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Quantification of the Neutron Streaming Effect in the Prismatic NGNP Fuel Blocks

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1. Introduction

A new physics analysis procedure is under development for a prismatic very high temperature gas-cooled reactor based on a conventional two-step procedure for the PWR physics analysis. The HELIOS[1] and MASTER[2] 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. Physics analysis of the prismatic VHTRs involves particular modeling issues such as a double heterogeneity of the coated fuel particles, a neutron streaming in the coolant channels, a strong core-reflector interaction, and large spectrum shifts due to changes of the surrounding environment and state parameters. Double heterogeneity effect could be considered by using a recently developed reactivity equivalent physical transformation method. Strong core-reflector interaction could be handled by applying an equivalence theory to the generation of the reflector cross sections. The effects of a spectrum shift could be covered by optimizing the coarse energy group structure.

One of the key issues in the prismatic VHTR physics analysis is a neutron streaming effect, which arises due to the existence of Helium coolant channels. It has been reported in the physics analysis of the HTR-10, HTR-PROTEUS and HTTR cores that this neutron streaming effects were significant.[3] In this study the neutron streaming effect in the prismatic NGNP[4] fuel blocks were quantified through three dimensional semi-transport calculations by using the DeCART[5] code.

2. Methods and Results

2.1 Modeling

It is known that a neutron streaming effect takes place due to the large helium coolant channels in a VHTR, and the direction-dependent diffusion coefficient along the coolant channel should be considered in the transport and diffusion 2-step calculations.[3] This neutron streaming effect is considerably dependent upon the size of coolant channels. This streaming effect for the prismatic VHTR fuels should be analyzed to decide whether a special treatment for this effect should be included in the 3-dimensional diffusion calculations or not. Therefore, as shown in Figure 1, simple 2- and 3-dimensional models were devised to include a coolant channel enclosed by fuel pins. Square fuel pin and coolant channel were designed to conserve the volume fractions in the prismatic NGNP fuel blocks. The effective thicknesses (x) for the coolant channels were estimated to be 0.9417 cm and 1.3352 cm for the fuel blocks without and with a control rod hole, respectively. Boundary conditions for this problem are vacuums for the top and bottom surfaces and reflections for the radial surfaces. The reference solution can be obtained from the 2-dimensional transport calculation for the 2-dimensional model in Figure 1.

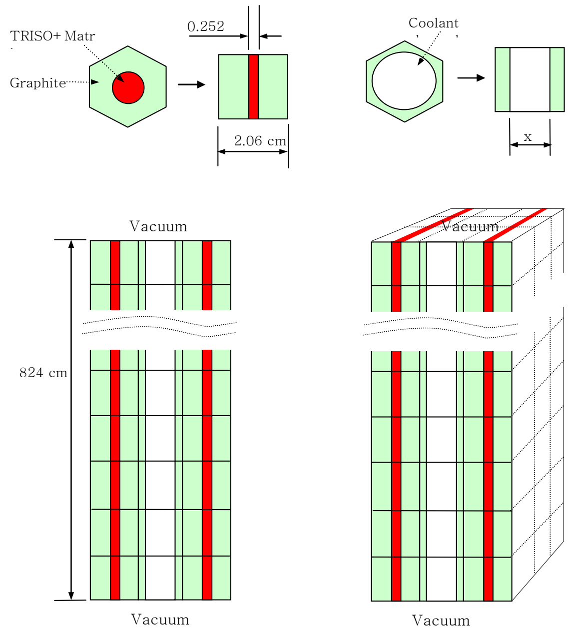

Figure 2. Simple models for the neutron streaming effect

The DeCART code is a whole-core semi-transport code with a coupling of a radial MOC (The method of characteristics) transport calculation and an axial NEM (Nodal expansion method) diffusion calculation. In the nodal method for an axial calculation, an isotropic diffusion coefficient is obtained from the radial MOC transport calculation and used in the axial diffusion calculation. Neutron streaming effect can be quantified explicitly by the 3-dimension semi-transport calculations by using DeCART. In order to guarantee this calculation, the DeCART calculation is performed with a different simple model where the coolant channels are replaced with fuel pins to remove the neutron streaming effect.

2.2 Result and Discussion

In order to estimate the neutron streaming effect on the reactivity, three different calculations described in Section 2.1 were performed by the 3-dimensional semi-transport code DeCART with a 47-group HELIOS library as follows:

(a) Case-1 corresponds to the fuel block without a control rod channel.
(b) Case-2 corresponds to the fuel block with a control rod channel.
(c) Case-3 corresponds to the fuel block without any coolant channel.

These calculations were performed at four different constant temperatures (300, 600, 900 and 1200 K). Table 1 provides a quantification of the neutron streaming effects. While the neutron streaming effect did not appear in Case-1 and Case-3, it appeared in Case-2 with a large coolant channel. Axial neutron streaming effect for the fuel block with a control rod hole was estimated to be about 70 *pcm*. Since the number of fuel blocks with a control rod channel is less than half of the total number of blocks in the core, the overall streaming effect will be negligible in the core calculation. Therefore, the neutron streaming effect does not have to be considered in developing the physics analysis procedure for a prismatic NGNP with a $UC_{0.5}O_{1.5}$ fuel.

Table 1. Quantification of the neutron streaming effects

Case	Temp. (K)	Multiplication factor		$\Delta\rho$ (pcm)
		Reference[(a)]	NEM[(b)]	
Small coolant channel (Case-1)	300	1.55971	1.55970	0
	600	1.51739	1.51740	0
	900	1.48627	1.48629	-1
	1200	1.46312	1.46317	-2
Large coolant channel (Case-2)	300	1.53859	1.53709	63
	600	1.49449	1.49299	67
	900	1.46214	1.46062	71
	1200	1.43802	1.43650	74
No coolant channel (Case-3)	300	1.50607	1.50609	-1
	600	1.45873	1.45876	-1
	900	1.42428	1.42431	-1
	1200	1.39845	1.39848	-2

(a) 2-dimensional MOC transport calculation
(b) 3-dimensional (radial MOC transport + axial NEM diffusion) calculation

The neutron streaming effect is estimated to be negligible for the prismatic NGNP fuels, which does not require an explicit consideration of the direction dependent diffusion coefficients. However, it is required to establish a procedure to edit direction dependent diffusion coefficient from the lattice calculation and to apply those to the diffusion core calculation for the general applications of the HELIOS/MASTER code package. This method also can be applied to the axial NEM calculations in the 3-dimensional semi-transport mechanism.

3. Conclusion

We have analyzed the neutron streaming effect quantitatively for prismatic NGNP fuels by using the DeCART code. Two and three dimensional models have been devised so that the solutions of two models will be identical. The neutron streaming effect is not significant and can be neglected for the prismatic NGNP fuel blocks. However, in order to apply the 2-step procedure under development to the physics analysis for other reactors such as a HTTR, it is required to have a feature to treat the neutron streaming effect explicitly.

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