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# Insufficient Self-shielding Correction in JSSTDL-300

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JSSTDL-300 is a multigroup library for shielding applications produced from JENDL-3.2. The self-shielding correction in JSSTDL-300 is probably inadequate due to the following two reasons, 1) the weighting flux of Legendre order 0 is applied to all Legendre orders, 2) the f-table of the scattering matrix is the same as that of the elastic scattering. Thus we examined the effects of these problems through a simple benchmark test, the model of which consisted of an aluminum, iron, nickel or copper sphere of 1 m in radius with a 20 MeV neutron source in the center. Neutron spectra in the sphere were calculated with ANISN and they were compared with those obtained with MCNP4C. It was found out that the effects were dependent on materials and were the largest for copper. Adequate f-table data and weighting flux should be adopted in generation of multigroup libraries.

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## I. INTRODUCTION

The self-shielding correction in multigroup libraries is essential in order to obtain appropriate results in Sn calculations. The Bondarenko method [1] by using f-table is often used as the self-shielding correction and gives good results. Recently it is pointed out that a weighting flux (WF) dependent on Legendre order is required for appropriate self-shielding correction as described in Sec. II [2].

JSSTDL-300 [3], a common multigroup library of neutron 300 groups and gamma 104 groups for shielding applications produced from JENDL-3.2 [4] with the PROF-GROUCH-G/B [5] code by Japanese Nuclear Data Committee, is widely applied in Japan. However, the self-shielding correction in JSSTDL-300 is probably inadequate due to the following two reasons,

1) The weighting flux of Legendre order 0 is applied to all Legendre orders.

2) The f-table for the scattering matrix is the same as that for the elastic scattering.

Effects of these problems are examined through a simple benchmark test in this paper.

## II. IMPORTANCE OF WEIGHTING FLUX

In the Bondarenko method, the following weighting flux should be used for averaging cross section data in a group,

$$W_\ell(E) = \frac{C(E)}{[\sigma_0 + \sigma_t(E)]^{\ell+1}} , \tag{1}$$

where $C(E)$ is a smooth part of the shape of the flux, $\sigma_0$ is called a background cross section, $\sigma_t(E)$ is a total cross section and $\ell$ is a Legendre order. However the weighting fluxes for $\ell \geq 1$ used in JSSTDL-300 are the following and are different from Eq. (1),

$$W_{\ell\geq 1}(E) = W_0(E) . \tag{2}$$

We have to remember that the $\mathrm{S_N}$ multigroup cross sections for discrete ordinates codes are not the same as the $\mathrm{P_N}$ multigroup cross sections included in JSSTDL-300. The $\mathrm{P_N}$ multigroup cross sections for a group g are defined as follows,

$$\sigma_{\ell tg}^{PN} = \frac{\int_g \sigma_t(E) W_\ell(E) dE}{\int_g W_\ell(E) dE} , \tag{3}$$

$$\sigma_{\ell g\leftarrow g'}^{PN} = \frac{\int_{g'} dE' \int_g \sigma_\ell(E'\rightarrow E) W_\ell(E') dE}{\int_{g'} W_\ell(E') dE'} , \tag{4}$$

where $\sigma_\ell(E' \rightarrow E)$ is a scattering cross section. Thus $\mathrm{P_N}$ multigroup cross sections with the weighting flux of Eq. (1) are different from those with the weighting flux of Eq. (2).

The relations between the $\mathrm{S_N}$ and $\mathrm{P_N}$ multigroup cross sections are as follows,

$$\sigma_{\ell g\leftarrow g'}^{SN} = \sigma_{\ell g\leftarrow g'}^{PN} \quad \text{for } g \neq g' , \tag{5}$$

$$\sigma_{\ell g\leftarrow g}^{SN} = \sigma_{\ell g\leftarrow g}^{PN} - (\sigma_{\ell tg}^{PN} - \sigma_{0tg}^{PN}) - \Delta_g^N , \tag{6}$$

$$\sigma_g^{SN} = \sigma_{0tg}^{PN} - \Delta_g^N , \tag{7}$$

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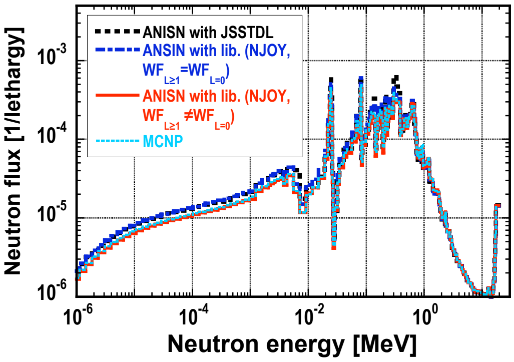

Fig. 1. (Color online) Neutron spectra at 30 cm from center (Aluminum).

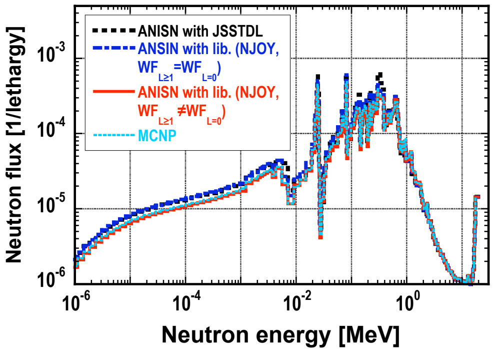

Fig. 2. (Color online) Neutron spectra at 30 cm from center (Iron).

where $\Delta_g^N$ can be chosen to minimize the effects of truncating the Legendre expansion at $\ell = N$. "$\Delta_g^N = 0$" is usually chosen, which is called "Consistent-P approximation". In this case, Eqs. (6) and (7) become

$$\sigma_{\ell g \leftarrow g}^{SN} = \sigma_{\ell g \leftarrow g}^{PN} - (\sigma_{\ell t g}^{PN} - \sigma_{0tg}^{PN}) \ , \tag{8}$$

$$\sigma_g^{SN} = \sigma_{0tg}^{PN} \ . \tag{9}$$

The difference between the $\mathrm{S_N}$ and $\mathrm{P_N}$ cross sections appears only in Eq. (8). The term in parentheses of the right hand side in Eq. (8) is zero in JSSTDL-300 because of Eq. (2), which leads to $\sigma_{\ell g \leftarrow g}^{SN} = \sigma_{\ell g \leftarrow g}^{PN}$. However, it is not always zero, which leads to $\sigma_{\ell g \leftarrow g}^{SN} \neq \sigma_{\ell g \leftarrow g}^{PN}$, if the weighting flux of Eq. (1) is adopted. Note that the term in parentheses of the right hand side in Eq. (8) is almost zero in no-resonance regions, because the weighting flux has a smooth shape in no-resonance regions. Therefore in resonance regions inadequate weighting fluxes give incorrect $\mathrm{S_N}$ cross sections, which cause inadequate results.

## III. SIMPLE BENCHMARK TEST

A simple benchmark test was carried out in order to examine effects of the above problems related to self-shielding correction in JSSTDL-300. The calculation model of this benchmark test consisted of a natural aluminum, iron, nickel or copper sphere of 1 m in radius with a 20 MeV neutron source in the center. Neutron spectra in the sphere were calculated with the Sn code ANISN [6]. The following multigroup libraries of neutron 175 groups (VITAMIN-J [7]) with self-shielding correction were adopted for ANISN,

1) JSSTDL-300 (collapsed to 175 groups),

2) Multigroup library with weighting flux independent on Legendre order generated from JENDL-3.2 by using modified NJOY99 [8] and TRANSX [9] (NJOY, $\mathrm{WF}_{\mathrm{L}\geq 1} = \mathrm{WF}_{\mathrm{L}=0}$),

3) Multigroup library with weighting flux dependent on Legendre order generated from JENDL-3.2 by using NJOY99 and TRANSX (NJOY, $\mathrm{WF}_{\mathrm{L}\geq 1} \neq \mathrm{WF}_{\mathrm{L}=0}$).

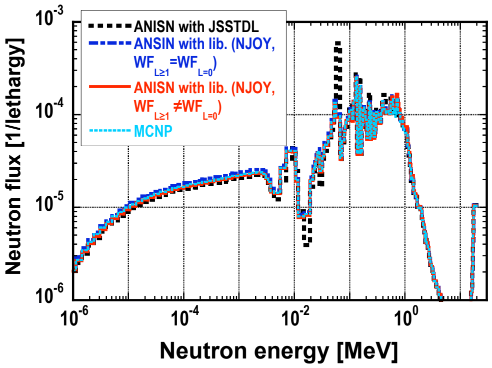

Fig. 3. (Color online) Neutron spectra at 30 cm from center (Nickel).

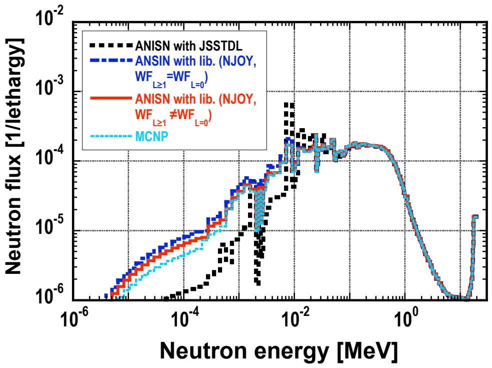

Fig. 4. (Color online) Neutron spectra at 30 cm from center (Copper).

Note that the weighting flux in the NJOY and TRANSX system is not Eq. (1) but

$$W_{\ell \geq 1}(E) = W_1(E). \tag{10}$$

The difference between ANISN calculations with the first and second libraries corresponds to the effect of the inadequate f-table data, while that between ANISN calculations with the second and third libraries corresponds to the effect of the inadequate weighting flux. These calculated results were compared with reference ones obtained with MCNP4C [10] and FSXLIBJ3R2 [11] generated from JENDL-3.2.

Figures 1 - 4 show calculated neutron spectra at 30

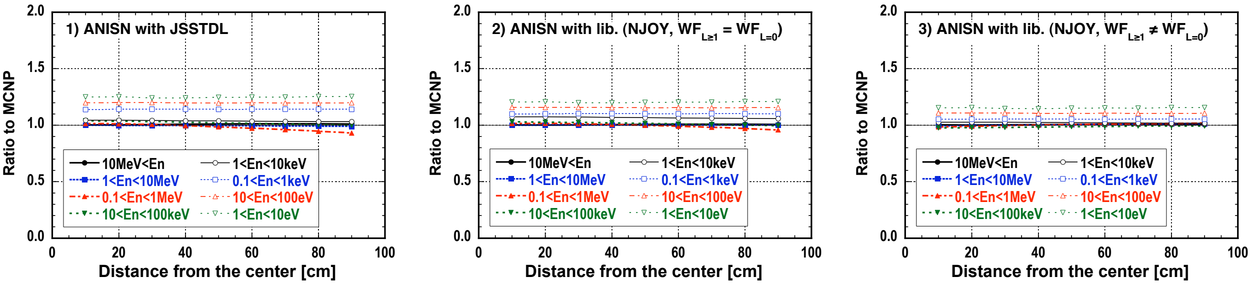

Fig. 5. (Color online) Ratio of integrated neutron fluxes with ANISN to those with MCNP (Aluminum).

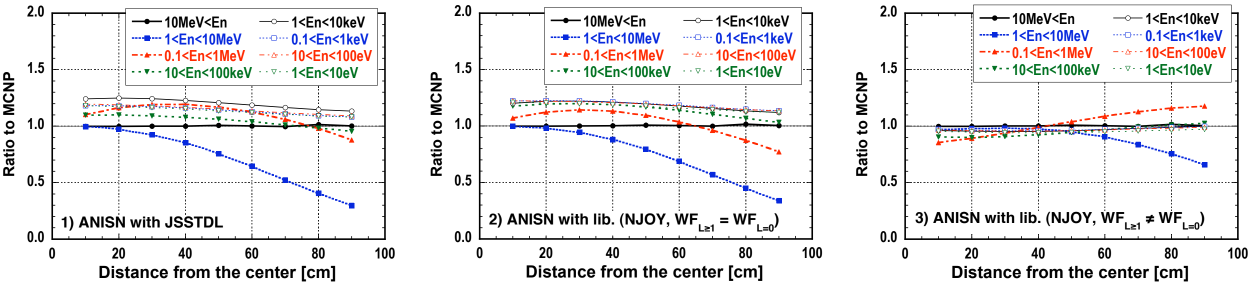

Fig. 6. (Color online) Ratio of integrated neutron fluxes with ANISN to those with MCNP (Iron).

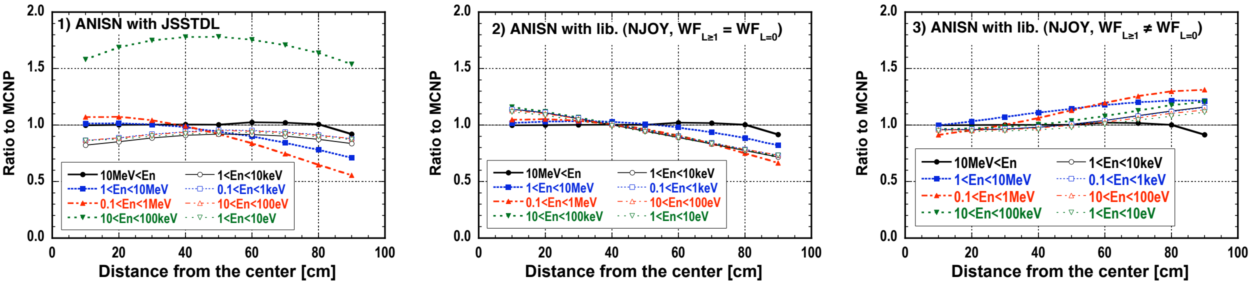

Fig. 7. (Color online) Ratio of integrated neutron fluxes with ANISN to those with MCNP (Nickel).

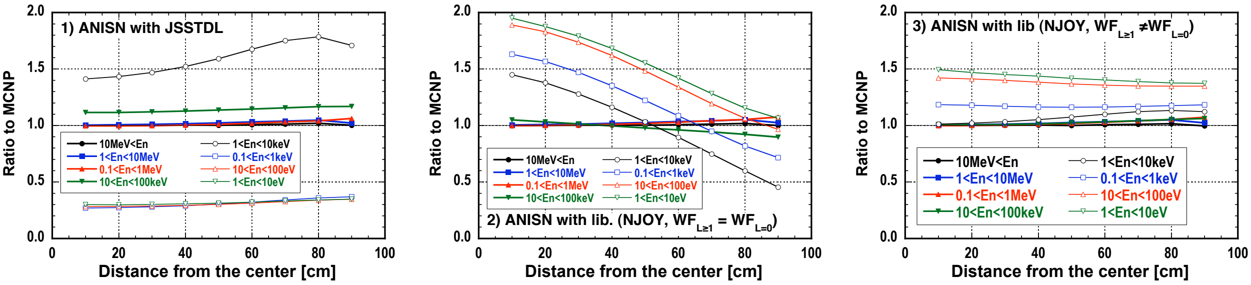

Fig. 8. (Color online) Ratio of integrated neutron fluxes with ANISN to those with MCNP (Copper).

cm from the center in the aluminum, iron, nickel and copper spheres, respectively. Since the self-shielding effect is small in aluminum, all the ANISN calculations for the aluminum sphere give almost the same results, which agree with the MCNP calculation result well. On the contrary, the ANISN calculation results are different each other for the iron, nickel and copper spheres. In order to investigate the difference among the ANISN calculation results in detail along the distance from the center of the sphere, ratios of integrated neutron fluxes calculated with ANISN to those with MCNP are plotted in Figs. 5 - 8 for the aluminum, iron, nickel and copper spheres, respectively. All the ANISN calculation results for the aluminum sphere are almost the same up to 90 cm from the center, which agree with the MCNP calculation result within 30%. The effect of the inadequate f-table in JSSTDL-300 is small in iron, while it is large for only integrated neutron flux from 10 to 100 keV in the nickel sphere and for neutron fluxes below 1 MeV in the copper sphere. The effect of the inadequate weighting flux is large in the iron, nickel and copper spheres. The ANISN calculation results with the

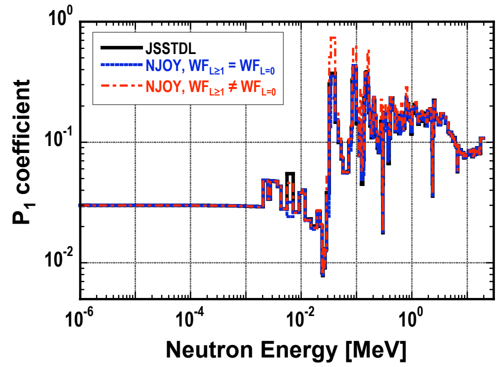

Fig. 9. (Color online) $P_1$ coefficients of the in-group scattering matrix (Aluminum).

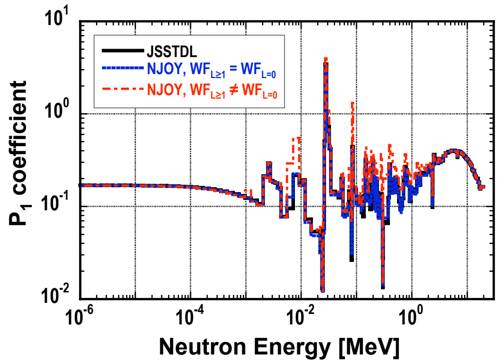

Fig. 10. (Color online) $P_1$ coefficients of the in-group scattering matrix (Iron).

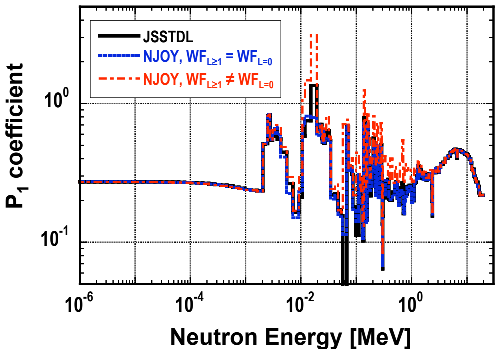

Fig. 11. (Color online) $P_1$ coefficients of the in-group scattering matrix (Nickel).

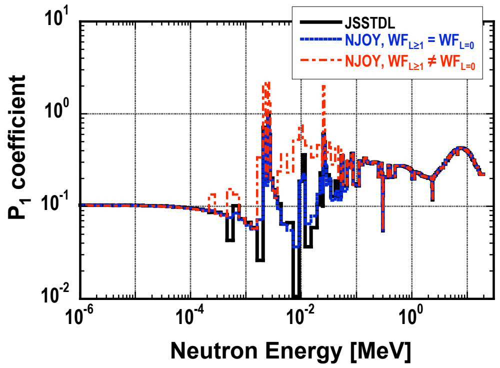

Fig. 12. (Color online) $P_1$ coefficients of the in-group scattering matrix (Copper).

third multigroup library, which adopted the appropriate weighting flux, agree with the MCNP calculation results best. However, the agreement between the ANISN calculation results with the third multigroup library and the MCNP calculation results is not so good particularly in the copper sphere. The reason of this disagreement is probably due to rather rough group structure.

The $P_1$ coefficients of the in-group scattering matrix of the three multigroup libraries are plotted in Figs. 9 - 12 for natural aluminum, iron, nickel and copper, respectively. It is demonstrated that those in JSSTDL-300 are very different from those in the third multigroup library, which leads to the difference of neutron fluxes in Figs. 5 - 8.

## IV. SUMMARY

The effects of the below problems related to the self-shielding correction in JSSTDL-300 were examined through a simple benchmark test.
1) The weighting flux of Legendre order 0 is applied to all Legendre orders.
2) The f-table for the scattering matrix is the same as that for the elastic scattering.
The following results were obtained.

1. Aluminum : The effects of the f-table and weighting flux are small.
2. Iron : The effect of the weighting flux is large, while that of f-table is not so large.
3. Nickel : The effect of the f-table is large only for integrated neutron flux from 10 to 100 keV, while that of the weighting flux is not so large.
4. Copper : The effects of the f-table and weighting flux are large.

Adequate f-table data and weighting flux should be adopted in generation of multigroup libraries.

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