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An Adaptation of the HELIOS/MASTER Code System to the Analysis of VHTR Cores

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I. INTRODUCTION

KAERI is developing a new computer code system for an analysis of VHTR cores based on the existing HELIOS[1]/MASTER[2] code system which was originally developed for a LWR core analysis.

In the VHTR reactor physics, there are several unique neutronic characteristics that cannot be handled easily by the conventional computer code system applied for the LWR core analysis. Typical examples of such characteristics are a double heterogeneity problem due to the particulate fuels, the effects of a spectrum shift and a thermal up-scattering due to the graphite moderator, and a strong fuel/reflector interaction, etc.

In order to facilitate an easy treatment of such characteristics, we developed some methodologies for the HELIOS/MASTER code system.[3,4] and tested their applicability to the VHTR core analysis.

II. METHODOLOGY AND TEST

II.A. Equivalent Cylindrical Fuel Model

The fuel pebbles stacked in the pebble-bed core should be transformed into cylindrical fuels to be handled by a two-dimensional lattice code such as HELIOS. The equivalent cylindrical fuel (ECF) model[5] plays this role by determining the geometry of the equivalent cylinder to preserve the material inventories and the mean chord length of a fuel region during this transformation.

Figure 1 shows a good performance of the ECF model during the depletion calculation.

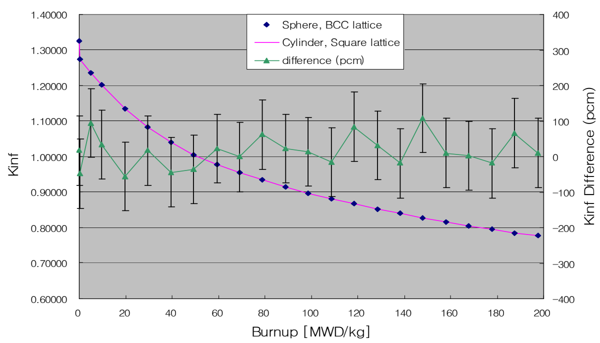

Fig. 1. Accuracy of ECF during depletion

II.B. Method of Reactivity-equivalent Physical Transformation

A volume-weighted homogenization (VWH) of a fuel zone with TRISO particles results in a significant reduction in the resonance self-shielding effect. This is well known as the double-heterogeneity problem. The method of a reactivity-equivalent physical transformation (RPT)[6] was proposed to transform the double-heterogeneous fuel problem into a single-heterogeneous one. This method reduces the size of the homogenized fuel zone as shown in Figure 2 so that both the double-heterogeneous and the single-heterogeneous problems may provide an identical self-shielding effect.

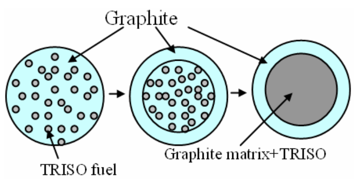

Fig. 2. RPT concept.

In Figures 3, accuracy of the RPT is assessed during an assembly depletion. It is clearly observed that the RPT solution shows a good accuracy up to a very high burnup, while the VWH solution has a large error.

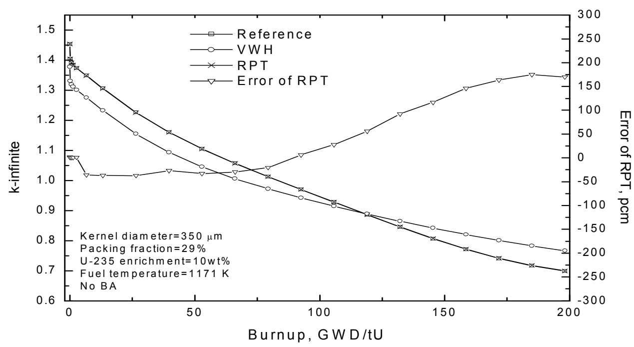

Fig. 3. Accuracy of RPT during depletion

II.C. Eight Energy Group Structure

The number of energy groups and their boundaries were determined, with which all the cross sections become environment-free, so that the cross sections may be calculated from a spectral calculation for a simple geometry. Group boundaries are adjusted to minimize the differences of the infinite multiplication factors ($k_{inf.}$) of the blocks and the core in Figure 4.

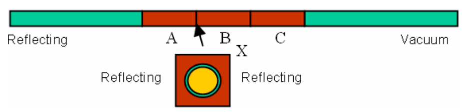

Fig. 4. One-dimensional VHTR core model

The results of this optimization shown in Table I indicate that when the number of groups is larger than eight, there is almost no improvement, and the maximum reactivity difference is about 45 pcm. Therefore, the eight-group structure can be regarded as an optimum.

Table I. Comparison of block-wise k_{inf}

Gr	Block				Core	
	X	A	B	C	X	A+B+C
4	1.52497	1629	30	1570	1.58425	-1034
6	1.52497	323	-88	315	1.58424	-154
8	1.52343	40	-44	39	1.58425	-17
9	1.52497	45	-41	44	1.58425	-18
12	1.52497	-22	-42	-21	1.58424	23

II.D. Equivalence Theory Application

To capture the effect of the strong spectral interaction between the core and the reflector, the equivalence theory was applied to the 1-D spectral geometry as shown in Figure 4. The discontinuity factors and the reflector cross sections derived from the HELIOS calculation for this geometry are directly used in the three dimensional MASTER calculation.

This equivalent procedure was verified against a 3-D benchmark problem derived from a typical pebble-bed VHTR core.[4] As shown in Table II and Figure 5, the diffusion solution predicts the Monte Carlo solution well and the errors are acceptable.

Table II. Comparison of k_{eff} of a 3-D benchmark problem

MASTER (C)	MC-CARD (R)	C-R (pcm)
1.21342	1.20928±3pcm	+414

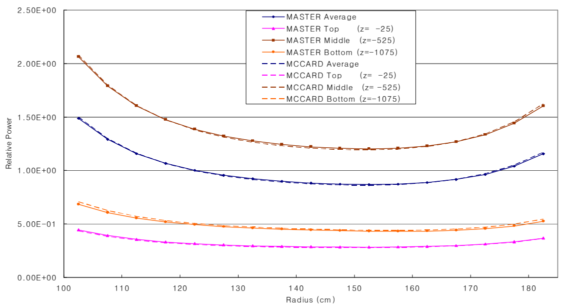

Fig. 5. Comparison of radial power distributions

III. HELIOS/MASTER CODE SYSTEM

All the methodologies described in the previous chapter were incorporated into the HELIOS/MASTER code system shown in Figure 6.

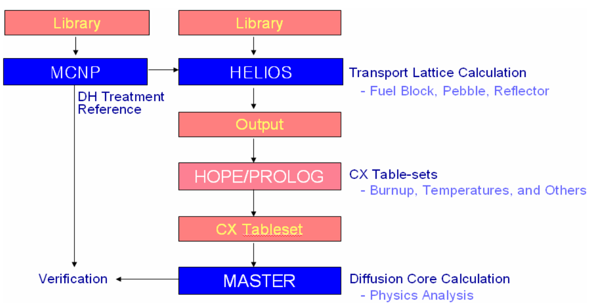

Fig. 6. HELIOS/MASTER code cystem

To verify this code system, we solved a typical three-dimensional prismatic VHTR core in a one-sixth symmetry. The MCNP model with an explicit treatment of all the TRISO particles was served as a reference to our code system. The results shown in Figure 7 show that HELIOS/MASTER predicts the MCNP solutions very well.

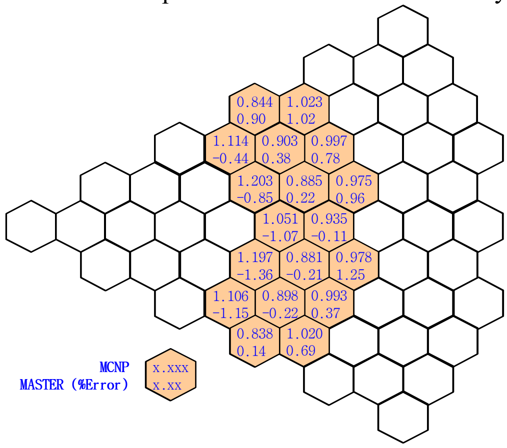

Fig. 7. Radial power distribution of a prismatic core

IV. CONCLUSIONS

The HELIOS/MASTER code system based on the two-step core analysis procedure has been established for an analysis of the VHTR cores and its applicability was tested against some VHTR benchmark problems. The results of these benchmark tests show that our code system is very accurate and practical for an analysis of both the prismatic and pebble-bed reactor cores.

ACKNOWLEDGMENTS

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