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Physics Analysis of a Prismatic VHTR with Asymmetric Control Rods by Using the HELIOS/MASTER Code Package

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1. Introduction

A new physics analysis procedure[1] is under development for prismatic VHTRs based on a conventional two-step procedure for a PWR physics analysis. The HELIOS[2] and MASTER[3] codes were employed to generate the coarse group cross sections through a transport lattice calculation, and to perform the 3-dimensional core physics analysis by a nodal diffusion calculation, respectively. Since prismatic VHTRs such as a GT-MHR include asymmetrically located large control rods, a control rod treatment is a challenging issue in a physics analysis. Previously, we performed a physics analysis for a prismatic VHTR in which symmetric control rods were assumed.[4] Large spectrum shifts due to a control rod insertion on the surrounding blocks could be covered by optimizing the coarse energy group structure. However, it was noted that some improvements should be made in the prediction of the reaction rates and the control rod worths.

In this study a new analysis procedure has been developed to deal with asymmetric control rods more accurately. Surface dependent discontinuity factors obtained from multi-block models were applied to the core calculations for a better prediction of the reaction rates and control rod worths. Benchmark calculations were performed for the GT-MHR[5] cores, where the reference solutions were obtained from the MCNP[6] calculations.

2. Methods and Results

2.1 GT-MHR Core

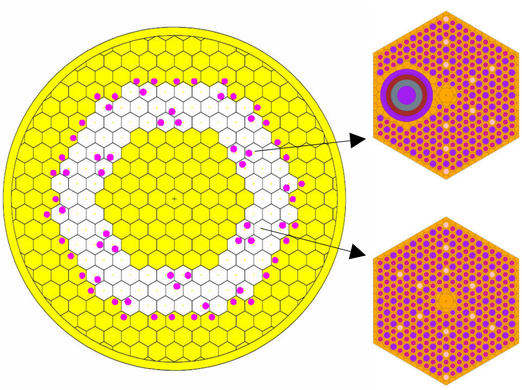


Figure 1. The MCNP model for the GT-MHR core

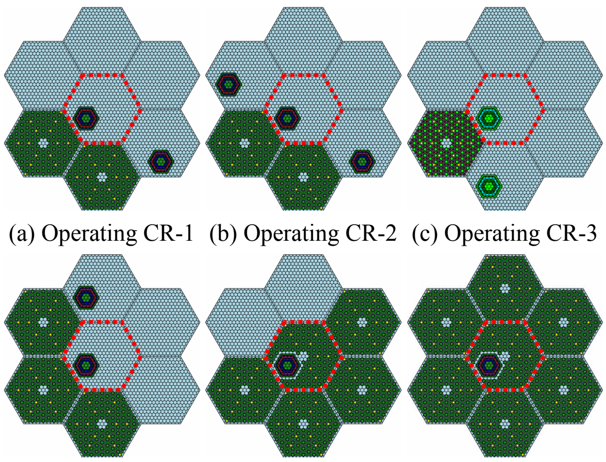
Figure 1 shows the MCNP models for the GT-MHR core and the constituent fuel blocks with and without control rod insertions. In the block, a 13 cm diameter hole to accommodate a control rod (CR) or a reserve shutdown system (RSS) is located asymmetrically. In an active core, the 12 fuel blocks adjacent to the internal reflector have a hole for the start-up control rods and other 18 fuel blocks include a hole for a movement of the RSS. The 36 radial reflector blocks contiguous with the active core have a hole to accommodate the operating control rods. The overall height of the B_4C absorber is 930 cm.

2.2 Equivalence Theory

Equivalence theory[7] has been applied to conserve the reaction rates for the blocks with a control rod insertion. Figure 2 provides the HELIOS multi-block models to obtain surface dependent discontinuity factors ($f_{G,s}$) to be used in the MASTER calculations, which is defined as follows:

$$f_{G,s} = \phi_{G,s}^{het} / \phi_{G,s}^{\mathrm{hom}} \quad (1)$$

where $\phi_{G,s}^{het}$ is a surface flux extracted from the HELIOS calculation, and $\phi_{G,s}^{\mathrm{hom}}$ is a surface flux extracted from the diffusion calculation with a finite difference discretization. The MASTER code has also been improved to treat direction dependent diffusion coefficients with a rotation specified by a user.



(a) Operating CR-1 (b) Operating CR-2 (c) Operating CR-3

(d) Operating CR-4 (e) Outer CR (f) Inner CR

Figure 2. Multi-block models to generate discontinuity factors

2.3 Benchmark Calculation

Benchmark calculations were performed for the GT-MHR cores with various control rod insertions: ARO (all rods out), ARI (all rods in), CRI (operating and start-up CRs in), ORI (operating CRs in), and SRI (start

Table 1. Comparison of the multiplication factors and control rod worths

Temp. (K)	Rod	keff	Δρ (pcm)		Control Rod Worth (pcm)			% Difference	
		MCNP	Case A*	Case B**	MCNP	Case A*	Case B**	Case A*	Case B**
300	ARO	1.07380	445	445					
	ARI	0.80360	4030	1852	31313	27727	29905	11.45	4.49
	CRI	0.87374	3942	1664	21323	17826	20104	16.40	5.72
	ORI	0.93414	2612	1083	13923	11756	13285	15.57	4.58
	SRI	1.04130	595	550	2907	2756	2802	5.17	3.61
1200	ARO	1.04487	42	42					
	ARI	0.76829	4642	2146	34453	29853	32350	13.35	6.11
	CRI	0.83545	4440	1777	23990	19592	22255	18.33	7.23
	ORI	0.89440	2867	1120	16101	13276	15023	17.55	6.70
	SRI	1.01712	67	10	2611	2587	2643	0.94	-1.23

* HELIOS/MASTER without discontinuity factors
** HELIOS/MASTER with discontinuity factors

-up CRs in). Multi group macroscopic cross sections for a block with and without a control rod insertion were edited from the mini core calculations.

Table 1 provides a comparison of the multiplication factors and control rod worths of HELIOS/MASTER with those of MCNP for the GT-MHR cores. The MASTER core calculations were performed with and without a consideration of the discontinuity factors. The computational results showed that there is a significant improvement in the prediction of the multiplication by adopting direction dependent discontinuity factors. Control rod worths of Case B are very consistent with those of MCNP to within a maximum error of 7.23 %.

Figure 3 shows a comparison of the radial block power distributions. There is a power tilt in the Case A power distributions when compared with those of MCNP. The outer block powers were overestimated and the inner block ones underestimated. Those of Case B are very consistent with the MCNP values, where the maximum error is about 3.66 %. As shown in Figure 4, the axial power distributions of HELIOS/MASTER are very consistent with those of MCNP.

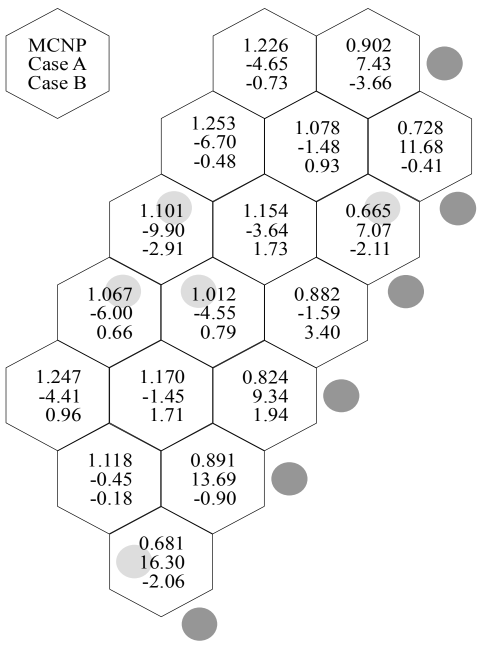


Figure 3. Comparison of the radial block power distributions (1200 K, ORI)

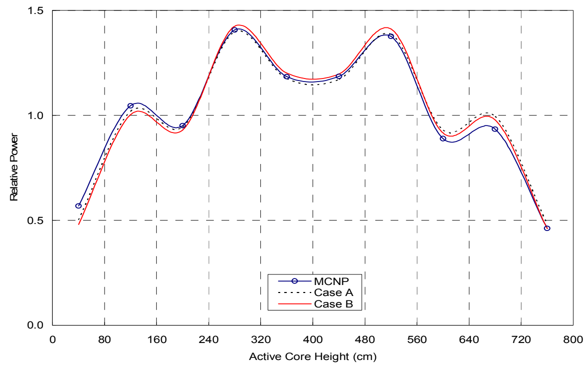


Figure 4. Comparison of the axial block power distributions (1200 K, ORI)

3. Conclusion

We developed a procedure to deal with a control rod movement for a prismatic VHTR with asymmetric control rods. Large difference of the control rod worths and the radial power tilt could be solved by employing direction dependent discontinuity factors. The benchmark results showed that this procedure works reasonably well.

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