Some Comments to JSSTDL-300

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Background - (1)

- At the 2002 symposium on nuclear data we pointed out that the self-shielding correction in VITAMIN-B6 is not appropriate since it uses weighting function independent on Legendre order.

Transport approximation [Consistent-P, TRANSX manual p.4 eq. (7), (8) and (9)**]**

$$\sigma_{lg\leftarrow g}^{SN} = \sigma_{lg\leftarrow g}^{PN} - \left(\sigma_{ltg}^{PN} - \sigma_{0tg}^{PN}\right) - \Delta_g^N \leftarrow 0$$

$$\sigma_g^{SN} = \sigma_{0tg}^{PN} - \Delta_g^N \leftarrow 0$$

VITAMIN-B6 : 0 for all L
NJOY-TRANSX : 0 for L=0
≠0 for L≥1

Revise

- VITAMIN-B6 has no transport approximation though it uses the weighting function dependent on Legendre order. Thus the self-shielding correction in VITAMIN-B6 is not appropriate.

$$\sigma_{lg\leftarrow g}^{SN} = \sigma_{lg\leftarrow g}^{PN} - \left(\sigma_{ltg}^{PN} - \sigma_{0tg}^{PN}\right) - \Delta_g^N \leftarrow 0$$

neglected in VITAMIN-B6

Background - (2) and Objective

- **JSSTDL-300**
  - Multigroup library generated from JENDL-3.2 for shielding with the PROF-GROUCH-G/B code.
  - Neutron 300 groups, gamma 104 groups
  - P_5 expansion
  - F-table for self-shielding correction

- The self-shielding correction in JSSTDL-300 is probably **inadequate** due to the following two reasons.
  1) The JSSTDL-300 uses the **weighting function** independent on Legendre order.
  2) The **f-table** of elastic scattering is used as that of scattering matrix for elastic scattering.

→ **How much are these effects?**

II. DATA NEEDS OF TRANSPORT CODES

The S_N transport codes solve the equation[11]

$$\mu \frac{\partial}{\partial x} \phi_g(\mu, x) + \sigma_g^{SN}(x)\, \phi_g(\mu, x) = \sum_{\ell=0}^{N} P_\ell(\mu) \sum_{g'} \sigma_{\ell g \leftarrow g'}^{SN}(x)\, \phi_{lg'} + S_g(\mu, x) \quad , \tag{1}$$

where one-dimensional plane geometry has been used for simplicity, μ is the scattering cosine, x is position, $\phi(\mu, x)$ is the angular flux for group g, ϕ_{lg} is the Legendre flux for group g, $P_\ell(\mu)$ is a Legendre polynomial, and $S_g(\mu, x)$ is the external and fission source into group g. The cross sections in Eq. (1) must be defined to make ϕ_g as close as possible to the solution of the Boltzmann equation. As shown in the reference,[11] the multigroup Boltzmann equation can be written in the P_N form:

$$\mu \frac{\partial}{\partial x} \psi(\mu, x) + \sum_{\ell=0}^{N} P_\ell(\mu)\, \sigma_{\ell tg}^{PN}(x)\, \psi_{\ell g} = \sum_{\ell=0}^{N} P_\ell(\mu) \sum_{g'} \sigma_{\ell g \leftarrow g'}^{PN}(x)\, \psi_{\ell g'} + S_g(\mu, x) \quad , \tag{2}$$

where the P_N cross sections are given by the following group averages:

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

and

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

In these formulas, $\sigma_t(E)$ and $\sigma_\ell(E' \rightarrow E)$ are the basic energy-dependent total and scattering cross sections, and $W_\ell(E)$ is a weighting flux that should be chosen to be as similar to ψ as possible. As will be seen later, these P_N cross sections are available on the MATXS libraries produced by NJOY.[12, 13, 14, 15] When Eq. (2) is compared with Eq. (1), it is evident that the S_N equations require

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

and

$$\sigma_{\ell g \leftarrow g}^{SN} = \sigma_{\ell g \leftarrow g}^{PN} - \sigma_{\ell tg}^{PN} + \sigma_g^{SN} \quad , \tag{6}$$

where σ_g^{SN} is not determined. The choice of σ_g^{SN} gives rise to a "transport approximation" and various recipes are in use.

A. Transport Approximations

It is convenient to write

$$\sigma^{SN}_{\ell g\leftarrow g} = \sigma^{PN}_{\ell g\leftarrow g} - (\sigma^{PN}_{\ell tg} - \sigma^{PN}_{otg}) - \Delta^N_g \quad , \tag{7}$$

and

$$\sigma^{SN}_{g} = \sigma^{PN}_{otg} - \Delta^N_g \quad . \tag{8}$$

The term in parentheses corrects for the anisotropy in the total reaction rate term of the Boltzmann equation, and Δ^N_g can be chosen to minimize the effects of truncating the Legendre expansion at $\ell{=}N$. The recipes available in TRANSX are as follows:

Consistent-P approximation:

$$\Delta^N_g = 0 \quad , \tag{9}$$

Inconsistent-P approximation:

$$\Delta^N_g = \sigma^{PN}_{otg} - \sigma^{PN}_{N+1,tg} \quad , \tag{10}$$

Diagonal transport approximation:

$$\Delta^N_g = \sigma^{PN}_{otg} - \sigma^{PN}_{N+1,tg} + \sigma^{PN}_{N+1,g\leftarrow g} \quad , \tag{11}$$

Bell-Hansen-Sandmeier or extended transport approximation:

$$\Delta^N_g = \sigma^{PN}_{otg} - \sigma^{PN}_{N+1,tg} + \sum_{g'} \sigma^{PN}_{N+1,g'\leftarrow g} \quad , \tag{12}$$

and

Inflow transport approximation:

$$\Delta^N_g = \sigma^{PN}_{otg} - \sigma^{PN}_{N+1,tg} + \frac{\sum_{g'} \sigma^{PN}_{N+1,g\leftarrow g'}\,\phi_{N+1,g'}}{\phi_{N+1,g}} \quad . \tag{13}$$

The first two approximations are most appropriate when the scattering orders above N are small. The inconsistent option removes most of the delta-function

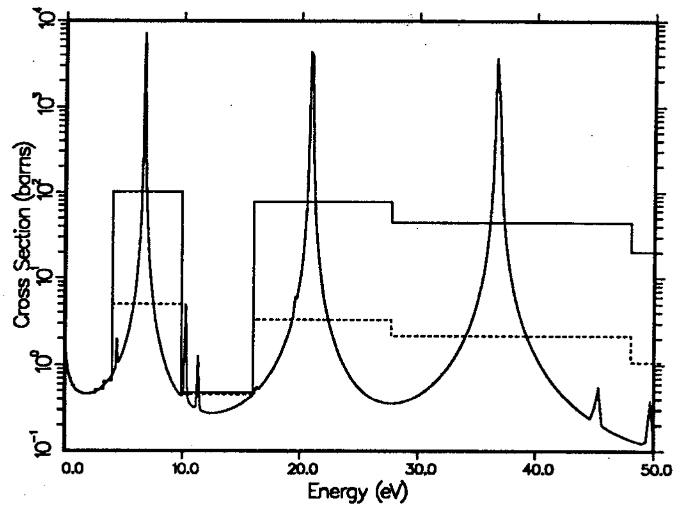


Figure 3: Comparison of pointwise and multigroup representations of ^{238}U capture. The solid histogram shows the effective multigroup cross sections for infinite dilution, and the dashed histogram shows the effective cross sections for a background cross section of 30 barns/atom. This is the 69-group structure used in the MATXS7 library.

the first three capture resonances of ^{238}U. A resonance material in a dilute mixture or in small pieces does not disturb a smooth flux very much by its presence—this is called the infinitely dilute case—but more resonance material will cause sharp dips in the flux corresponding to each resonance. The reaction rate $\sigma\phi$ will be reduced. The resonance is said to be "self-shielded."

The magnitude of this self-shielding effect is in general a complicated function of the geometry and composition of the system. However, it has been found that a simple model called the Bondarenko Method[16] or Background Cross Section Method[17] does a surprisingly good job of representing the effects for many applications. The flux is assumed to vary inversly as the total macroscopic cross section. The model flux for the group averages for isotope i is written as

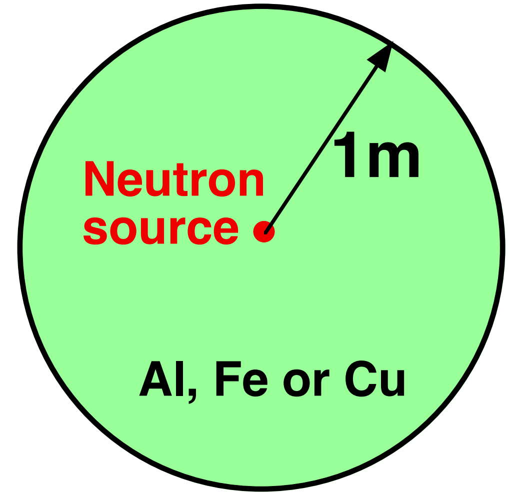
$$\phi^i_\ell(E) = \frac{C(E)}{[\sigma^i_0 + \sigma^i_t(E)]^{l+1}} \quad , \tag{23}$$

where $C(E)$ is the smooth part of the shape of the flux, and σ^i_0 is called the background cross section (it represents the effects of all the other isotopes). The effect of the total cross section in the denominator is to put a dip in the flux for each peak in the cross section, and σ^i_0 controls the relative size of the dip (σ^i_0=∞ gives the infinitely dilute case discussed above). The ℓ dependence shown

Simple Benchmark Test - (1)

- Calculation model:
  - A natural aluminum (self-shielding correction small), iron, nickel or copper (self-shielding correction large) sphere of 1 m in radius with a point neutron source in the center of the sphere
  - Neutron source

    energy : 17.332 – 19.64 MeV
    (1st group of VITAMIN-J structure [175 groups])
    uniform distribution



- Code : ANISN

  MCNP (Reference, Library : FSXLIB-J32 [JENDL-3.2])

- Neutron spectra and integrated neutron fluxes in the sphere are calculated.

Simple Benchmark Test - (2)

- Libraries for ANISN: (neutron 175 groups, self-shielding correction)

1) JSSTDL-300
2) Multigroup library with Weightig function independent on Legendre order generated from JENDL-3.2 with NJOY-TRANSX (NJOY, $WF_{L\geq1}=WF_{L=0}$)
3) Multigroup library with Weightig function dependent on Legendre order and no transport approximation generated from JENDL-3.2 with NJOY-TRANSX (NJOY, $WF_{L\geq1}\neq WF_{L=0}$, No transport approximation)
4) Multigroup library with Weightig function dependent on Legendre order and transport approximation [consistent-P] generated from JENDL-3.2 with NJOY-TRANSX (NJOY, $WF_{L\geq1}\neq WF_{L=0}$, Transport approximation [consistent-P])

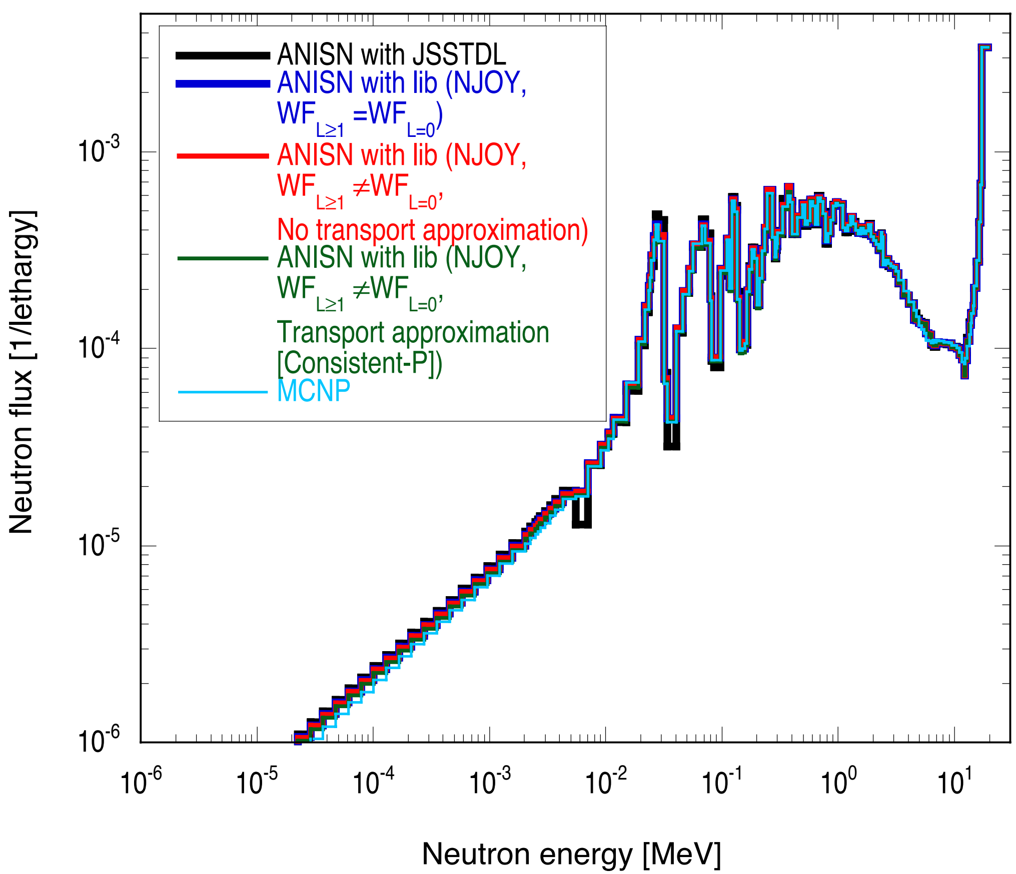
Effect due to f-table (1) vs 2))

Effect due to weighting function (2) vs 3))

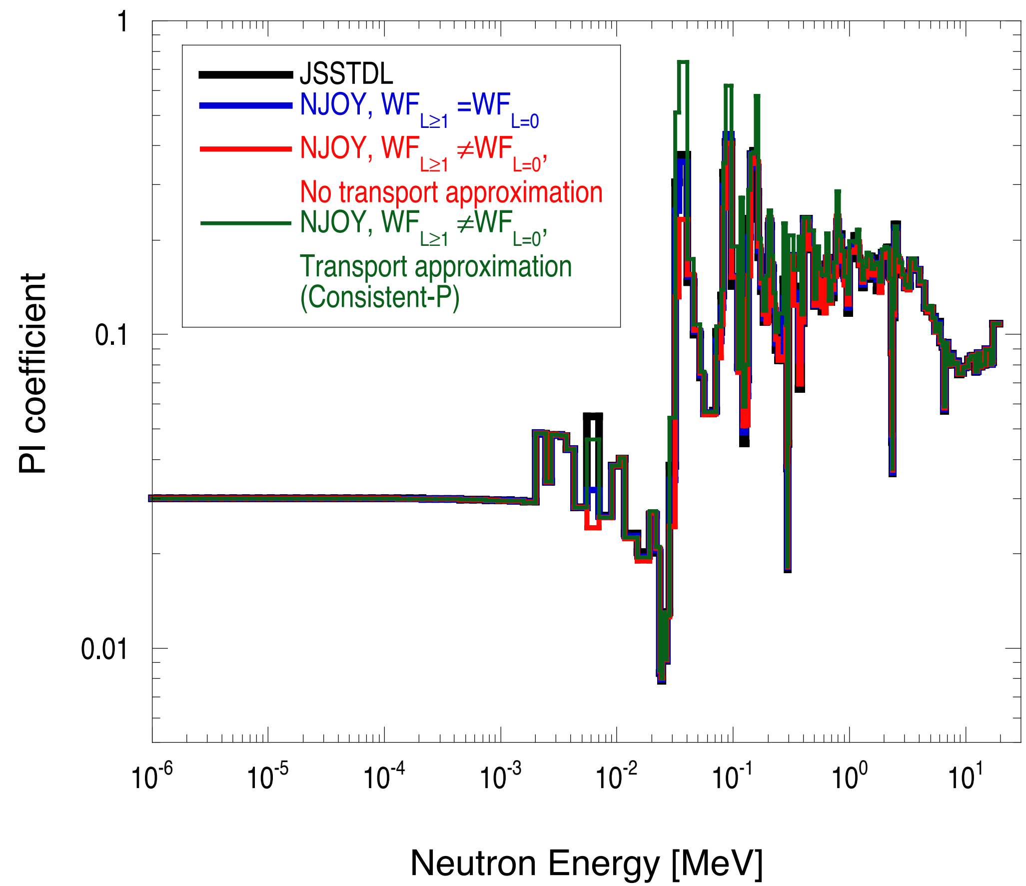
Effect due to transport approximation (3) vs 4))

The f-table of scattering matrix is adequate in NJOY-TRANSX.

Calculated neutron spectra and P$_1$ coefficients of in-group scattering matrix (Al)

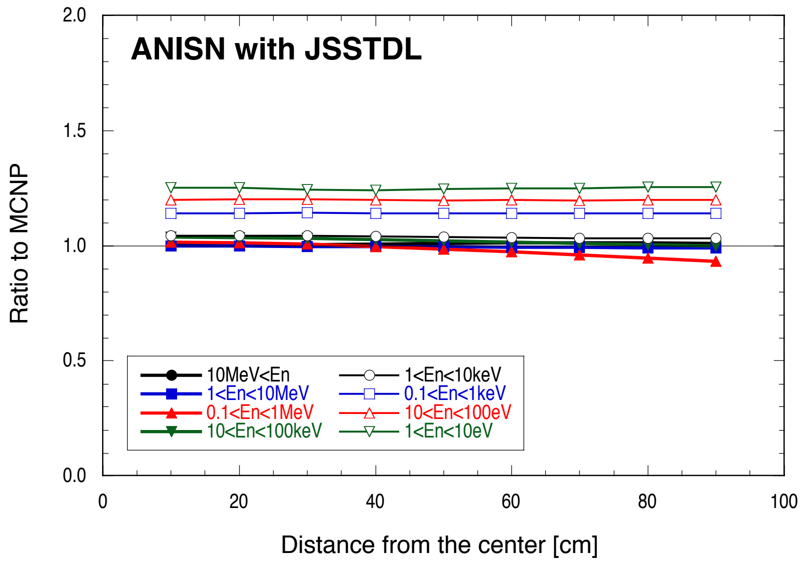


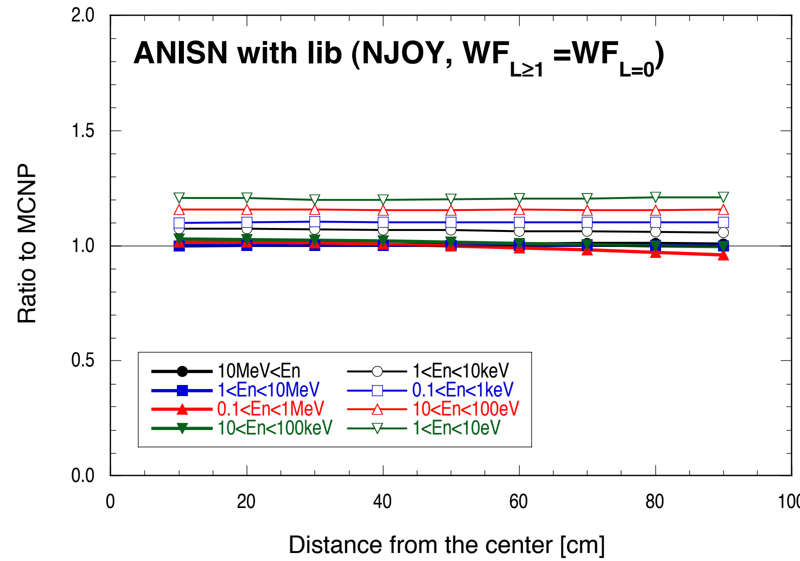
Neutron spectra at 10cm from center

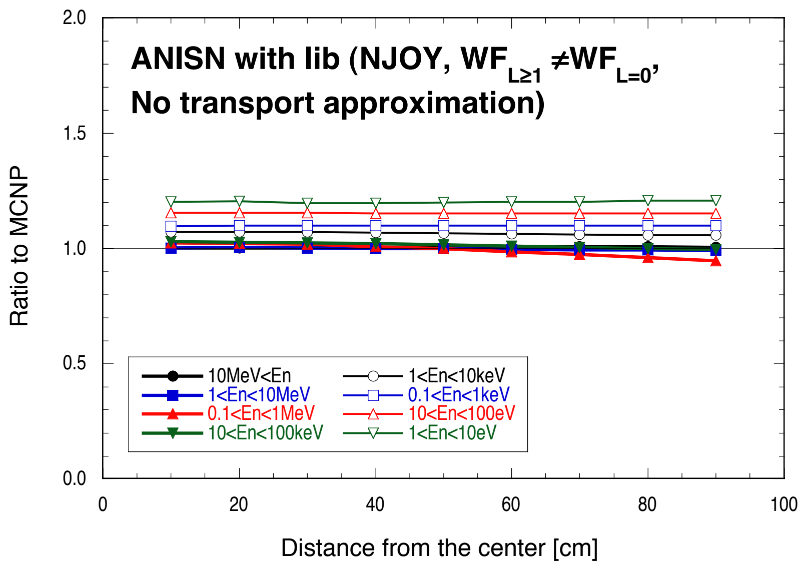


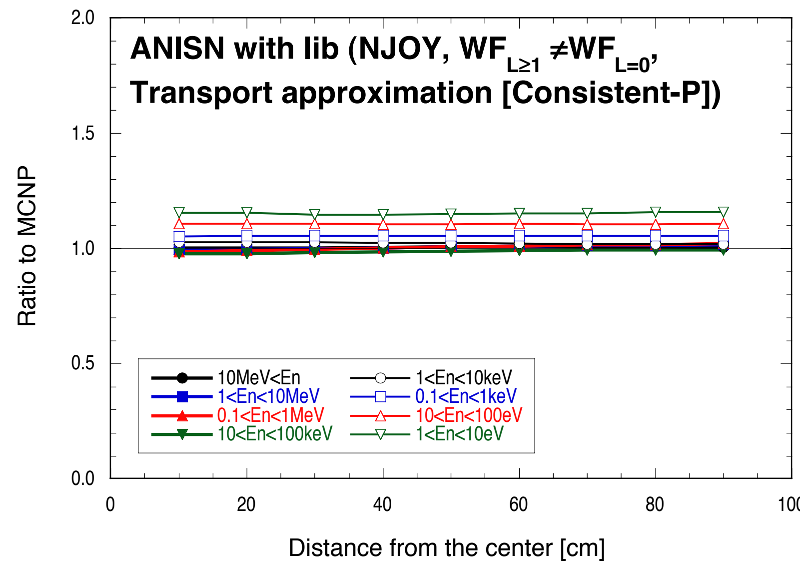
P$_1$ coefficients of in-group scattering matrix

Ratio of integrated neutron fluxes with ANISN to those with MCNP in aluminum sphere

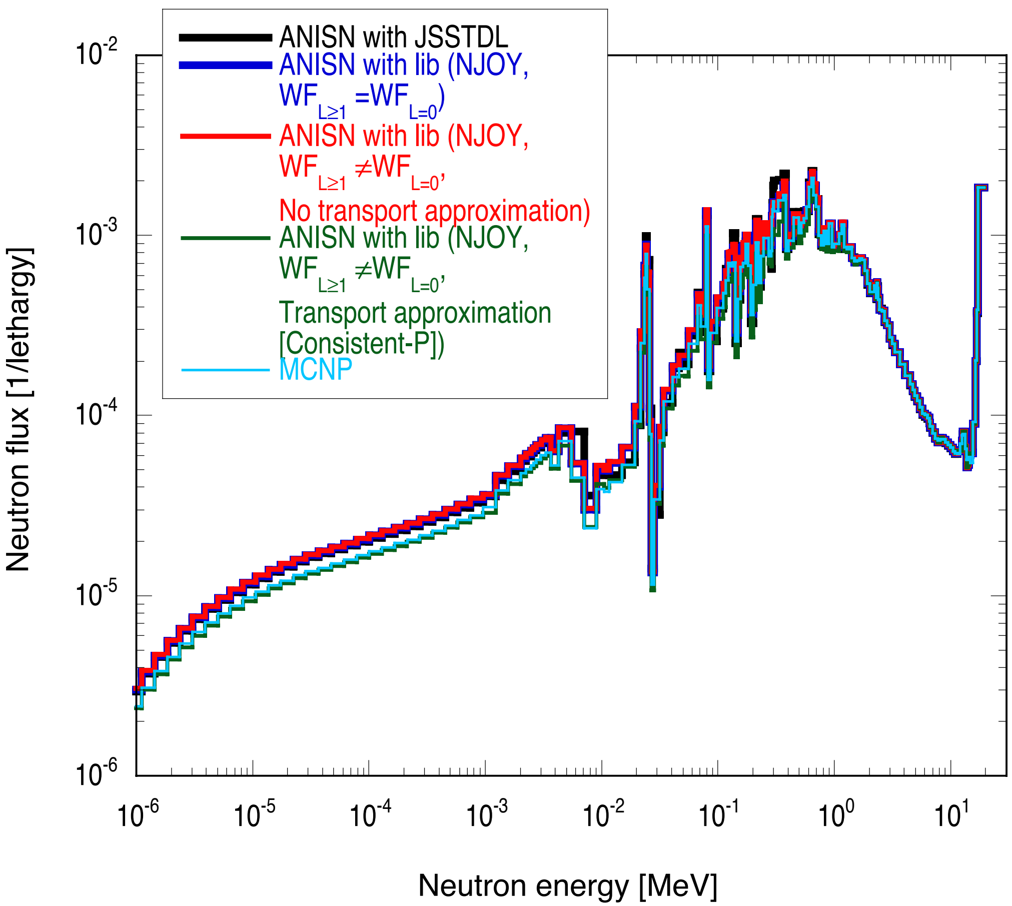


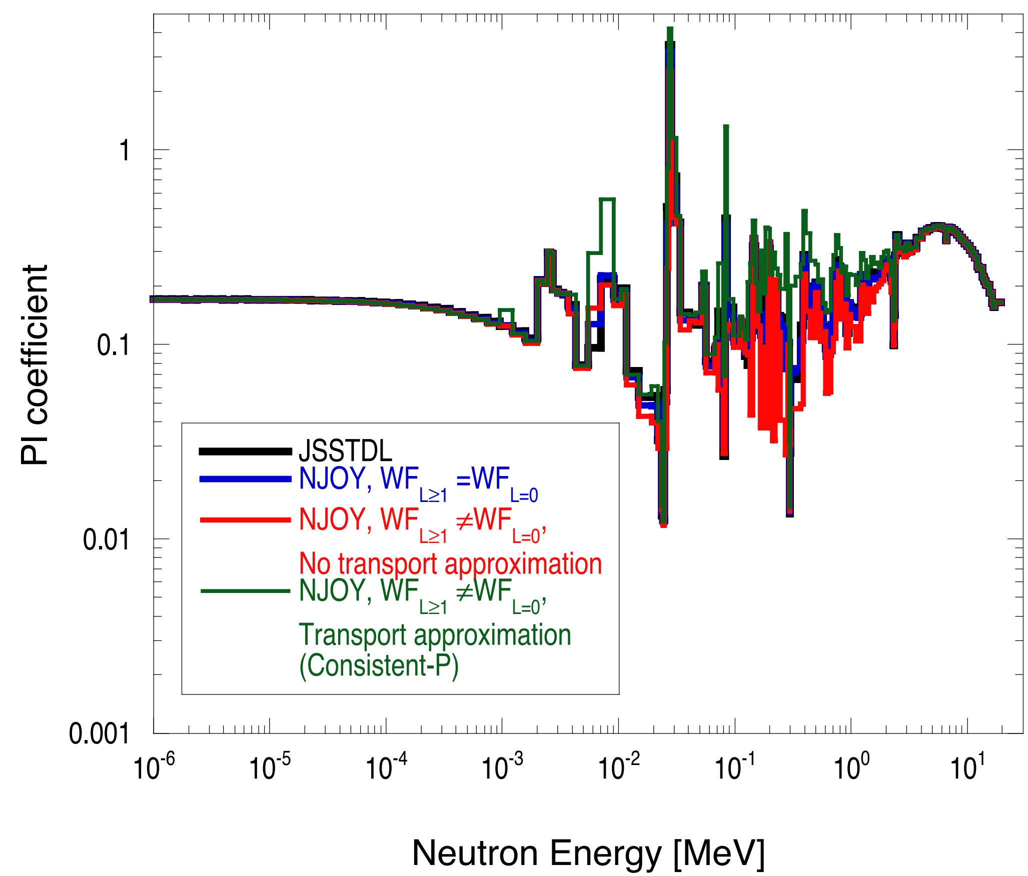






Calculated neutron spectra and P_1 coefficients of in-group scattering matrix (Fe)

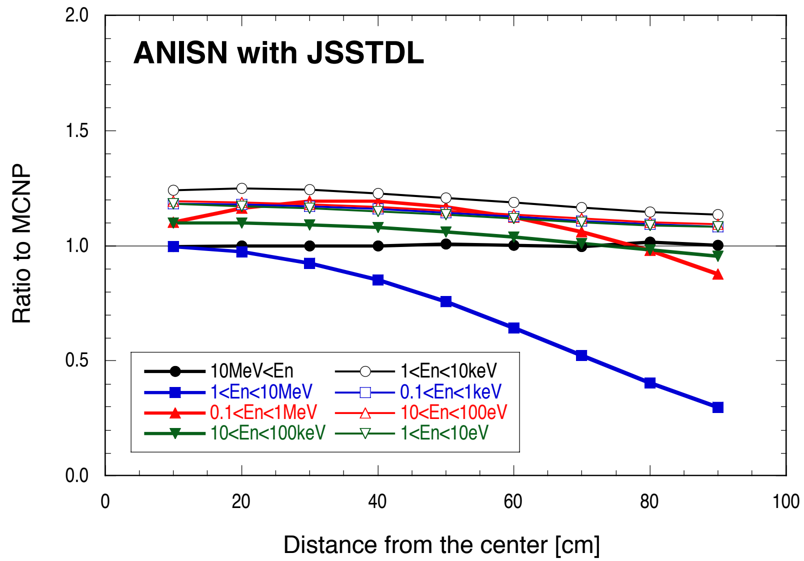


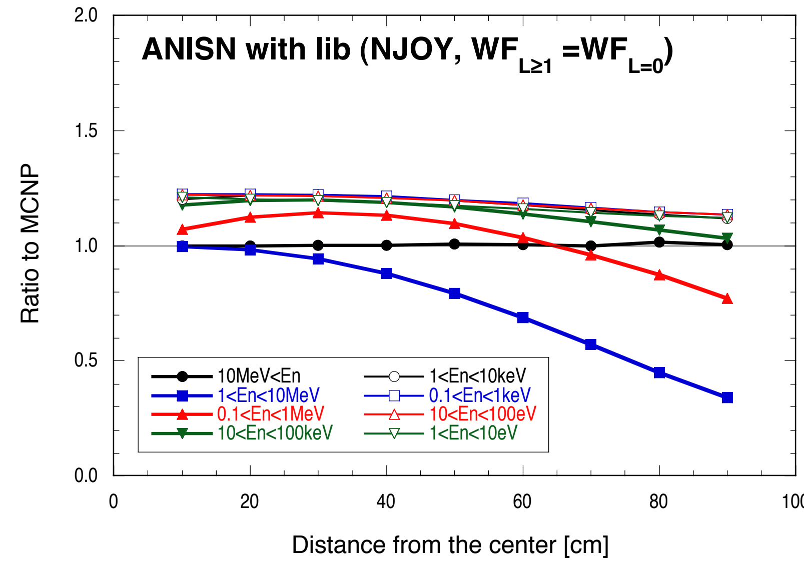


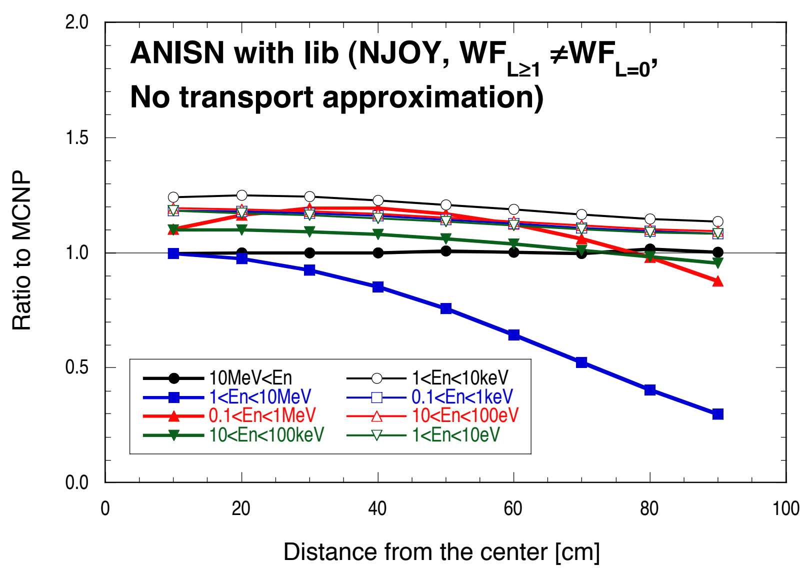
Neutron spectra at 10cm from center

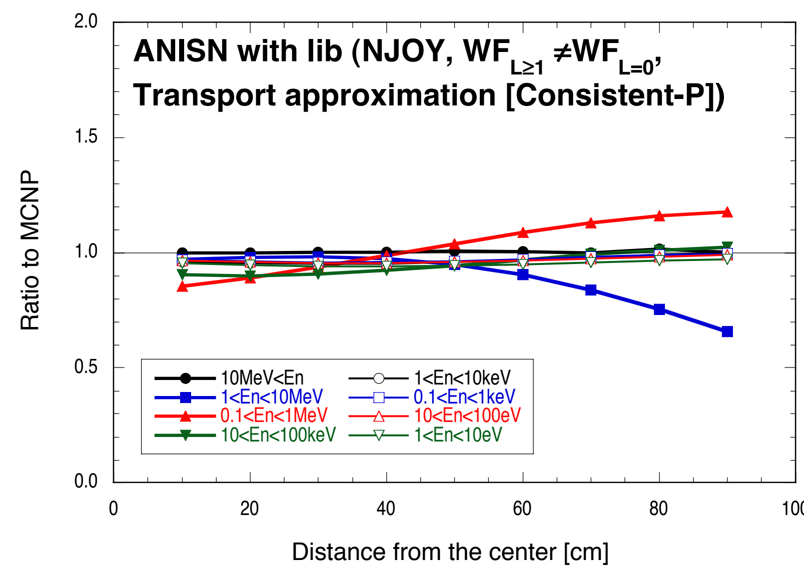
P_1 coefficients of in-group scattering matrix

Ratio of integrated neutron fluxes with ANISN to those with MCNP in iron sphere

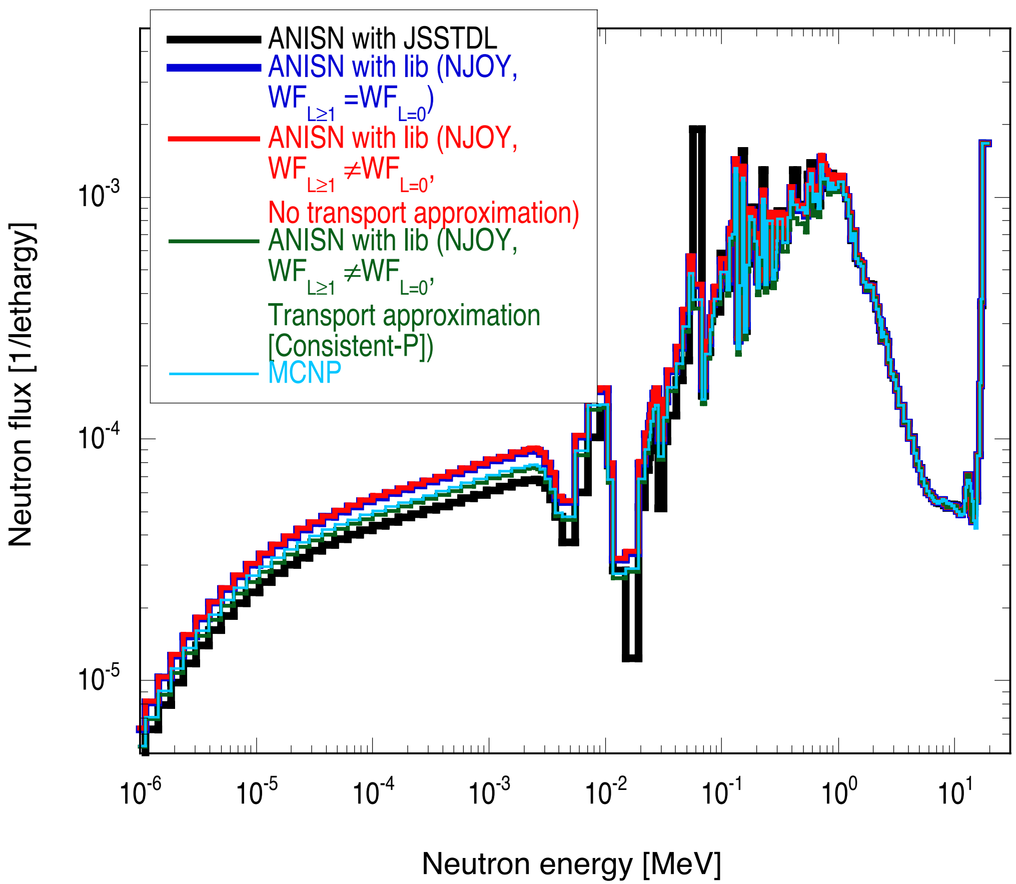




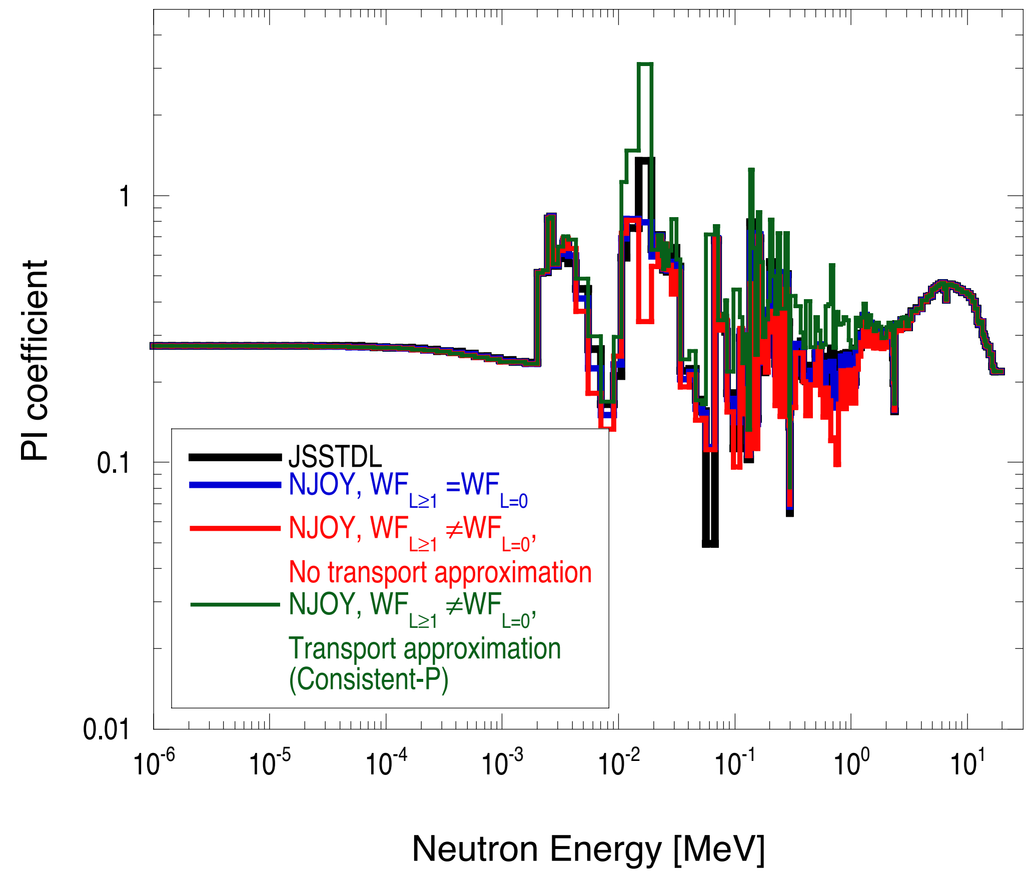




Calculated neutron spectra and P_1 coefficients of in-group scattering matrix (Ni)

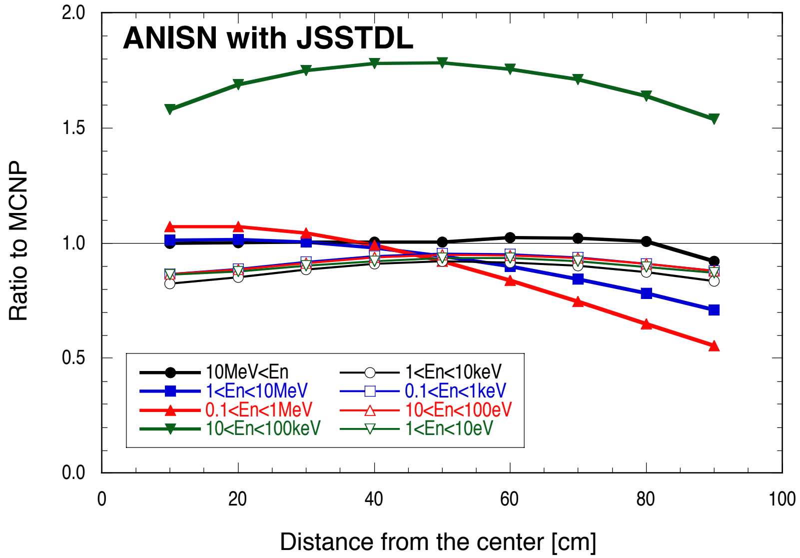


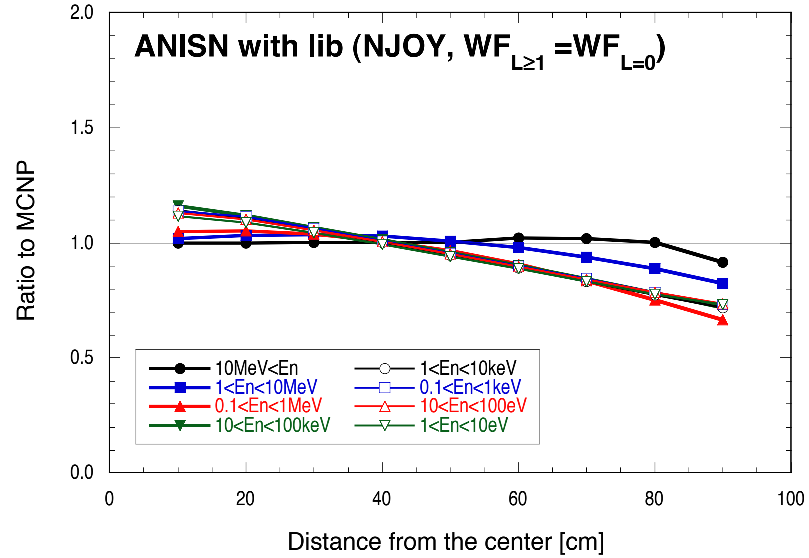
Neutron spectra at 10cm from center

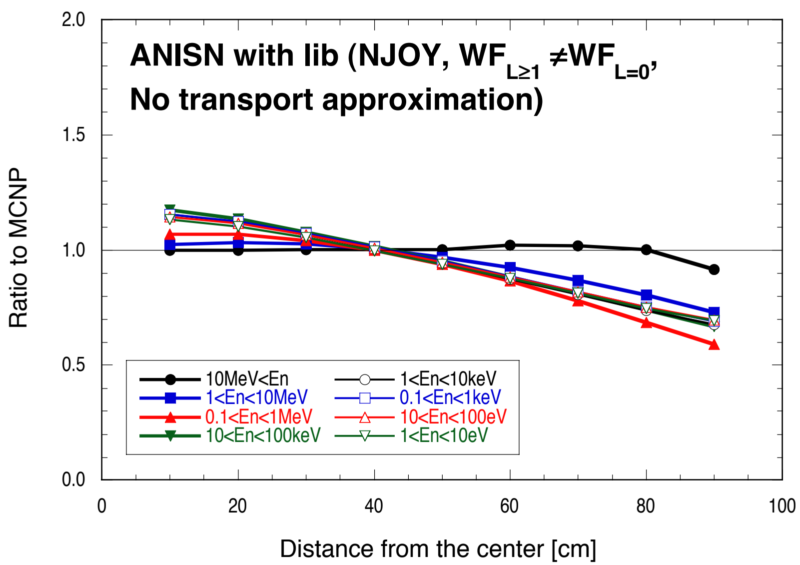


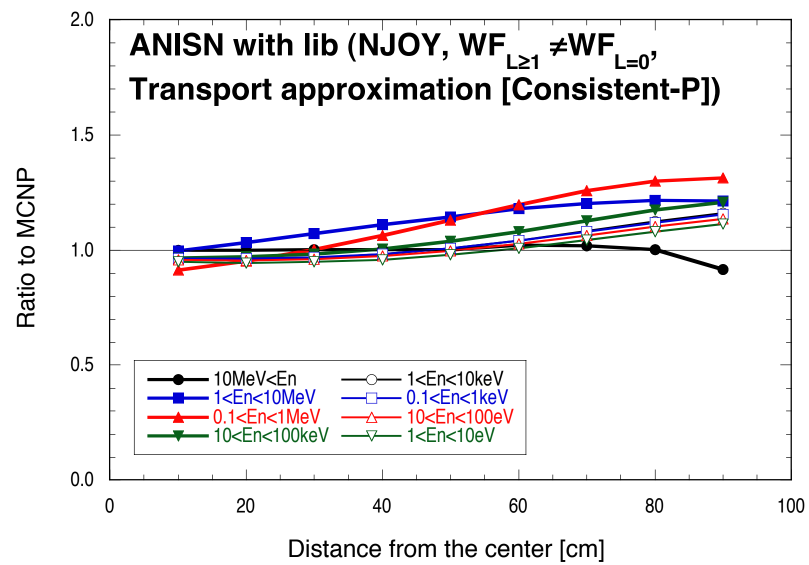
P_1 coefficients of in-group scattering matrix

Ratio of integrated neutron fluxes with ANISN to those with MCNP in nickel sphere

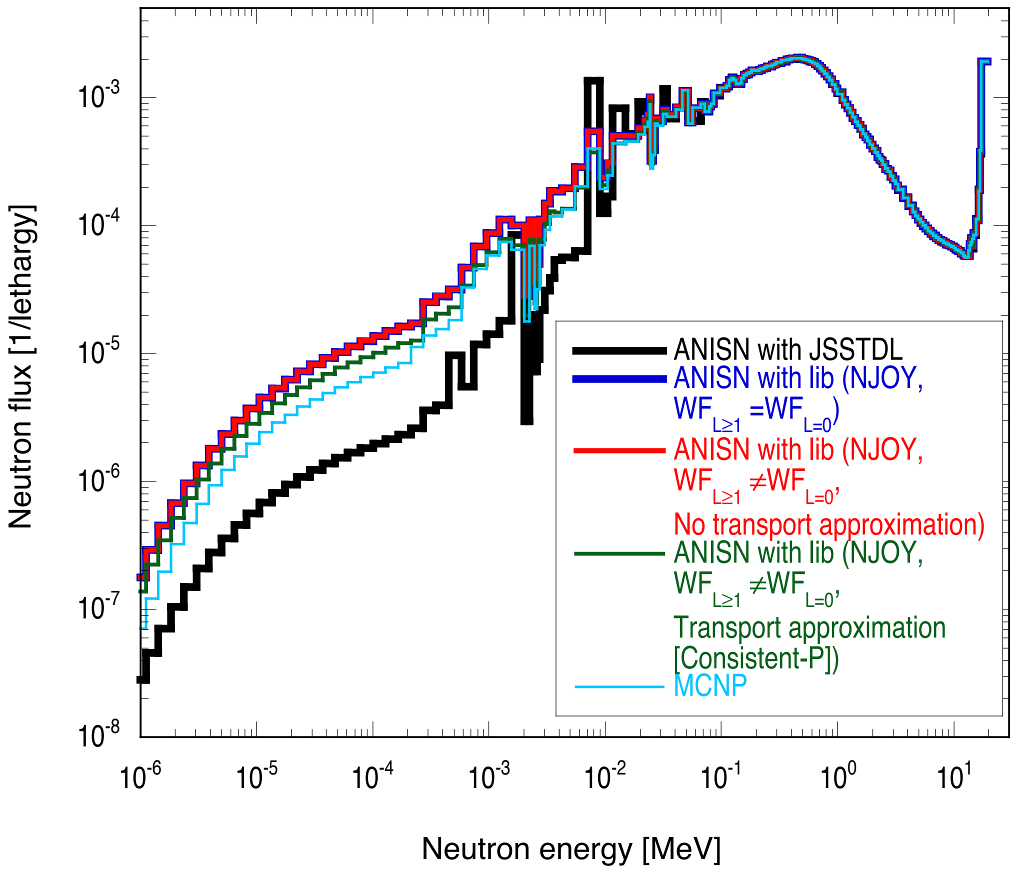




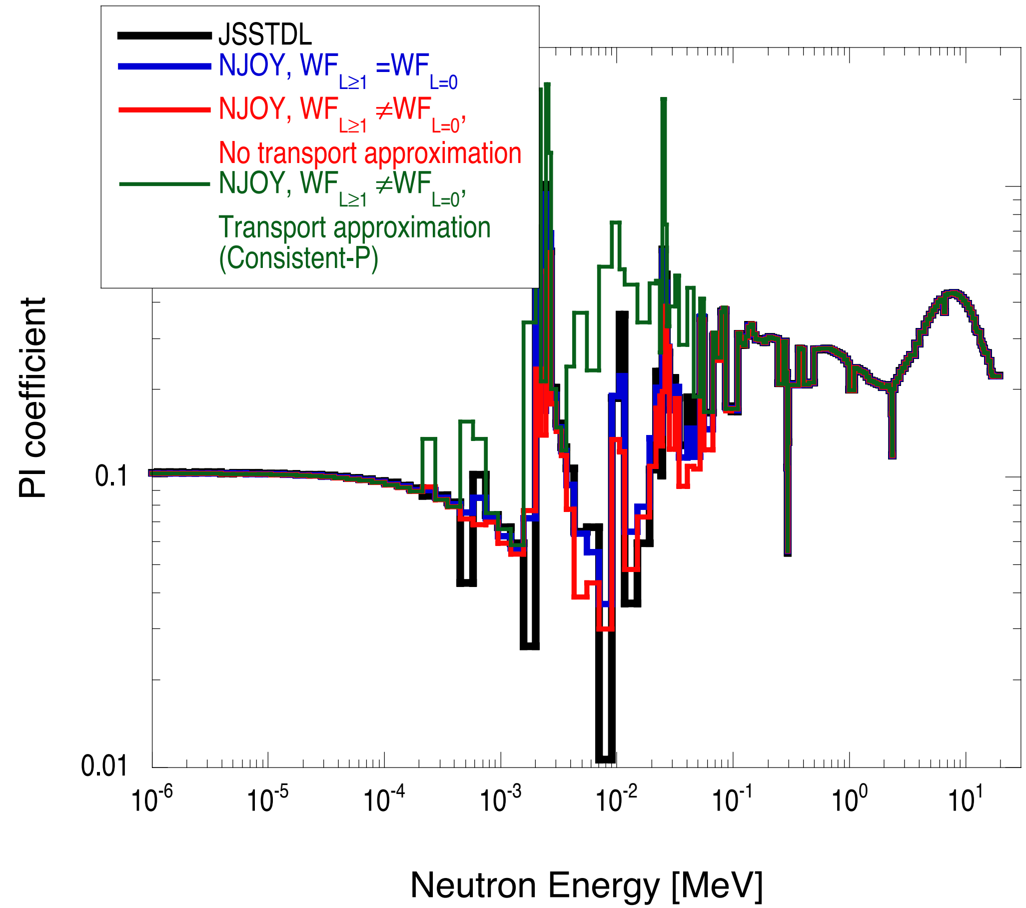




Calculated neutron spectra and P_1 coefficients of in-group scattering matrix (Cu)

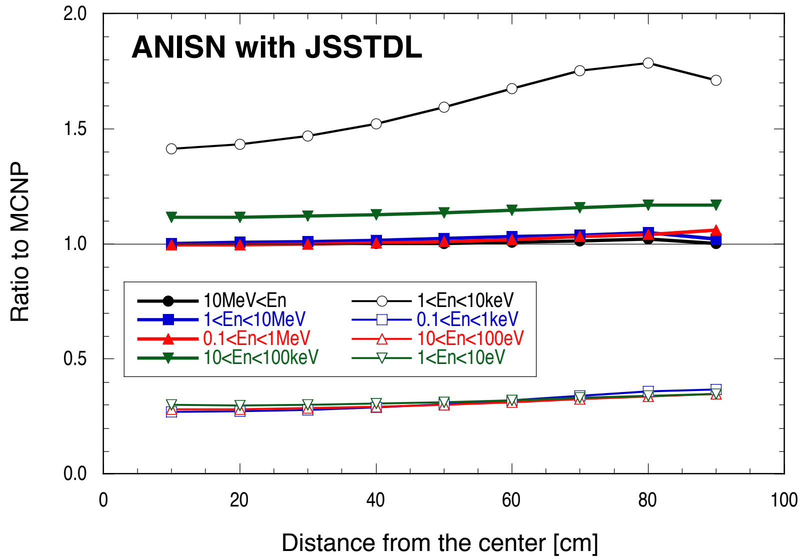


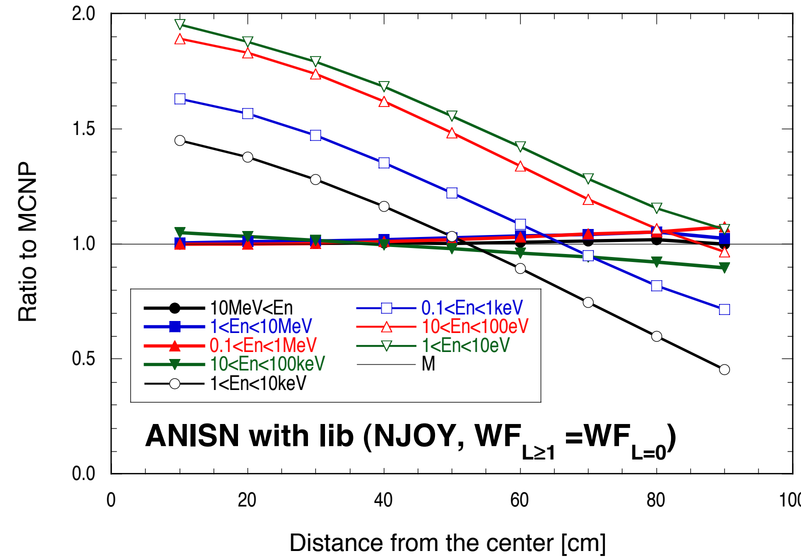
Neutron spectra at 10cm from center

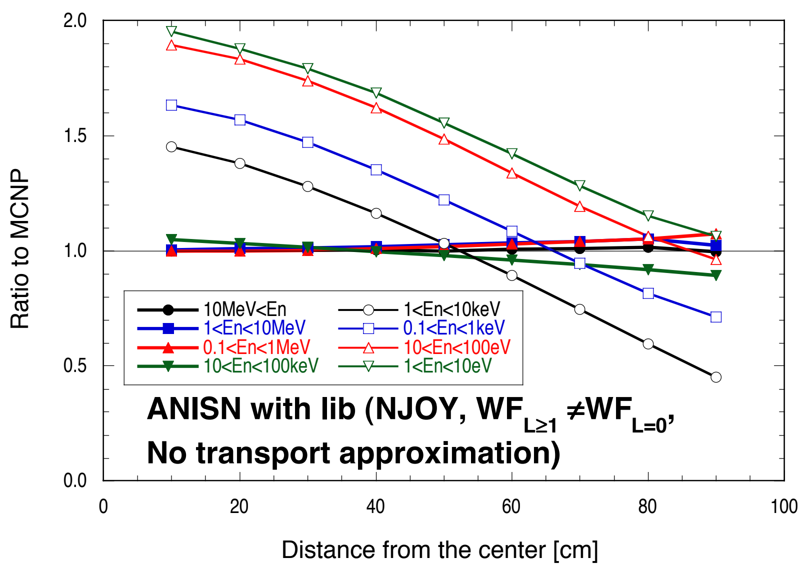


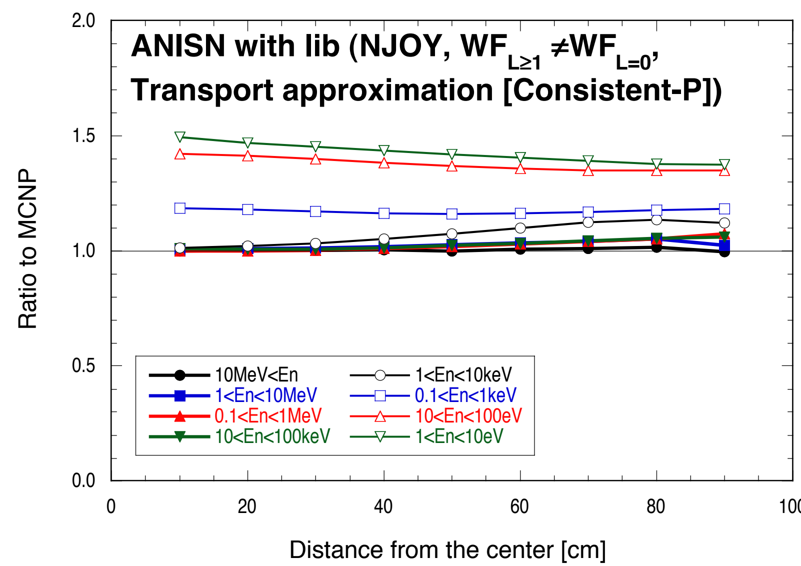
P_1 coefficients of in-group scattering matrix

Ratio of integrated neutron fluxes with ANISN to those with MCNP in copper sphere









Summary

- The effects of the below problems of JSSTDL-300 for the self-shielding correction were examined through a simple benchmark test.
  1) The f-table of elastic scattering is used as that of scattering matrix for elastic scattering.
  2) The JSSTDL-300 uses the weighting function independent on Legendre order.

- The following results were obtained.
  1) The effect of treatment of f-table in JSSTDL-300 is large in copper, while that is smaller in iron and nickel.
  2) The effect of weighting function independent on Legendre order (transport approximation) is large.

- The JSSTDL-300 library should be modified for the f-table and weighting function (appropriate transport approximation).