Axial Block Shuffling in a Block-Type VHTR for Improved Core Performances

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1. Introduction

Fuel reloading should be done periodically in block-type VHTRs (Very High Temperature Reactors) to maintain a required cycle length. In each reloading, part of fuels in the core is replaced by fresh fuels. Either a 2-batch or 3-batch fuel management is often adopted[1].

A typical fuel reloading scheme is radial shuffling of fuel columns, in which positions of fuel columns are changed. However, a radial fuel shuffling has several drawbacks such as difficulty in power distribution control and limited shuffling due to control rod positions. As an alternative fuel management, the axial-only fuel shuffling schemes were introduced[2,3]. In Ref. 2, a simple 2-batch axial scheme was used, while 3- and 4-batch axial fuel management strategies were adopted in Ref. 3. When the batch size is 3 or 4, there are lots of possible axial shuffling strategies. We tried to find an optimal axial shuffling strategy of a VHTR in terms of the fuel temperature and cycle length (or discharge burnup).

2. Core Model and Analysis Methodology

Figure 1 shows a plane view of a 600MWth core model with a zoning of the TRISO packing fraction (PF) to flatten the radial power distribution. The core model is derived from GT-MHR[1] of General Atomics. Without the PF zoning, the power density of the inner-most fuel ring is significantly higher than those of outer rings.

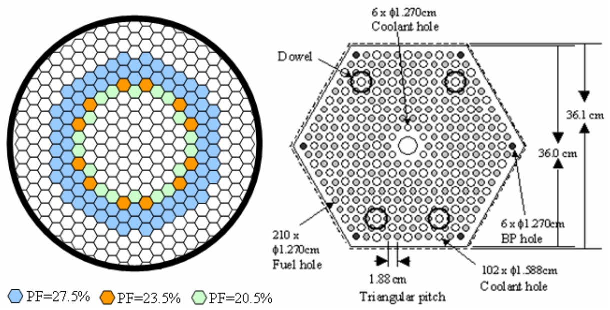

Fig. 1. Configuration of the core and fuel block.

There are 108 fuel columns in the whole core and each fuel column is comprised of 9 fuel blocks for a 3-batch axial fuel shuffling. Height of the active core 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 950°C, respectively.

The fuel kernel is a UO_2 of 12% uranium enrichment and the diameter of the kernel is 500μm. In this study, a typical coating thickness is used: 100μm for the buffer, 35μm for the inner and outer PyC, and 40μm for the SiC. A sintered mixture of B_4C and carbon matrix is used as the burnable absorber (BA) compact, as is used in the HTTR design[4]. In the BA compact, the volume fraction of the natural boron is 0.98%, which provides a reasonable reactivity swing of ~7,500pcm.

The core analysis is done with the HELIOS[5]-MASTER[6] code system, in which a two-step modern diffusion nodal approach is used and thermal-hydraulic feedback effects are also considered. The double-heterogeneity effect of the TRISO fuel is resolved by the RPT method[7]. The RPT method transforms a double-heterogeneous problem into a conventional single-heterogeneous one. Each shuffling scheme is evaluated in an equilibrium cycle of a 3-batch fuel management. An equilibrium cycle is directly searched by repeating cycle-wise calculations.

3. Search of an Optimal Axial Shuffling Scheme

Based on heuristic knowledge and experiences, we evaluated many potential candidate shuffling strategies. Basically, the optimization is a multi-objective process: minimization of the fuel temperature, maximization of the cycle length and discharge burnup. In addition, we tried to obtain a uniform discharge burnup in each fuel column.

Figure 2 shows three cases of the shuffling strategies considered in this work and the corresponding core performances are summarized in Table I. The blue and red directions indicate the block movement in subsequent cycles. In the current MASTER code, thermal-hydraulic calculations are performed in a single coolant channel for each fuel column. Thus, the actual fuel temperature can be higher than the values in Table I. One can note that Case c provides the lowest fuel temperature, while Case b has a slightly longer cycle length. Taking into account the fuel temperature issue in VHTR, Case c is considered better than Case b. The cycle length can be easily extended by increasing the fuel packing fraction. In this paper, only a partial optimization was done. We think that a full optimization would provide a better shuffling scheme.

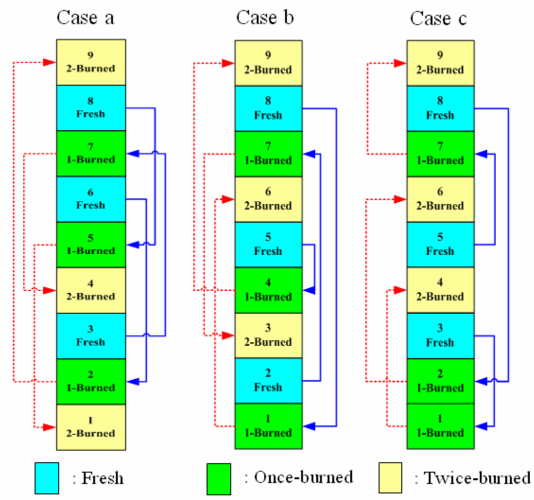

Fig. 2. Axial fuel shuffling schemes.

Table I. Equilibrium core performance

Shuffling scheme	Cycle length, Day	Maximum fuel temperature, °C		Burnup, GWD/tU
		BOC	EOC	
Case a	427	1,113	1,134	99.8
Case b	439	1,047	1,126	102.5
Case c	436	1,066	1,083	101.8

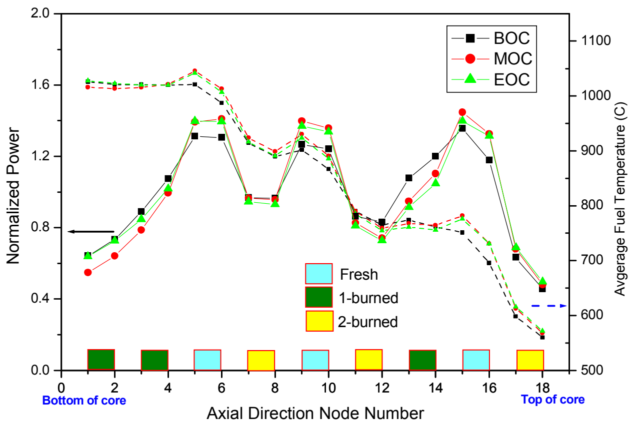

Fig. 3. Axial power and fuel temperature distributions in Case c.

Figure 3 shows the axial power and fuel temperature distributions for Case c. Three axial peaks at fresh blocks are clearly observed and the axial power profile changes only slightly during the cycle. It is worthwhile to note that the maximum fuel temperature occurs at the fresh block and the 2-burned blocks are exposed to relatively low temperatures. Figure 4 shows that the inner-most ring undergoes a higher burnup than other rings, although the power profile is quite flat.

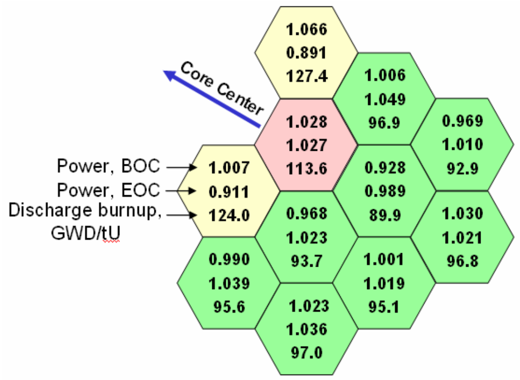

Fig. 4. Power and burnup distributions in Case c.

5. Conclusions

Unlike the conventional radial fuel shuffling, the axial power distribution can be easily controlled by using an axial-only fuel block shuffling strategy such that the fuel temperature should be minimized in a block-type VHTR. The radial power profile can also be effectively adjusted by zoning the fuel packing fraction. An axial fuel shuffling scheme is advantageous in that the maximum fuel temperature occurs in low-burnup fuel blocks while highly-burned fuels are in low temperature conditions. A minor drawback was identified: the inner-most fuel ring has a significantly higher discharge burnup than the other outer fuel rings in the annular VHTR core. It is expected that the problem can be resolved by either splitting the BA loading or introducing an additional complementary radial shuffling of fuel blocks.

References

1. Potter and A. Shenoy, "Gas Turbine-Modular Helium Reactor (GTMHR) Conceptual Design Description Report," GA Report 910720, Revision 1, General Atomics, July 1996.
2. K. Kunitomi et al., "Japan's Future HTR-the GTHTR300," Nucl. Eng. Des., **233**, 2004..
3. Y. Kim and F. Venneri, "Optimization of TRU Burnup in Modular Helium Reactor," *ICAPP'07, Nice, France, May 13-18, 2007*.
4. H. Matsuo, F. Kobayashi, and K. Sawa, "Irradiation Behaviour of Boronated Graphite for HTTR," Proc. of IAEA Specialists Meeting on the Present Status of Graphite Development for GCRs, Tokai, 1991.
5. R. J. Stamm'ler et al., "HELIOS Method," Studsvik Scanpower, 1998.
6. J. M. Noh et al., "Development of a Computer Code System for the Analysis of VHTR Cores," ICAPP'06, Reno, USA, Jun. 4-8, 2006.
7. Y. Kim and M. Baek, "Elimination of Double-Heterogeneity through a Reactivity-Equivalent Physical Transformation," GLOBAL 2005, Tsukuba, Japan, Oct. 9-13, 2005.