Verification of New Doubly-Heterogeneous Self-shielding Method in SCALE

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INTRODUCTION

The SCALE (Standardized Computer Analyses for Licensing Evaluation) code package [1] usually uses two steps in the resonance self-shielding calculations. The first step uses the BONAMI code which applies equivalence theory and narrow resonance (NR) approximation for the calculation of the effective multi-group cross sections. The second step uses the CENTRM module to compute a high-resolution flux spectrum (typically 50,000-7000 energy points) by solving the discrete ordinates transport equation using continuous nuclear data in a one-dimensional unit cell. The PMC module processes problem-dependent self-shielded data using the CENTRM point-wise (PW) flux for weighting.

Recently, the intermediate resonance (IR) approximation was implemented in BONAMI as a faster but less rigorous alternative to the CENTRM/PMC self-shielding methodology. This required the computation of IR parameters and Bondarenko self-shielding factors for inclusion in the multigroup library, and modification of the BONAMI code to use the IR method. The modified version of BONAMI is referred to as BONAMI-IR.

DESCRIPTION OF THE ACTUAL WORK

For application to high-temperature gas reactor (HTGR) analysis, the BONAMI-IR method has been additionally upgraded to address doubly heterogeneous (DH) systems such as TRISO fuel. The new method is similar in principle to the current SCALE DH treatment with CENTRM. SCALE currently treats DH self-shielding using two deterministic PW transport calculations with CENTRM. The first computes space-dependent PW fluxes for an infinite array of spherical fuel grains contained in a graphite matrix. These fluxes are used to compute PW disadvantage factors for flux weighting the fuel grain/matrix PW cross sections into a homogeneous compact mixture. The second PW calculation is performed for the lattice unit cell consisting of the homogenized fuel compact and graphite moderator. PW fluxes from the second CENTRM case are used to average the PW data into self-shielded multigroup values for the homogenized compact and graphite materials. [2]

The new approach implemented in BONAMI-IR derives analytical expressions for the energy-dependent flux using the IR approximation and equivalence theory, instead of using CENTRM to compute the PW fluxes numerically. [3] The resulting expressions for the DH self-shielded cross sections are consistent with the Bondarenko method; i.e., they depend only on the value of the background cross section, so that BONAMI-IR can interpolate the shielding factors from the master multigroup cross-section library.

Like the current SCALE DH method in CENTRM, the new equivalence theory method applies disadvantage factors to the nuclear data of the fuel grains and graphite matrix material to obtain cross sections for a homogenized fuel compact mixture. It was found that results are quite sensitive to parameters appearing in the escape cross section, e.g., the Dancoff and Bell factors.

Figure 1 shows a simplified model of a unit cell for the High Temperature Test Reactor (HTTR) benchmark that has been used for testing. The unit cell eigenvalue calculations were performed with two methods. The first used the multigroup (MG) Monte Carlo mode in KENO with the current SCALE DH treatment based on CENTRM/PMC to provide self-shielded cross sections for the homogenized fuel compact. The second calculation also used the MG mode in KENO for the cell eigenvalue calculation, but the self-shielded cross sections were obtained from the BONAMI-IR code with the new DH method.

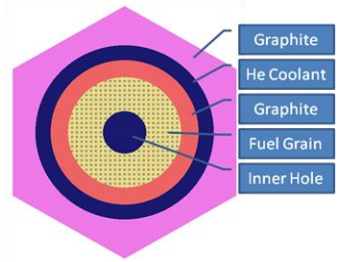

Fig. 1. HTTR simplified unit cell model.

Table I. Preliminary results of DH method in BONAMI-IR vs. CENTRM

Fuel volume in compact	**KENO MG (CENTRM)**	**KENO MG (BONAMI-IR)**	**KENO MG (BONAMI-IR vs. CENTRM)**
8.3% (base case)	1.34936 ± 0.00021	1.34817 ± 0.00020	-119 pcm
10.94%	1.27841 ± 0.00021	1.27476 ± 0.00022	-365 pcm
6.02%	1.42820 ± 0.00019	1.42940 ± 0.00026	120 pcm

RESULTS AND DISCUSSIONS

Table I summarizes the results of the new BONAMI-IR DH method compared with the existing CENTRM DH method. The reference case has a grain packing fraction of 30% within the fuel compact, which corresponds to a fuel volume fraction of about 8.3%. Two additional cases were considered which changed the reference packing fraction of the base case by ±20%.

The eigenvalue comparison of KENO MG (CENTRM) and KENO MG (BONAMI-IR) shows that the new method gives comparable results to the CENTRM approach and runs much faster. Because the discrepancies for a typical LWR pin cell (non-TRISO, i.e., no DH) are on the same order as those for a HTTR unit cell with the new DH treatment, we conclude that the accuracy of the new DH treatment with BONAMI-IR is comparable to the current DH method using CENTRM.

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