Analysis of Burnable Poison Characteristics for Reactivity Swing Minimization in Block-type VHTR

Chang Keun Jo, Yonghee Kim, and Jae Man Noh
Korea Atomic Energy Research Institute, P.O.Box105, Yuseong, Daejeon, Korea 305-600
jck@kaeri.re.kr

1. Introduction

In block-type uranium-loaded VHTRs (Very High Temperature Reactors), a relatively high uranium enrichment (12-15% U-235) is used and the reactivity swing is very large without the aid of a burnable poison (BP). From the reactor control and safety points of view, the reactivity swing needs to be minimized.

Currently, two BP applications are observed in VHTR designs, one is a coated particle[1] type and the other is a sintered mixture of BP and a carbon matrix[2]. In the case of a particle type BP, it is found that the self-shielding effect is relatively large, and the BP depletion rate is rather slow, leading to a big residual reactivity or burnup penalty. On the other hand, a sintered mixture shows a relatively small burnup penalty since BP granules are dispersed in to a carbon matrix. We have used a sintered BP concept to minimize the reactivity swing and the residual reactivity. In order to minimize the reactivity swing, several BP materials are evaluated and various kinds of BP applications are considered in this paper.

2. Core Model and Analysis Methodology

Figure 1 shows a plane view of a 600MWth core model employing a 3-batch fuel management. Basically, the model is derived from GT-MHR[1] of General Atomics. There are 108 fuel columns in the whole core and each fuel column is comprised of 9 fuel blocks, instead of 10 for the original design. 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.

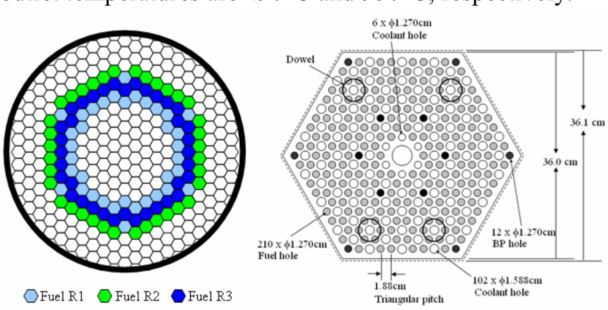

Fig. 1. Configuration of the core and fuel block.

We have considered two BP loading strategies, either 6 BP holes or 12 BP holes. In the case 6 BP holes, only the 6 holes located in the corners of the hexagon are used and the others are replaced by fuel holes. In this work, a conventional 3-batch radial shuffling is considered. In the 3-batch fuel management approach, the fresh fuel is loaded into the R2 region and moved into R3 and then R1.

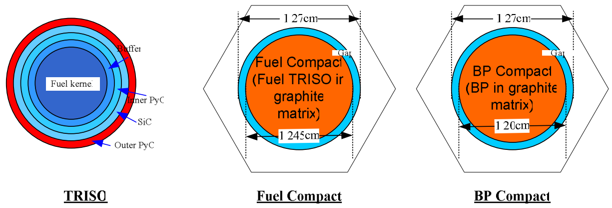

Fig. 2. Configurations of the TRISO, fuel and BP compacts

The fuel kernel is a UO_2 of a 12% uranium enrichment and the diameter of the kernel is 500μm. TRISO packing fraction is 27.5%. In this study, a typical coating thickness is used: 100μm for the buffer, 40μm for the inner and outer PyC, and 40μm for the SiC. The configurations of the TRISO, the fuel and BP compacts are shown in Fig. 2.

The core analysis is done with the HELIOS[3]-MASTER[4] 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[5]. The RPT method transforms a double-heterogeneous problem into a conventional single-heterogeneous one. The impact of a BP is evaluated for an equilibrium cycle of the 3-batch fuel management approach. An equilibrium cycle is directly searched by repeating cycle-wise calculations.

3. Fuel Block Depletion

For three BP materials (B_4C, Er_2O_3, Gd_2O_3), basic block depletion calculations were done with the HELIOS code. Natural boron is used for boron carbide. In this evaluation, the number of BP holes is 6. Figure 2 shows the reactivity behavior for several BP loadings of the 3 BP materials. In Fig. 2, the BP content is a volumetric fraction of the BP in a BP compact.

Figure 3 shows that the gadolinia (Gd_2O_3) is depleted very rapidly and the erbia (Er_2O_3) undergoes a slow depletion. Consequently, the residual reactivity of the erbia is higher than the boron carbide and gadolinia.

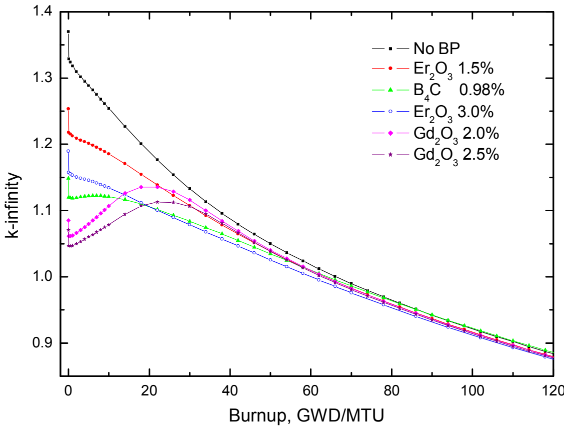

Fig. 3. Impacts of BPs on the reactivity of fuel block.

4. Effects of BPs in Equilibrium Core

For various kinds of boron-carbide, erbia, and gadolinia BPs, we have done 3-D equilibrium cycle analyses. Both 6 and 12 BP holes are considered and mixed B_4C and Gd_2O_3 BPs are evaluated as well. In the case of 12 BP holes, the fuel mass per block is 97.1% of the 6-BP-hole case. The results are summarized in terms of the cycle length, reactivity swing, and average discharge burnup in Table I. Figure 4 shows the reactivity changes for each corresponding equilibrium cycle.

Table I. Comparison of various BP applications

No. of BP holes	BP type	Cycle length, Day	Reactivity swing, pcm	Burnup, GWD/tU
6	No BP	477	15,130	103.8
	B_4C 0.98%	457	8,528	99.4
	Gd_2O_3 2.5%	460	6,789	100.0
	Er_2O_3 1.5%	460	11,676	100.0
	B_4C 0.8%, Gd_2O_3 0.4%	456	7,267	99.2
12	No BP	472	15,381	105.7
	B_4C 0.49%	455	7,702	101.9
	B_4C 0.98%	419	2,718	93.8
	Gd_2O_3 1.25%	460	4,932	103.0
	Er_2O_3 0.75%	440	8,653	98.5
	B_4C 0.49%, Gd_2O_3 0.6%	444	3,898	99.4
	B_4C 0.6%, Gd_2O_3 0.2%	446	4,680	99.8

5. Conclusions

This paper provides the characteristics of BPs for reactivity change in VHTR. From the results, it is indicated that a BP loading in 12 BP holes compared with 6 BP holes provides a better performance in terms of the available cycle length and discharge burnup, in spite of a smaller fuel loading. In addition, a 12-BP-hole concept also provides a more flattened assembly power distribution. For a similar reactivity swing, the burnup penalty is smallest with gadolinia and the erbia is subject to the largest residual reactivity. When the gadolinia loading is sufficiently high, the maximum reactivity can occur in the middle of a cycle. The BP loading significantly increases the radial power peaking, which results in a relatively high fuel temperature. We found that the k-infinity value of a fresh fuel block can be significantly smaller than unity with only a BP loading, which can considerable mitigate the criticality issue of a fresh fuel.

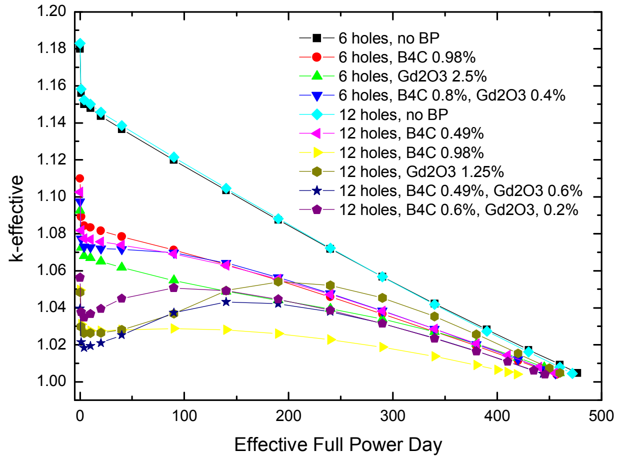

Fig. 4. Reactivity changes in equilibrium cycle.

ACKNOWLEDGEMENTS

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