Nucl Eng Technol 47 (2015) 791–803

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.journals.elsevier.com/nuclear-engineering-and-technology/

Original Article

POINTWISE CROSS-SECTION-BASED ON-THE-FLY RESONANCE INTERFERENCE TREATMENT WITH INTERMEDIATE RESONANCE APPROXIMATION

MEER BACHA * *and HAN GYU JOO*

Department of Nuclear Engineering, Seoul National University, 1 Gwanak-ro Gwanak-gu, Seoul 151-742, Republic of Korea

ARTICLE INFO

Article history:
Received 14 April 2015
Received in revised form
23 July 2015
Accepted 23 July 2015
Available online 9 October 2015

Keywords:
Dancoff factor
Enhanced neutron current method
Equivalence theory
Resonance integral
Self-shielding
Subgroup method

ABSTRACT

The effective cross sections (XSs) in the direct whole core calculation code nTRACER are evaluated by the equivalence theory-based resonance-integral-table method using the WIMS-based library as an alternative to the subgroup method. The background XSs, as well as the Dancoff correction factors, were evaluated by the enhanced neutron-current method. A method, with pointwise microscopic XSs on a union-lethargy grid, was used for the generation of resonance-interference factors (RIFs) for mixed resonant absorbers. This method was modified by the intermediate-resonance approximation by replacing the potential XSs for the non-absorbing moderator nuclides with the background XSs and neglecting the resonance-elastic scattering. The resonance-escape probability was implemented to incorporate the energy self-shielding effect in the spectrum. The XSs were improved using the proposed method as compared to the narrow resonance infinite mass-based method. The RIFs were improved by 1% in ^{235}U, 7% in ^{239}Pu, and >2% in ^{240}Pu. To account for thermal feedback, a new feature was incorporated with the interpolation of pre-generated RIFs at the multigroup level and the results compared with the conventional resonance-interference model. This method provided adequate results in terms of XSs and k-eff. The results were verified first by the comparison of RIFs with the exact RIFs, and then comparing the XSs with the McCARD calculations for the homogeneous configurations, with burned fuel containing a mixture of resonant nuclides at different burnups and temperatures. The RIFs and XSs for the mixture showed good agreement, which verified the accuracy of the RIF evaluation using the proposed method. The method was then verified by comparing the XSs for the virtual environment for reactor application-benchmark pin-cell problem, as well as the heterogeneous pin cell containing burned fuel with McCARD. The method works well for homogeneous, as well as heterogeneous configurations.

* *Corresponding author.*
E-mail address: meerbacha@yahoo.com (M. Bacha).

http://dx.doi.org/10.1016/j.net.2015.09.001
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1. Introduction

The equivalence theory-based [1] resonance-integral (RI) method [2] is commonly used for self-shielding calculations in many lattice-physics codes. One of the most challenging tasks in self-shielding calculations is the generation of effective cross sections (XSs) in mixed-absorber configurations. Most methods, such as the subgroup method [3], are efficient and accurate in determining effective XSs for isolated resonant nuclides. In the case of mixed absorbers, these methods apply some adjustments or modifications to the XSs. There can be unknown weaknesses in such methods concerning mixed-absorber configurations.

The nTRACER direct whole-core calculation code [4], which is capable of dealing with the local heterogeneity of the core constituents without homogenization in the single-step calculation, employs the subgroup method for resonance treatment. It uses its own multigroup (MG) XS library generated from the ENDF-B/VII XS data [5] through an internal procedure that also determines the optimized subgroup parameters [3]. Recently, an alternative XS processing feature was introduced in nTRACER in order to utilize the WIMS-IAEA XS library. This library contains the RI data and no subgroup parameters. In this article, the in-house nTRACER library and the WIMS library [6] will be abbreviated as nTL and WIL, respectively. In the conventional RI-based resonance-treatment methods, the RI table is used to generate the effective XSs in a heterogeneous configuration and the RI data are tabulated as a function of background XSs and temperatures. The conventional RI method was implemented in nTRACER in conjunction with WIL, for which no subgroup data are available. For the determination of the background XSs under equivalence theory, the enhanced neutron-current method [7] was applied. This method directly evaluates the background XSs and does not need the escape XSs or the Dancoff factors.

The resonance treatment of an isolated resonant nuclide can be accurate in terms of effective XSs. With multiple resonant nuclides, the resonance interference among various resonance nuclides must be treated properly in order to accurately obtain the effective XSs. The most accurate method for evaluating the effective XSs in the mixed absorbers is to solve the neutron-slowing equation for all resonant nuclides in a mixture. This method is feasible at the pin-cell level, but is impractical for the assembly and core calculations using current computational resources. One of the approximations involves considering only one resonant nuclide at a time without considering the effects of other available resonant nuclides. This approximation would result in large discrepancies in XSs in the mixed-absorbers case. Another approximation is to augment the background XS with the average absorption XS of the system. This approach is known as the conventional Bondarenko iteration approach [3] for resonance interference treatment. In this approach, each resonant nuclide influences on all other nuclides in the mixture. The larger the absorption XS of the nuclide, the greater its impact on other resonant nuclides. In this approach, the effective XSs always increase because of the augmentation of absorption XSs to the background XSs. Therefore, the conventional method cannot show the decreasing trend of XSs from the interference. To account for the resonance interference in the mixture of resonance absorbers, some methods modify the resonance integrals by the density ratios [8]. However, the larger the number of absorbers in the mixture, the more complex the method. Recently, a new method was developed for the evaluation of resonance interference factors (RIFs) at the multigroup level [9]. This method generates the RIFs for the resonant nuclides at various temperatures, compositions, and background XSs. These tabulated multigroup factors can be interpolated for the temperature and background XSs. This method provides good results at the cost of high computational burden.

The term RIF was introduced in a much earlier paper [10] in which the microscopic XSs were tabulated on a union-lethargy interval for each resonant absorber and temperature. This method was based on the narrow resonance infinite mass (NRIM) or the wide-resonance (WR) flux approximations for on-the-fly generation of the RIFs. These calculations were performed once per burnup step for each composition and background XS. This method provided better results than the conventional method, however, did not adequately model the thermal feedback. A method is required to improve the accuracy of XSs, as well as present a better and more robust way of treating temperature feedback.

This study presents a modification of the above method. Instead of using the WR or NRIM approximation for the resonant absorbers, the intermediate resonance (IR) approximation was used with the neglect of the resonance elastic-scattering term. For the accuracy of XSs, the resonance-escape probability was implemented to account for the energy self-shielding effect in the spectrum. This study aimed to implement an efficient resonance-interference treatment model in nTRACER with WIL. With this method, the XSs in the resonance-energy range were accurately and robustly evaluated. The accuracy of the XSs increased using the proposed method and the thermal-feedback effect was handled with interpolation of temperature-dependent RIFs at the multigroup level, with pre-generated RIFs interpolated for the system temperature. This method was more accurate than both the conventional and NRIM-based methods and efficiently treated temperature feedback with no computational cost. The application of the resonance-escape probability increased the accuracy of RIFs, as well as XSs. In this manuscript, the IR-based XS table method will be denoted as XST, while the IR-based XS table method with resonance-escape probability will be expressed as modified XST. In this method, the RIF calculation was performed once per burnup step, with little extra computational burden and no large amounts of memory required. This study focuses on the applicability of this method to the homogeneous pin-cell problem at various burnups and temperatures, and the heterogeneous virtual environment for reactor application (VERA)-benchmark pin-cell problems. A heterogeneous pin cell with burned fuel is also analyzed and the reliability of the thermal-feedback effect for the RIFs is discussed in detail.