A Direct Iteration Method using Resonance Integral Table for the Self-Shielding Calculations

Ser Gi Hong , Kang-Seog Kim, and Jae Seung Song
[a]*Korea Atomic Energy Research Institute, Duckjin-dong, Yuseong-gu, Daejon, Korea*

[*]*Corresponding author: hongsg@kaeri.re.kr*

1. Introduction

In this paper, a direct iteration method using the resonance integral table is introduced for the self-shielding calculations. The basic purpose of this paper is to show the possibility that the HELIOS[1] subgroup method can be replaced with this method. This method doesn't use the subgroup data but only the resonance integral tables given in library. The basic idea of this method is to use the Bondarenko's iteration[1] in order to obtain the self-shielded effective cross sections with the background cross sections which are calculated by the heterogeneous transport calculation. This method is implemented in the KARMA lattice calculation code[2] and tested.

2. Theory and Method

The resonance nuclides are classified into several categories as in the HELIOS subgroup method[1]. For each category, the resonance transport calculations are performed for the resonance energy groups to obtain the equivalence cross section (and background cross section). The transport equation is given by

$$\hat{\Omega}_n \cdot \nabla \varphi_{n,c,g,m}(\vec{r}) + \Sigma_{r,c,g,m}(\vec{r})\varphi_{n,c,g,m}(\vec{r}) = \sum_i \lambda_{ig} N_i \sigma_{pig} \equiv \lambda_g \Sigma_{pg} \quad (1)$$

In Eq.(1), the index *m* means the level of the absorption cross section and the concept of absorption level is used to parameterize the equivalence cross section versus the absorption cross section. The removal macroscopic cross section is given by

$$\Sigma_{r,c,g,m} = \Sigma_{a,c,g,m} + \lambda_g \Sigma_{pg} . \quad (2)$$

$$\Sigma_{a,c,g,m} = \sigma_{a,g,c,m} \frac{\sum_i N_i R_{\infty,i,g}}{R_{\infty,r(c),g}} . \quad (3)$$

where R_∞ represents the resonance integral at infinite dilution. At present, the subgroup absorption levels of the representative nuclide (*r*) are used as the levels of the absorption cross section for the category c. The heterogeneous resonance transport calculations give the macroscopic background cross section and equivalence which are given by

$$\Sigma_{b,c,g}(\sigma_{a,g,c,m}) = \frac{\Sigma_{a,c,g,m}\phi_{c,g,m}}{1-\phi_{c,g,m}} , \quad (4a)$$

$$\Sigma_{e,c,g}(\sigma_{a,g,c,m}) = \Sigma_{b,c,g}(\sigma_{a,g,c,m}) - \lambda_g \Sigma_{pg} \quad m = 1,..,M . \quad (4b)$$

The above procedure is the exactly same as those of the subgroup method. So, the subroutines of KARMA involved in the above procedures can be directly used for this method. The next step is to calculate the effective resonance cross sections by using the Bondarenko iteration on the background cross section for all the resonance nuclides. This iteration procedure can be summarized as follows : 1) The microscopic cross sections are guessed, 2) The effective resonance cross sections($\sigma_{a,i,g}$) are calculated by the Segev's interpolation[1] corresponding to the background cross section from the resonance integral (RI) tables which are given in library. 3) An interpolation argument is calculated by

$$\sigma^*_{i,g} = \frac{R_{\infty,r(c),g}}{R_{\infty,i,g}} \sigma_{a,i,g} . \quad (5)$$

4) The new equivalence cross section ($\Sigma_{e,i,g}$) by using the above interpolation argument from the prepared table of the equivalence cross section are calculated and the new background cross section is calculated by

$$\sigma_{b,i,g} = \frac{1}{N_i}\Sigma_{b,i,g} = \frac{1}{N_i}(\lambda_g \Sigma_{pg} + \Sigma_{e,i,g}) . \quad (6)$$

5) The convergence of the background cross section are checked and the above steps are repeated if the iteration is not converged.

The method described above is denoted by RI Method (II).

Next, a more direct method is described. In this method, the classification of the resonance nuclides are still used but the tabulation of the equivalence cross section is not required. On the other hand, the direct Bondarenko's iteration is used in each class. In this method, the iteration starts with the initially guessed background cross sections and then, the effective absorption cross sections are calculated by using the RI tables with the Segev's interpolation. Then, the following heterogeneous transport calculations are done for each class:

$$\hat{\Omega}_n \cdot \nabla \varphi^{(l)}_{n,c,g}(\vec{r}) + \Sigma^{(l)}_{c,g}(\vec{r})\varphi^{(l)}_{n,c,g}(\vec{r}) = \lambda_g \Sigma_{pg}, \quad \Sigma^{(l)}_{c,g} = \sum_{i \in c} \sigma^{(l)}_{i,a,g} N_i \quad (7)$$

Then, the background cross sections are updated by the following equation :

$$\sigma^{(l+1)}_{b,i,g} = \frac{1}{N_i} \frac{\Sigma^{(l)}_{c,g}\phi^{(l)}_{c,g}}{1-\phi^{(l)}_{c,g}} . \quad (8)$$

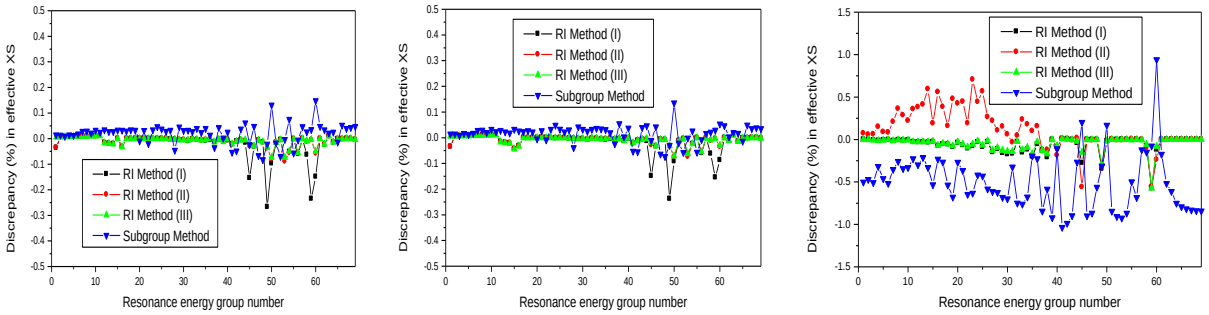
The new absorption cross sections are calculated by using RI tables with the Segev's interpolation.

In the next section, we tested the two special cases of this method : 1) RI Method (I) treats all the resonance

nuclides in a single class, 2) RI Method (III) treats each resonance nuclide in its own class (i.e., one class includes only one resonance nuclide.).

3. Numerical Test

To test the direct iteration method using the RI tables, a simple pin cell problem is selected. The pin is just UO_2 fresh fuel (3.526wt% enrichment and fuel temperature of 300K) while the clad material is aluminum. The aluminum is considered to neglect the resonance effect of clad material. The MERIT program[3] was used to generate the resonance integrals for sixty nine resonance energy groups and the SUBDATA program[4] was used to generate the subgroup data. In MERIT calculations, the resonance interference effects between the resonance nuclides (i.e., ^{235}U and ^{238}U) were not considered. The effective microscopic resonance cross sections which are calculated by MERIT for a reference case will be used as the reference cross sections for comparison.



a. ^{235}U capture b. ^{235}U nu*fission c. ^{238}U capture

Fig. 1. Comparison of the discrepancies of microscopic effective cross section

Table I : Comparison of the infinite multiplication factors

	With MERIT XS	Subgroup Method	RI Method (I)	RI Method (II)	RI Method (III)
K_{inf}	1.39759	1.39810	1.39785	1.39764	1.39779
Discrepancy (pcm)	Reference	26	13	3	10

Fig. 1 compares the discrepancies (%) in the microscopic effective cross sections for ^{235}U and ^{238}U. between the different resonance treatment methods. The effective cross sections by MERIT were used as the reference one. The KARMA calculations with different resonance treatment methods (Subgroup method, RI Method (I~III)) are done only for the reference case of the cases which are used in the MERIT calculations. Basically, the cross section library for KARMA is 190 energy group structure having 69 resonance energy groups. In this comparison, it should be noted that the subgroup data are generated so as to conserve the resonance integrals. The results show that the direct iteration methods with RI except for the RI Method (II) gives quite accurate (<0.5%) effective cross sections for all the cases and that the subgroup method gives very accurate values for ^{235}U but its errors are larger for ^{238}U than the direct iteration methods (I and III) with RI. The relatively large errors in RI Method (II) are due to the fact that this method uses an interpolation for equivalence cross section.

Table I compares the K_{inf} values. The reference value is obtained by using KARMA with the effective microscopic cross sections obtained by MERI. Table I shows that the direct iteration methods with RI give quite accurate K_{inf} values relatively to the subgroup method. As conclusion, the direct iteration methods with RI can be effectively used for the resonance calculations.

Acknowledgement

This work is supported by "Development of the Major Design Codes for a Nuclear Power Plant" project sponsored by Korea Ministry of Knowledge Economy.

REFERENCES

[1] R. J. Stamml'er, et al., "HELIOS Methods," Studsvik Scandpower Internal Report (1998).
[2] K. S. Kim and S. G. Hong et al., "Transport Lattice Code KARMA 1.1," to be presented in this meeting.
[3] K. S. Kim et al., "MERIT Code Development for the Generation of Intermediate Parameters and Resonance Integral Tables," Proc. Of KNS 2006 Spring Mtg., GangChon, Korea (2006).
[4] K. S. Kim, "Software Verification and Validation Report (SUBDATA1.0)," NCD-CA-SVVR-015(r0), KAERI.