MERIT Code Development for the Generation of Intermediate Resonance Parameters and Resonance Integral Tables

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1. Introduction

Resonance treatment is the most important part in the deterministic transport lattice calculation. The conventional resonance treatment requires resonance integrals tabulated as a function of the background cross section (σ_b) in advance. In the transport lattice calculation, a background cross section is estimated at first, and then the self-shielded resonance cross section can be obtained by looking up a resonance integral (RI) table. This RI table can be prepared by various methods, which include the Bondarenko method[1], the homogeneous method and the heterogeneous method[2,3]. These methods are categorized by how to calculate the ultra fine group self-shielded fluxes. The third one is the best because it solves the slowing down equation in a heterogeneous geometry. P. H. Kier[2] at Argonne national laboratory developed the RABBLE code and F. Leszczynski[3] at CNEA in Argentina developed RMET21 for this purpose. One of the drawbacks in these codes is that they do not include a module to generate the corresponding σ_b's.

A new transport lattice code LIBERTE has been developed which adopts a subgroup method for a resonance treatment. This subgroup method requires RI tables and intermediate resonance parameters[4] (λ) generated by the heterogeneous method. Therefore, we have developed a new code MERIT (program for Multi-regional Effective Resonance Integral Table) to generate RI tables and λ's. This code includes a module to edit ultra fine group (> millions) cross sections with an equal lethargy width, a module to solve the slowing down equation in the homogeneous and 1-D cylindrical geometries by integral transport, a module to calculate the corresponding σ_b's by the method of characteristics, and a module to calculate λ's.

2. Methods and Results

2.1 Slowing down calculation[2]

In order to obtain the effective resonance cross sections the self-shielded neutron spectra should be obtained by solving a slowing down equation. The MERIT code solves a slowing down equation in the homogeneous and heterogeneous 1-D cylindrical geometries by an integral transport. In the integral transport theory the integrated flux is

$$\phi_{ig} = \frac{C_{ig}}{\Sigma_{ig}}, \tag{1}$$

where C_{ig} is the collision rate in region i for group g and Σ_{ig} the macroscopic total cross section. In this formulation, the collision rate is obtained from the expressions involving the slow-down sources, the first-flight escape and transmission probabilities, and the interface currents. The calculation of a regional slowing down is based on the assumption that neutrons are scattered elastically and isotropically.

The source for a region is

$$S_g = \sum_{j=1}^{J}\sum_{n=1}^{L_j} P_{nj}\Sigma^j_{s,g-n}\phi_{g-n}\Delta u_f, \tag{2}$$

where P_{nj} is the probability per unit lethargy that a neutron is scattered down n groups in a scattering collision with material j, L_j is the maximum number of group through which a neutron can be down-scattered in a scattering collision with material j, $\Sigma_{s,g-n}\phi_{g-n}$ is the reaction rate at which neutrons are scattered by material j in group g-n, and Δu_f is the lethargy width of a fine group. P_n is as follows:

$$P_n\Delta u_f = \frac{1}{1-\alpha}(1-e^{-\Delta u_f})^2 e^{-(n-1)\Delta u_f}, \tag{3}$$

$$\alpha = \left(\frac{A-1}{A+1}\right)^2,$$

where A is the atomic mass.

The next step is to calculate the collision rates. The collision rate in the homogeneous case is

$$C_i = S_i. \tag{4}$$

The collision rate in the 1-D cylindrical geometry is

$$C_i = \begin{cases} (1-T_i^{OO})J_i^- + (1-P_i^+)S_i, & i=1 \\ (1-T_i^{OI})J_{i-1}^+ + (1-T_i^{OO}-T_i^{IO})J_i^- +, & \\ (1-P_i^+-P_i^-)S_i, & i=2,I \end{cases} \tag{5}$$

where J_i is the cosine current, P_i is the escape probability, and T_i is the transmission probability. The effective microscopic resonance cross sections can be obtained by a flux volume weighting.

2.2 Hydrogen-equivalent parameter

Intermediate resonance parameter (λ) is also called a hydrogen-equivalent parameter which was introduced in the intermediate resonance approximation proposed by

Goldstein and Cohen[4]. This parameter is a probability that a neutron passes through a resonance. λ=1 means a narrow resonance and λ=0 the wide resonance. Resonance integrals are tabulated as a function of σ_b ($\equiv\lambda\sigma_p$) where λ is defined as 1 for hydrogen. For other nuclides, λ can be obtained by comparing solutions in U^{238}/H mixtures with mixtures where the hydrogen was partly replaced by the other nuclides.

2.3 Background cross section

Resonance integrals are expressed as a function of σ_b. After an effective resonance cross section is obtained through the ultra fine group slowing down calculation, the corresponding σ_b should be obtained in the same geometry and composition by solving a broad group slowing down equation:

$$\hat{\Omega}_m \cdot \nabla \varphi_{mg}(\vec{r}) + \Sigma_{tg}(\vec{r})\varphi_{mg}(\vec{r}) = \frac{1}{4\pi}\lambda_g \Sigma_{pg}, \qquad (6)$$

where Σ_{tg} and Σ_{pg} are total and potential cross section and φ_{mg} is a self-shielded angular flux. The corresponding σ_b is obtained as follows:

$$\Sigma_{bg}(\sigma_{ag}) = \frac{\Sigma_{ag}\phi_g}{1-\phi_g}, \quad \sigma_{bg} = \Sigma_{bg}/N_R, \qquad (7)$$

where Σ_{ag} is the absorption cross section, ϕ_g is the self-shielded scalar flux and N_R is the particle number density of the representative resonant nuclide.

2.4 Calculation and results

Figures 1 and 2 show the comparisons of RI's from the MERIT calculations with RI's from the HELIOS[5] library for the 59th resonance group and σ_b=57.9 barn of U^{238}. The overall trend is very similar, and the differences came from using different ENDF/B versions, which shows that the MERI code is working reasonably well. Hydrogen-equivalent parameters calculated from the RI tables are very consistent with the HELIOS ones for the resonant energy groups.

3. Conclusion

We developed a new code MERIT to generate the hydrogen-equivalent parameters and the resonance integral tables. Results of the sample calculations showed that this MERIT code is working reasonably well. RI table and the hydrogen-equivalent parameters generated by the MERIT code will be used in the new library for LIBERTE[6].

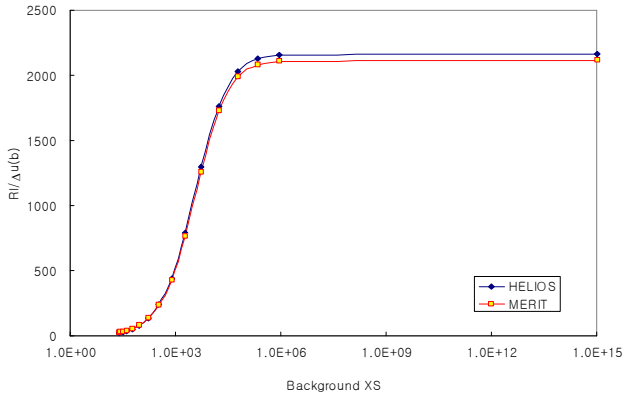

Figure 1. U^{238} resonance integral vs. σ_b in the 59th group

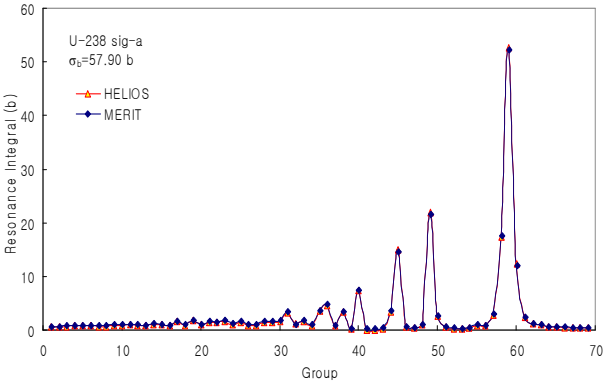

Figure 2. Group-wise U^{238} resonance integrals at σ_b =57.9 barn

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