Resonant and Heterogeneous Effects in the Doubly Heterogeneous Particulate Fuels

Kang-Seog Kim, Jae Man Noh, Chung Chan Lee, Sung Quun Zee
Korea Atomic Energy Research Institute P.O. Box 105, Yuseong, Daejon, 305-333 Korea, kimks@kaeri.re.kr

1. Introduction

A new physics analysis procedure[1] is under development for a prismatic very high temperature gas-cooled reactor (VHTR) based on a conventional two-step procedure for the PWR physics analysis. The first step is to generate the coarse group cross sections through a transport lattice calculation, and the second one is to perform the 3-dimensional core physics analysis by a nodal diffusion calculation. 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. Among these modeling issues the double heterogeneity effect is the most significant and estimated to be several thousands of *pcm* in reactivity. Therefore, this double heterogeneity should be properly represented in the core physics codes.

Double heterogeneity effect can be divided into two parts which include an estimation of the effective resonance cross sections and a transport simulation for a media where fuel particles are randomly distributed. In this study these two characteristics of the double heterogeneity were analyzed and quantified by using a Monte Carlo code MCNP[2] and a deterministic transport code LIBERTE[3].

2. Methods and Results

We analyzed the overall effect of a double heterogeneity through the MCNP calculations with the ENDF/B-VI R8 library. Individual fuel particles were treated explicitly and were homogenized with a graphite matrix. These sensitivity calculations were performed for the single pin, fuel block and core using the prismatic NGNP[4] fuel. Table 1 provides the effects of the double heterogeneity on the reactivities for fuel pin, fuel block, and core in which simple cubic array was assumed for the heterogeneous cases. As shown in Table 1, the double heterogeneity effect is about 3% for the fuel pins, and is changeable according to the changes of the temperature and the problem size. The double heterogeneity effect increases as the temperature increases, and decreases as the problem size increases. In the core problems the double heterogeneity effect is about 2%, which is still not to be negligible. As the problem size increases, the amount of the loaded graphite also increases. There are two different heterogeneities in the VHTR fuel. In other words, there are two different escape probabilities which are strongly related with the resonance self-shielding. These two escape probabilities come from the TRISO particle and the fuel compact configurations. As the amount of the graphite moderator increases, the latter escape probability will be increased and dominant. And then the double heterogeneity effect will be decreased.

Table 1. Double heterogeneity effect

TYPE	Temp. (K)	Keff.		D.H. (pcm)
		Homo.	Hetero.	
Pin	300	1.35923	1.41727	2958
	600	1.29948	1.36376	3519
	900	1.26001	1.32601	3778
Block	300	1.47497	1.53112	2391
	600	1.42305	1.48272	2757
	900	1.38772	1.44922	2979
Core	300	1.38967	1.42670	1868

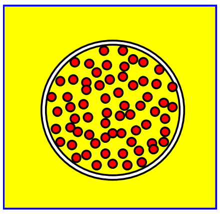
* Standard Deviation <±0.00081

A double heterogeneity effect can be divided into two parts which include resonant and heterogeneous effects. These two effects arise from a comparison of the doubly and the singly heterogeneous fuels. Resonant effect comes from the estimation of effective resonance cross sections and a heterogeneous effect from the neutron transport calculations. We have analyzed these two parts quantitatively. The analysis procedure is as follows:

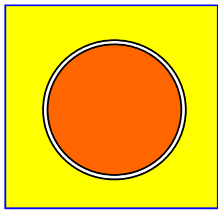
(1) Perform the MCNP calculations for the two single pins (Figure 1) with an explicit fuel particle distribution and the homogeneous fuel by changing the pin pitch and the size and packing fraction (PF) of TRISO as follows:
   Case-A : Size 0.0385 cm / PF 0.28916
   Case-B : Size 0.0450 cm / PF 0.28916
   Case-C : Size 0.0385 cm / PF 0.23904
   The overall double heterogeneity effect is obtained by the following equation.

$$\Delta\rho_{DH} = \rho_{het}^{MCNP} - \rho_{hom}^{MCNP} \quad . \tag{1}$$

(2) Edit effective microscopic capture and fission cross sections and the number of the released neutrons per fission for U^{235} and U^{238} in the MCNP calculations with the same energy group boundaries with a HELIOS[5] library.



(a) Heterogeneous



(b) Homogeneous

Figure 1. Single pin models

(3) Modify library with new cross sections and perform the transport calculations for the homogeneous and the heterogeneous fuel pins by using the LIBERTE code without resonance treatment.

(4) The heterogeneous effect can be obtained from the MCNP and the LIBERTE calculations by using the following equation.

$$\Delta\rho_{Stream} = (\rho_{hom}^{LIB.} - \rho_{hom}^{MCNP}) - (\rho_{het}^{LIB.} - \rho_{het}^{MCNP}) \quad . \quad (2)$$

And the resonant effect can be calculated from the difference between eq. (1) and eq. (2).

Figures 2 and 3 provides the results of the quantitative analysis for the double heterogeneity effects. The double heterogeneity effects are about 2100 ~ 4300 *pcm*. Figure 2 shows the resonant and the heterogeneous effects for Cases A and B where the TRISO sizes are different and the packing fractions are identical. The resonant effect is much larger than the heterogeneous effect. While there is almost no change in the resonant effect, there is a large increase in the heterogeneous one as the TRISO size increases. Figure 3 shows the resonant and the heterogeneous effects for Cases A and C where the TRISO sizes are identical and the packing fractions are different. As shown in Figure 3, there is no change in the heterogeneous effect, but the resonant effect increases as the packing fraction decreases. It is noted that the resonant effect is dependent upon the packing fraction and the heterogeneous one dependent upon the particle size. As the pin pitch increases, the total double heterogeneity effect decreases. As the pin pitch increases, the resonance effect decreases due to the lesser self-shielding effect from the larger escape probability. This analysis results showed that the effective resonance cross sections should be properly estimated and the neutron transport calculations should be performed precisely at the same time to obtain the accurate solution.

3. Conclusion

We have analyzed the double heterogeneity effects quantitatively. The computational results showed that the resonant effect is much larger than the heterogeneous effect. This means that the effective resonance cross sections should be correctly estimated prior to the transport calculation for the doubly heterogeneous fuel problems. This consequence should be considered in the preparation of the resonance integral tables and their usage in the transport lattice calculations.

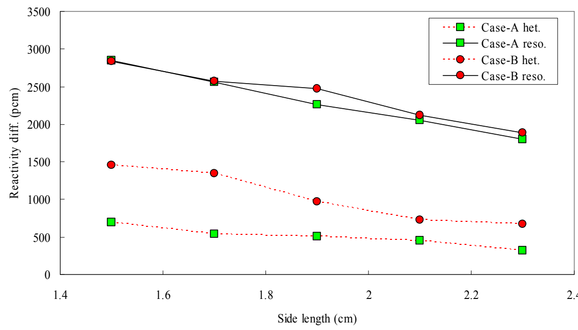


Figure 2. Resonant and heterogeneous effects for the different TRISO sizes

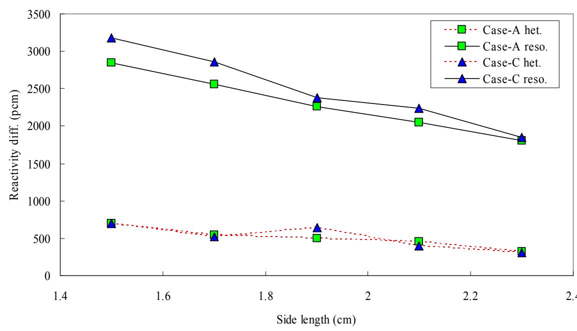


Figure 3. Resonant and heterogeneous effects for the different packing fractions

REFERENCES

[1] K. S. Kim, et al., "Development of Two-Step Procedure for the Prismatic VHTR Physics Analysis," PHYSOR'06, Vancouver, Canada, Sept. 10~14, 2006 (2006)
[2] J.F. Briesmeister, "MCNP4C – A General Monte Carlo N-Particle Transport Code," LA-13709-M, Los Alamos Nat'l Lab. (2000)
[3] Kang-seog Kim, et al., "Development of DENT 2D Code Based on the Characteristics Method," *Trans. Am. Nuc. Soc.*, 86, 369-371 (2002)
[4] P. E. MACDONALD, et al, "NGNP Preliminary Point Design – Results of Initial Neutronics and Thermal-Hydraulic Assessment," INEEL/EXT-03-00870 Rev. 1 (2003)
[5] R. J. Stamml'er, et al., "HELIOS Methods," Studsvik Scandpower (1998)