# Two-Step Procedure Development for the VHTR Physics Analysis using 1-D Core Model

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## 1. Introduction

New nuclear design procedure is under development for the reactor physics analysis of the very high temperature gas-cooled reactor (VHTR). The conventional two-step procedure developed for the commercial pressurized water reactors (PWR) is adopted as a standard procedure for the prismatic and pebble type VHTR reactor physics analysis. We employed HELIOS [1] code for the transport lattice calculation to generate few group constants, and MASTER [2] code for the 3-D core calculation to perform the reactor physics analysis.

The neutronic characteristics of VHTR is quite different from the PWR one in many aspects. VHTR employs a graphite moderator which results in long neutron diffusion length. A particulate fuel with multi-coating layers, called TRISO, is employed to achieve a high fuel performance and fission gas confinement, which is randomly dispersed in a graphite matrix. This causes a so-called double heterogeneity problem in the lattice calculation requiring a special treatment. Therefore, the conventional two-step procedure should be modified to be appropriate to the VHTR neutronic characteristics.

Since it is very difficult and complicated to develop the appropriate procedure using 3-dimensional model, we developed a simplified 1-dimensional model to show most of the VHTR core characteristics. And we also developed overall procedure for the VHTR reactor physics analysis including the generation of few group cross sections for blocks and reflectors.

## 2. Methods and Results

### *2.1 1-D Model*

The prismatic NGNP [3] core developed by Idaho National Laboratory has been chosen as a reference one. NGNP core represents an annular stack of hexahedral prismatic fuel assemblies as shown in Figure 1. Since NGNP core include 3 columns of blocks, 1-D core model also includes 3 blocks to be equivalent in the optical length. Each block includes 14 pin cells where the fuel compact is same as the real one and the pin cell pitch has been decided to preserve the moderator volume per fuel compact. This 1-dimensional core calculation is performed by HELIOS and verified by MCNP [5].

Prior to HELIOS calculation, double heterogeneity of fuel compact has been eliminated by the reactivity-equivalent physics transformation (RPT) [4], where all the neutronic parameters such as reaction rates and eigenvalue are conserved exactly.

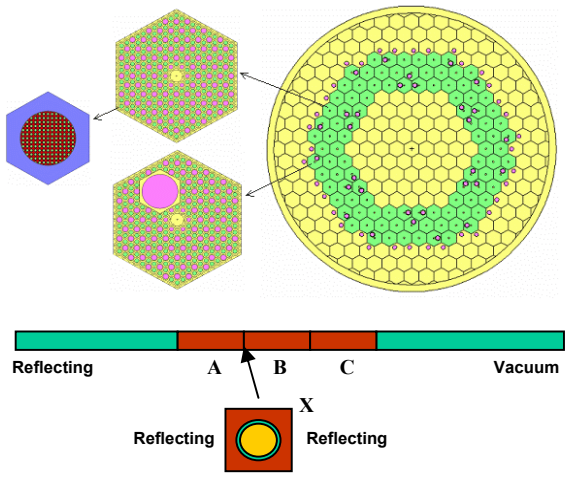


Figure 1. VHTR 1-D Model

### *2.2 Energy Group Boundary*

So as to decide number of energy groups and their boundaries, the neutron spectra changes according to the location of bocks and temperature variation should be considered. Figure 2 shows that the neutron spectra are hardened as temperature grows up and the thermal neutron spectra of blocks sided by reflector are higher than those of inner blocks.

Few group macroscopic cross sections and neutron spectra are edited from HELIOS output for blocks A, B and C of 1-D core model and a single block model (X).

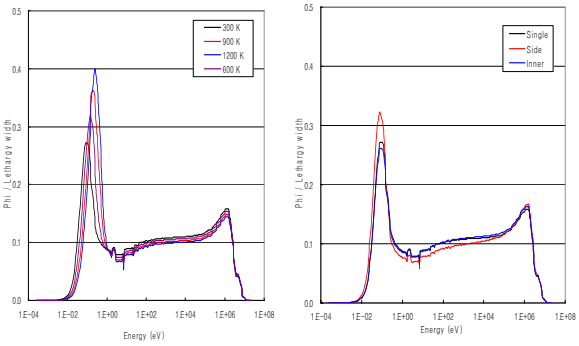


Figure 2. Neutron spectra of the VHTR blocks

Group boundaries are adjusted to minimize the differences of group-wise cross sections and the infinite multiplication factors ($k_{inf.}$), where $k_{inf.}$ for block is calculated using region-wise cross sections and spectra of X, and $k_{inf.}$ for core using region-wise cross sections and spectra of A, B and C. At first the optimization process was performed only for 300 K by changing number of energy groups from 4 to 12. Table 1 shows that when number of groups is larger than 8, there is almost no improvement, and the maximum reactivity difference is about 45 pcm. When adopting groups less than 8, homogeneous power shapes are quite different from HELIOS ones resulting in a problem in pin power reconstruction. Therefore, the optimization process was applied to 8-group case with the various temperatures. The results show that the reactivity differences are less than 105 pcm.

Table 1. Comparison of the multiplication factors

| Temp. (K) | Gr | Block | | | | Core | |
|---|---|---|---|---|---|---|---|
| | | X | A | B | C | X | All* |
| 300 K | 4 | 1.52497 | 1629 | 30 | 1570 | 1.58425 | -1034 |
| | 6 | 1.52497 | 323 | -88 | 315 | 1.58424 | -154 |
| | 7 | 1.52497 | 218 | -213 | 205 | 1.58424 | -128 |
| | 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 |
| 300 K | 8 | 1.52510 | 106 | -5 | 103 | 1.58498 | -63 |
| 600 K | 8 | 1.47864 | 75 | -4 | 70 | 1.54500 | -43 |
| 900 K | 8 | 1.44421 | 62 | -8 | 56 | 1.51453 | -34 |
| 1200 K | 8 | 1.41771 | 61 | -9 | 55 | 1.49065 | -32 |

* A+B+C

*2.2 Procedure for Cross Section Generation*

In order to develop the cross section generation procedure for block and reflectors, one-dimensional diffusion calculations adopting a finite difference discretization (FDM) are performed using homogeneous cross sections from HELIOS models. Region-wise discontinuity factors were evaluated through the simplified equivalence theory [6] using the interface currents and region-wise cross sections. When using macroscopic cross sections edited from 1-d core models and adjusted by discontinuity factors, the eigenvalues and block power distributions of 1-D FDM calculations are equivalent to those of HELIOS.

For simplicity we developed new procedure not to apply the discontinuity factors to blocks but to apply those only to reflectors. When we apply cross sections from a single block model and the adjusted ones using the equivalence theory, the results are shown in Table 2 and Figure 3. The results show that that multiplication factors, the block powers and pin powers are well consistent within the maximum error of 215 pcm, 0.5%, and 1.1%.

Table 2. Comparison of the multiplication factors and the pin powers

| Temp. (K) | $k_{eff.}$ | | | Power Diff. |
|---|---|---|---|---|
| | HELIOS | FDM | Diff. (pcm) | |
| 300 | 1.43489 | 1.43933 | -215 | -0.2 |
| 600 | 1.40756 | 1.41171 | -209 | -0.3 |
| 900 | 1.38255 | 1.38605 | -183 | -0.5 |
| 1200 | 1.36580 | 1.36427 | 82 | 0.4 |

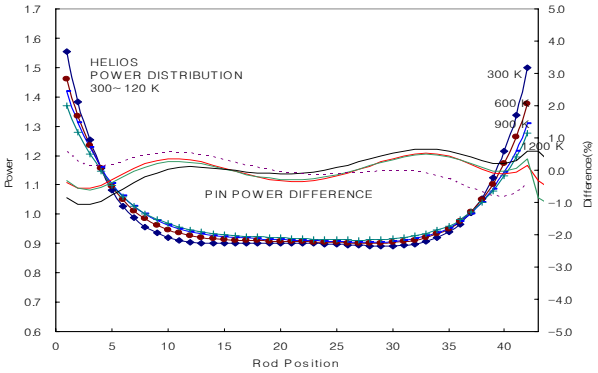


Figure 3. Neutron spectrum of the VHTR blocks

## 3. Conclusion

We developed a procedure to decide number of energy groups and their boundaries, and to generate the block and reflector cross sections. Cross sections for block can be generated from a single block calculation, and cross sections for reflectors can be calculated using 1-D core model with a simplified equivalence theory. The results show that this procedure works well and can be applied to the real core calculations. This procedure can be applied to both the prismatic and pebble-type reactor physics analyses.

## REFERENCES


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