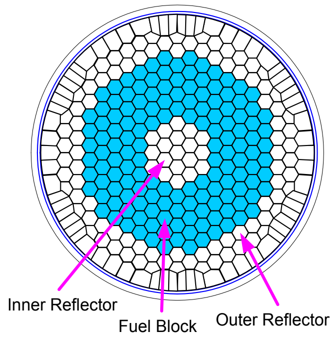

Fig. 1 Core Configuration of the 5-ring DB-MHR

Two types of kernel concept are considered, one is a [0.2%UO_2+99.8%($PuO_{1.8}$+NpO_2)]+0.6mole SiC getter (Case I), the other one is a [30%UO_2 + 70%($PuO_{1.8}$+NpO_2)]+ 0.6mole SiC getter (Case II). The SiC kernel getter is added to the kernel as an oxygen getter to reduce the CO pressure buildup in the buffer zone of the TRISO fuel. The diameter of the SiC-gettered kernel is decided to be 350m to improve the fabricability of the TRISO fuel. In the kernel design with a SiC getter, the volume fraction of the SiC getter is about 24.37%. The coating thickness is as follows: 100 μm for the buffer, 35 μm for the inner PyC layer and SiC coating and 40 μm for the outer PyC coating.

In order to maintain the peak fuel temperature as low as possible during LPCC event, a radial and axial hybrid fuel shuffling scheme is considered as shown in Fig. 2. The fuel blocks in middle ring region (sky-blue) are shuffled axially and the others are shuffled radially. The shuffling scheme is not optimized yet.

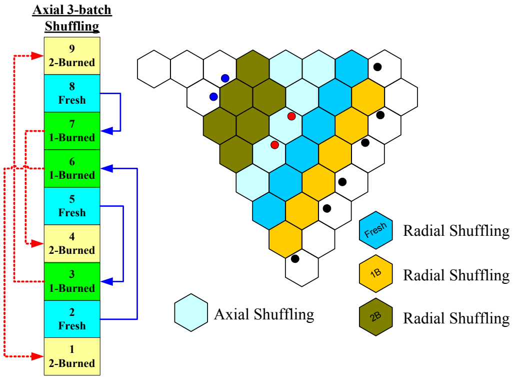

Fig. 2 Radial & axial hybrid fuel shuffling scheme

The core design and analysis were performed with the HELIOS/MASTER-GCR[3] code system. Also, the decay heat was evaluated for the core by using the McCARD[5]/ORIGEN-2 calculational procedure [4]. The library of the McCARD is used with the ENDF-B/VI.

3. Analysis Results

Various values of the TRISO packing fraction (PF) are considered to optimize the core performance. And, in order to improve the core characteristics, a B_4C burnable poison is considered. The purpose of the BP loading is to minimize the burnup reactivity swing and the power peaking. In the paper, the core performance and characteristics were evaluated for the equilibrium core in terms of the TRU fuel burnup, power distributions, core temperature distributions, burnup reactivity swing, and reactivity feedback coefficients.

Table I summarizes the nuclear core design of DB-MHR core with a SiC-getterred kernel. As shown in

Table I, the cycle length of the core clearly depends on the TRISO packing fraction in the core. In order to maintain about 3000 pcm reactivity swing, the volumetric fraction of burnable poison (BP) are adjusted. The burnup penalty of the burnable poison is about 30 EFPDs for all cases. The burnup of total plutonium is above 60% for all cases. However, the burnup of total TRU in Case I is higher than that of Case II due to the U-238 isotope in a feed fuel. In particular, the burup of Pu-239 is above 95%.

Table I. Summary of the neutronic analysis of the equilibrium core

Case	TRU Packing Fraction (%)	Feed Fuel Mass (Kg)	BP(%)	Cycle Length (day)	Reactivity Swing (pcm)	Avg. Discharged Burnup (kWd/kgU)	Burnup (%)	
							Total TRU	Pu-total
Case I [0.2%UO2+99.8%(PuO1.8+NpO2)+0.6MoleSiC]	4.9	312.6	No BP	335	16,006	640.671	63.9	69.1
			B4C 0.9	305	2,916	584.688	58.5	63.3
	5.9	372.6	No BP	402	14,190	645.236	64.5	70.3
			B4C 0.9	372	3,160	598.234	59.9	65.4
	6.9	437.4	No BP	474	12,703	648.098	64.9	71.2
			B4C 0.9	438	3,096	599.957	60.2	66.1
Case II [30%UO2+70%(PuO1.8+NpO2)+0.6MoleSiC]	7.0	438	No BP	340	12,248	464.737	46.4	66.9
			B4C 0.65	311	2,990	425.771	42.6	61.3
	8.0	504.6	No BP	393	10,776	466.667	46.7	67.1
			B4C 0.6	359	3,058	426.845	42.9	61.6

Figure 3 shows the core average decay heat at EOC of the Case I and II DB cores, in comparison with that of the conventional UO_2-loaded core and higher packing fraction with and without americium. It should be noted that decay heats of the TRU cores for Case I (PF=4.9%, 5.9%) and Case II are noticeably lower than in the UO_2 core when the cooling time is above 100 hours. In the Case I PF=6.9%, the decay heat of TRU core is lower than that of UO2 core when cooling time is above about 90 hours. If the feed fuel mass are about 370 kg and 500 kg in Case I and Case II, respectively, the decay heat of the TRU core is lower than in the UO_2 core during the 100-hour cooling. Clearly, for a given TRISO design, the fuel PF should be minimized for a minimal decay heat of the TRU fuel.

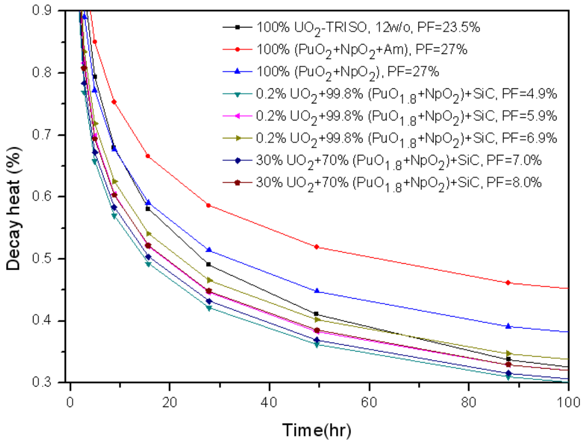

Figure 3. Core-averaged decay heat at EOC

4. Conclusions

In this paper, a SiC-gettered TRU kernel fuel has been introduced to reduce the CO pressure in the buffer zone of a TRISO in a DB-MHR core. It has been confirmed that the SiC getter hardly affect the neutronic performances of the DB-MHR core. When the U addition is small, the fuel discharge burnup ranges from 58% to 60%, depending on the fuel inventory. In the case of 30% U addition to the fuel, the fuel burnup is reduced to 43%. Thus, it is clear that the U addition should be minimized to achieve a deep-burn. We have also shown that decay heat of the TRU fuel can be even lower or comparable to that of UO_2 fuel by limiting the TRU fuel inventory, which is subject to the cycle-length requirement of the core.

Acknowledgements

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