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On the relationship between changes in k and changes in homogenized 2-group constants

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Abstract

The relationships between changes in k_∞ and changes in homogenized 2-group constants are derived. These relationships are used to explain seemingly contradictory results from two separate transport codes where it was found that they agree far more closely on the change in each cross-section than they do on the change in k_∞. The study showed that this possibility was due to the fact that changes in k_∞ were the results of various combinations, including differences of ratios of cross-sections.
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1. Introduction

The United States is planning to use some of its excess weapons plutonium (Pu) to make mixed-oxide fuel for existing light water reactors (LWRs). The first step in such an analysis, in the absence of benchmarks, would be to compare the calculational results, such as fluxes and reaction rates, from different reactor physics codes and libraries used with assemblies of MOX and LEU. One should hope that the results of analyses using cross-sections generated by the two separate codes should be equivalent. In those areas where the results are equivalent, certain assurance is given that the results are correctly predicting behavior.

In these studies, the two lattice physics codes used were HELIOS-1.5 [1] and CASMO-3 [2]. As the origin of the cross-sections used in the two codes are basically ENDF-B/VI and ENDF-B/IV

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Libraries, respectively, some discrepancies in the results were expected and indeed occurred.

In some of the cases, the codes agree far more closely on the change in each cross-section than they do on the change in k_∞. This seems contradictory at first, and led us to investigate further the relationship between changes in the 2-group cross-sections and changes in k_∞. The results of that study will be presented here.

The relationship between k_∞ and the 2-group cross-sections will be derived. Next, the results of a few of the calculations made by HELIOS and CASMO will be presented. These results will contain some of the discrepancies noted, and the equations derived will be used as an aid in understanding the discrepancies.

2. Theoretical derivation

In this section the relationship between changes in k and changes in homogenized 2-group constants will be derived. Here we use "H" and "C" to distinguish between the two transport codes, HELIOS and CASMO.

2.1. The relationship between k and the two-group cross-sections

We begin with the equations that are used in an assembly level transport calculation. If power iteration is used for the fine-group eigenvalue calculation, then

$$\begin{aligned}
&\int_{\partial A} \hat{n}\cdot\vec{J}_g^{n+1}(\vec{r})\,\mathrm{d}^2r \\
&\quad+\int_A\left[\Sigma_{a,g}(\vec{r})+\sum_{g'\neq g}\Sigma_{s,g\to g'}(\vec{r})\right]\phi_g^{(n+1)}(\vec{r})\,\mathrm{d}^3r \\
&\quad=\int_A\left[\sum_{g'\neq g}\Sigma_{s,g'\to g}(\vec{r})\phi_{g'}^{(n+1)}(\vec{r})\right. \\
&\qquad\left.+\frac{1}{k^{(n)}}\chi_g\sum_{g'}\nu\Sigma_{f,g'}(\vec{r})\phi_{g'}^{(n)}(\vec{r})\right]\mathrm{d}^3r, \\
&\quad g=1,\ldots,G, \qquad (1a)
\end{aligned}$$

$$\begin{aligned}
k^{(n+1)} &= k^{(n)}\frac{\int_A\left[\sum_g\nu\Sigma_{f,g}(\vec{r})\phi_g^{(n+1)}(\vec{r})\right]\mathrm{d}^3r}{\int_A\left[\sum_g\nu\Sigma_{f,g}(\vec{r})\phi_g^{(n)}(\vec{r})\right]\mathrm{d}^3r} \\
&= \frac{\int_A\left[\sum_g\nu\Sigma_{f,g}(\vec{r})\phi_g^{(n+1)}(\vec{r})\right]\mathrm{d}^3r}{\frac{1}{k^{(n)}}\int_A\left[\sum_g\nu\Sigma_{f,g}(\vec{r})\phi_g^{(n)}(\vec{r})\right]\mathrm{d}^3r}. \qquad (1b)
\end{aligned}$$

Here the integrals over A are over the assembly volume, and the integral over δA is over the assembly surface. The parenthetical superscript represents iteration index. Each surface is treated as a reflecting boundary; in many methods this reflection is enforced for each group at each iteration making the surface term in Eq. (1a) equal zero. (This will often depend on how tightly the code converges its within group iteration.) Eqs. (1) contain integrals and a continuous spatial variable r, but this is simply a notational convenience. In the actual calculation, spatial quantities are discrete; nevertheless, they satisfy a form of Eqs. (1) in that spatial integrals are represented as sums of products of spatial cell volumes times cell averaged quantities.

If Eq. (1a) is summed over all "fast" groups, the result is

$$\begin{aligned}
&\int_A\sum_{\text{fast }g}\left[\Sigma_{a,g}(\vec{r})+\sum_{g'\neq g}\Sigma_{s,g\to g'}(\vec{r})\right]\phi_g^{(n+1)}(\vec{r})\,\mathrm{d}^3r \\
&\quad=\int_A\left[\sum_{\text{fast }g}\sum_{g'\neq g}\Sigma_{s,g'\to g}(\vec{r})\phi_{g'}^{(n+1)}(\vec{r})\right. \\
&\qquad\left.+\frac{1}{k^{(n)}}\sum_{\text{fast }g}\chi_g\sum_{g'}\nu\Sigma_{f,g'}(\vec{r})\phi_{g'}^{(n)}(\vec{r})\right]\mathrm{d}^3r. \qquad (2a)
\end{aligned}$$

Many of the scattering terms now cancel from the right and left sides of the equation; the only ones remaining are those that involve scattering between "fast" and "thermal" groups:

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