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TRU Deep-Burn in MHR Fueled with Diluted Kernel TRISO

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1. Introduction

As an alternative to TRU transmutation in fast reactors based on repeated reprocessing of spent fuels, the deep-burn (DB) in graphite-moderated MHR (Modular Helium Reactor) is under investigation.[1] In the DB concept, an ultra high burnup is pursued without costly repeated reprocessing and re-fabrication of spent TRU fuels. The spent fuel of DB-MHR is either fed synergistically into fast reactors or directly disposed of in a repository.

In MHRs, a ceramic-coated particle fuel (TRISO) is used. A recent study on the deep-burn shows that the fuel burnup can be as high as 58% with a four-batch fuel management in a prismatic MHR core.[2] Kim and Noh[3] showed that the kernel size should be minimized to enhance the fuel burnup through reduced fuel self-shielding effects. In this paper, a new kernel concept, a carbon-diluted kernel[4], is introduced to reduce the self-shielding of the TRU fuel and the DB capability of an MHR core is evaluated with the MCCARD[5] code.

2. MHR Core Model and Diluted Kernel

Figure 1 shows the annular 600 MWth DB-MHR core considered. The active core height is 792.9cm and it is surrounded by 120cm-thick top/bottom reflectors. A standard block design is adopted in this work and the active core is comprised of 8 axial layers. Control rods and burnable poisons are not modeled in this study.

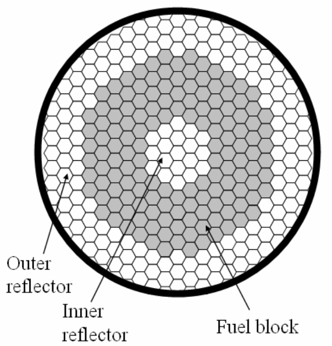

Fig. 1. Layout of DB-MHR core with 144 fuel columns.

Figure 2 shows the concept of TRISO with a carbon-diluted kernel, in which very small particles ($TRUO_2$) are randomly dispersed in a carbon matrix. Note that a conventional concentrated kernel is a pure fuel. In a diluted kernel, fertile nuclides such as Pu-240 can be efficiently converted into fissile Pu-241 due to reduced self-shielding.

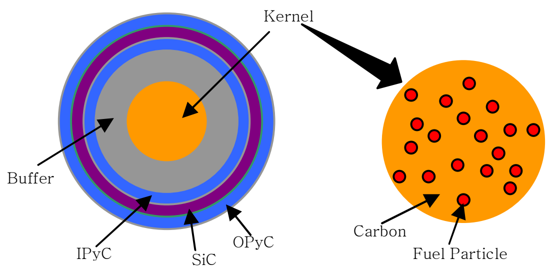

Fig. 2. TRISO with a carbon-diluted kernel.

In this work, the following specific design parameters are used: kernel diameter=300μm, diameter of fuel particle=30μm, volume fraction of fuel particles=20%, buffer=100μm, IPyC=35μm, SiC=35μm, OPyC=40μm. The packing fraction of TRISO in fuel compact is determined to be 35%. A TRU vector extracted from 50GWD/MTU LWR fuel is used: Np-237 (6.8%), Pu-238 (2.9%), Pu-239 (49.5%), Pu-240 (23%), Pu-241 (8.8%), Pu-242 (4.9%), Am-241 (2.8%), Am-242m (0.02%), Am-243 (1.4%).

3. Monte Carlo Depletion Analysis

The DB performance of DB-MHR core is evaluated for an equilibrium fuel cycle. For efficient and accurate core analysis, the RPT[6] (Reactivity-equivalent Physical Transformation) method is used. In the depletion calculation, 210 fuel pins are grouped into 19 depletion regions. The neutron analysis is done without temperature feedback. Instead, the active core temperature is set at 1200K, inner, outer, and top reflectors at 900K, and bottom reflector at 1200K.

Unlike the conventional radial block shuffling, an axial-only fuel shuffling scheme is developed in this work. Figure 3 depicts a 4-batch fuel management used: the most-burned fuel blocks are placed at top/bottom of the core to minimize the axial neutron leakage. Optimization of the fuel shuffling is not considered in this paper.

An equilibrium cycle is searched by using direct MCCARD depletion calculations. The results are shown in Fig. 4. It is observed that an equilibrium cycle is obtained after 12 cycles and the equilibrium cycle length is 320 days.

For a comparison purpose, a concentrated kernel is also evaluated and compared with the diluted kernel. In the case concentrated kernel, a 200μm kernel diameter and 18% packing fraction were used such that the fuel inventory is comparable to that of diluted kernel fuel.

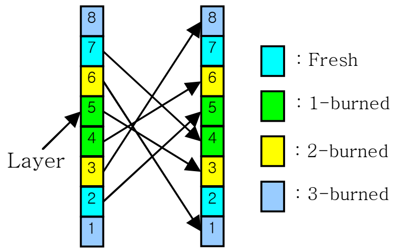

Fig. 3. Axial fuel shuffling scheme

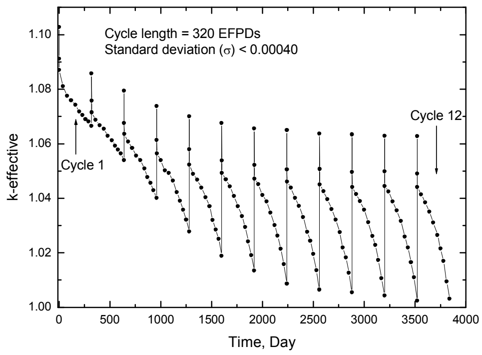

Fig. 4. Equilibrium cycle search by MCCARD.

Table I summarizes the TRU transmutation performance of the DB-MHR core. With the diluted kernel, the fuel discharge burnup is very high, 63.2%, with a 4-batch fuel management, which is noticeably higher than that of a concentrated kernel TRISO. The neutron leakage was found to be 2.5~2.6% in the axial shuffling cases, while it is usually 3.5% in the case of a conventional radial shuffling scheme.

Table I. TRU transmutation performance

Diluted Kernel (Cycle length=320 Days)				
Region	Heavy metal, kg		Burnup, %	
	BOC	EOC	BOC	EOC
Fresh	303.8	244.3	0	19.6
1-burned	244.3	169.4	19.6	44.2
2-burned	169.4	123.9	44.2	59.2
3-burned	123.9	111.9	59.2	63.2
Core	841.4	649.5		
Concentrated Kernel (Cycle length=310 Days)				
Fresh	303.7	232.0	0	23.6
1-burned	232.0	173.7	23.6	42.8
2-burned	173.7	132.5	42.8	56.4
3-burned	132.5	117.0	56.4	61.5
Core	841.9	655.2		

Figure 5 compares the equilibrium reactivity behaviors. It is observed that a diluted kernel results in a much smaller reactivity swing that a concentrated kernel. This is mainly because of the enhance neutron capture by Pu-240 in a diluted kernel TRISO.

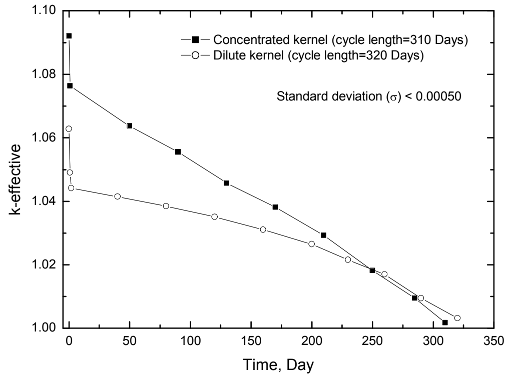

Fig. 5. Equilibrium cycle reactivity change.

4. Conclusions

A carbon-diluted kernel provides a noticeably higher TRU discharge burnup in DB-MHR cores that a conventional concentrated kernel fuel. In addition, a diluted kernel results in a much smaller reactivity swing, compared with a concentrated kernel. It is expected that an optimized diluted kernel would provide a substantially higher fuel burnup.

References

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