# Benchmark Test of JENDL High Energy File with MCNP

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Benchmark tests of the preliminary version of JENDL High Energy File with the MCNP code have been continued. A problem in JENDL High Energy File is pointed out that the angular distribution of elastically scattered neutrons by iron-56 is too emphasized toward 0 degree. Good results are obtained in the analyses of concrete shield experiments and iron secondary gamma-ray experiments.

## 1. Introduction

Evaluation of JENDL High Energy (JENDL-HE) File is now in progress, and expected to be completed by the end of 1998 for the phase-I data up to 50 MeV. We have started benchmark tests of the preliminary version of JENDL-HE File for neutron transport cross section data up to 50 MeV by analyzing available shielding benchmark experiments [1-5] summarized in Table 1. The first results of the tests

Table 1 Benchmark experiments employed for the tests.

| Facility / Institute | INS / Univ. Tokyo | RCNP / Osaka Univ. | TIARA / JAERI |
|---|---|---|---|
| Neutron Source | 52-MeV Proton on Graphite | 65-MeV Proton on Copper, Collimated | 43- & 68-MeV Proton on Lithium, Collimated |
| Source Spectrum | White | White | Quasi-Mono-Energetic |
| Material | C, Fe, Concrete, Water | C, Fe, Pb, Concrete | Fe, Concrete, Polyethylene |
| Measured Quantity | Neutron & Photon Spectrum | Neutron & Photon Spectrum | Neutron Spectrum, Fission Rate |
| References | [1] | [2] | [3-5] |

have been reported elsewhere [6]. After that, we have obtained some new findings about cross section data in JENDL-HE through the benchmark tests. In this report, results of the benchmark tests are described featuring the new findings.

## 2. Benchmark Calculation

The Monte Carlo transport calculation code MCNP-4B [7] was used for the benchmark calculations. Cross section data of the preliminary version of JENDL-HE were processed into an ACE format cross section data library for MCNP by the NJOY-94.66 code. The LA-150 cross section library up to 150 MeV [8], which is now being developed at Los Alamos National Laboratory, U. S., was also processed. Since JENDL-HE was under evaluation, some cross section data needed for the calculations were not available. Benchmark calculations were performed for the iron and concrete experiments in Table 1. Calculations for iron could be performed by using the JENDL-HE data while those for concrete were performed with cross section data of Al, Si,Ca and Fe in JENDL-HE File by supplying cross section data of H and O from ENDF/B-VI and 100XS [9], respectively.

Source neutron conditions provided by each benchmark experiment [1-5] were used as source terms for the neutron transport calculations. Neutron events were scored by track length estimators of which sizes were the same as the neutron detectors used in the experiments.

In the INS and RCNP experiments, gamma-ray spectra measured behind the shields were given. To test secondary gamma-ray production cross sections in the libraries, neutron-gamma-ray coupled transport calculations were also performed. Since the high energy proton bombardment on the targets generates source gamma-rays as well as source neutrons, gamma-ray transport calculations were performed with using source gamma-ray conditions obtained in the experiment [1, 2]. Gamma-ray spectra obtained in the source neutron and gamma-ray calculations were summed to compare with the experimental data.

Calculated results with JENDL-HE and LA-150 were compared with the experimental data and some previous calculations with the 100XS library.

## 3. Summary of the Previous Benchmark Test

Brief summary of the previous benchmark results [6] is as follows.

(1) In the analysis of the TIARA iron shield experiment, JENDL-HE underestimates neutron fluxes above 10 MeV with increase of shield thickness. This underestimation can be explained by the too small elastic and too large non-elastic scattering cross sections in the energy range from 20 to 50 MeV.

(2) Calculations with JENDL-HE give good results for concrete shields. In the analysis of the TIARA concrete shield experiment, calculated to experimental ratios (C/Es) for the peak neutron flux (35 ~ 45 MeV) and tail neutron flux (10 ~ 35 MeV) range from 0.9 to 1.5 for the shield thicknesses up to 150 cm.

(3) In the analysis of the FNS iron benchmark experiment [10, 11] for fusion, the calculation with JENDL-HE does not reproduce the experimental neutron spectrum in a low energy range from 1 eV to 1 MeV although calculated spectra with both JENDL Fusion File and JENDL-3.2 agree fairly well with the experimental data. The reason is that JENDL-HE does not adopt the validated elemental iron data in JENDL Fusion File nor JENDL-3.2 as the cross section data below 20 MeV but merges the isotopic iron data in JENDL Fusion File that have not been validated.

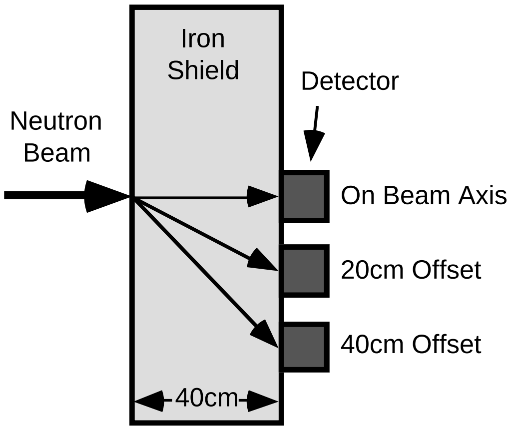


Fig. 1 Detectors located on the neutron beam axis and the two offset positions in the TIARA iron shield experiment. Detectors located with large offset distances are likely to observe neutrons scattered with large angles.

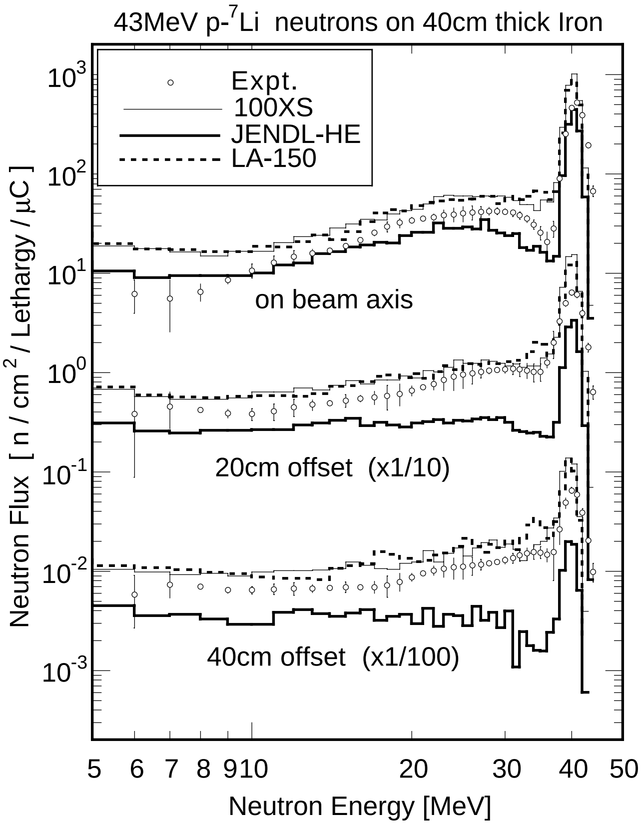


Fig. 2 Neutron spectra measured in the TIARA iron shield experiment in comparison with calculations with JENDL-HE, LA-150 and 100XS. Spectra are measured on the beam axis and with offset distances of 20 cm and 40 cm behind the iron shield of 40 cm thickness.

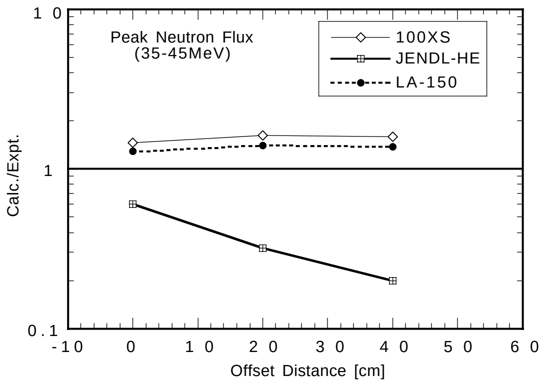


Fig. 3 The C/E values of peak neutron fluxes from 35 to 45 MeV for JENDL-HE, LA-150 and 100XS calculations as a function of the offset distance for the TIARA iron shield experiment.

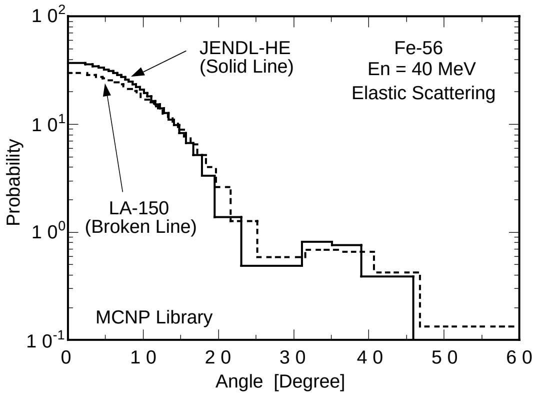


Fig. 4 Angular distribution of elastically scattered neutrons by iron-56 for incident neutron energy at 40 MeV contained in the MCNP libraries for JENDL-HE and LA-150.

## 4. New Findings through the Benchmark Test

In addition to the previous results, the following new findings were obtained.

(1) The TIARA shielding experiment has a unique feature that neutron spectra are measured at several detector positions not only on an extension of the incident neutron beam axis but also with offset distances of 20 cm and 40 cm as illustrated in Fig. 1. This feature is very useful to test angular distribution of scattered neutrons because neutron spectra measured with large offset distances likely to observe neutrons scattered with large angles. Figure 2 compares measured and calculated neutron spectra for the TIARA iron shield experiment. A trend is found in Fig. 2 that the calculation with JENDL-HE underestimates neutron fluxes with increase of the offset distance. The trend is exhibited clearly in Fig. 3 which shows C/E values for peak neutron fluxes for the neutron spectra in Fig. 2 as a function of the offset distance. The C/E curves by LA-150 and 100XS are almost flat while C/E values by JENDL-HE decrease with increase of the offset distance. A possible reason of the trend is found in the angular distribution of elastically scattered neutrons by iron-56 shown in Fig. 4. Anisotropy of the angular distribution toward 0 degree for JENDL-HE is too emphasized, and less neutrons are scattered with large scattering angles. When the angular distribution is emphasized toward 0 degree, the peak neutron flux measured on the beam axis (0 cm offset) will increase. However, the C/E value without the offset distance (0 cm) by JENDL-HE is still less than 1.0. This contradiction can be explained by the too small elastic scattering cross sections in JENDL-HE, as mentioned earlier.

The flat C/E curves by LA-150 and 100XS suggests that the angular distribution of secondary neutrons for the iron data in these libraries are adequate. Those C/E curves are, however, systematically larger than 1.0. A possible reason of this is that the elastic scattering cross section is somewhat larger contrary to JENDL-HE.

(2) Neutron spectra measured in the TIARA concrete shield experiment are compared with calculated results by JENDL-HE, LA-150 and 100XS in Fig. 5. The LA-150 result is newly obtained. All the three calculations predict the measured neutron spectra transmitted through the thick concrete shields up to 150 cm fairly good. Especially, the JENDL-HE calculation shows the best results among the three.

(3) Figures 6 and 7 show gamma-ray spectra behind the iron shields measured in the INS and RCNP experiments in comparison with calculated results by JENDL-HE and LA-150. In general, calculations with both libraries show good agreements with the experimental

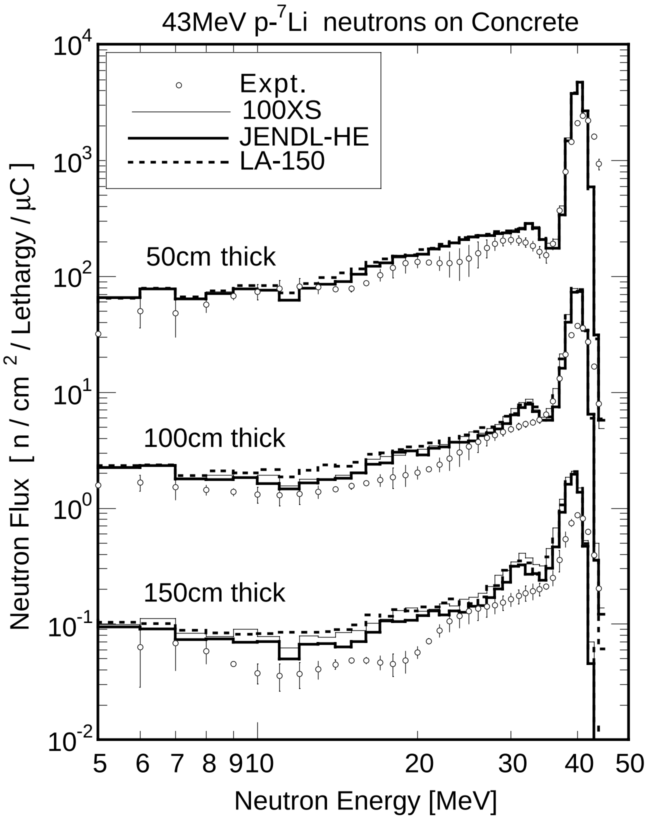
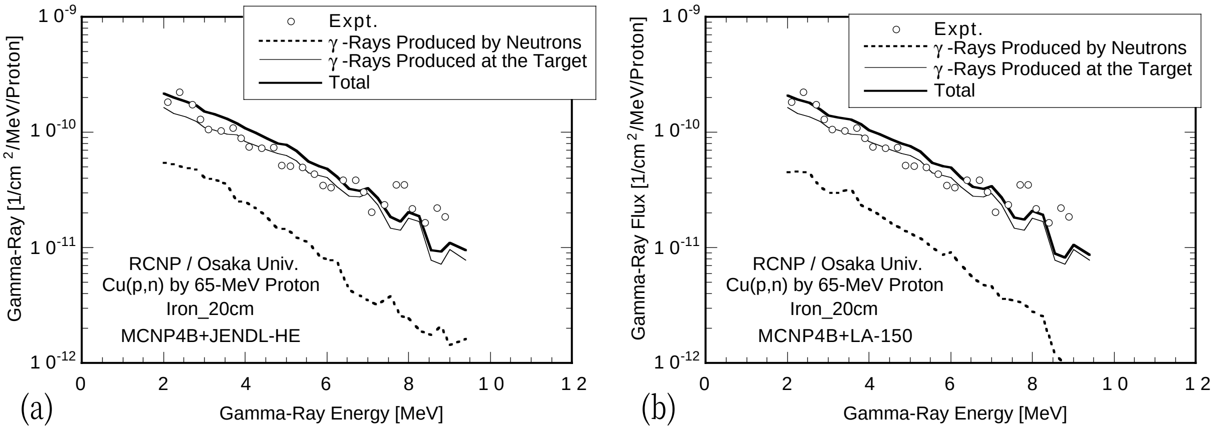
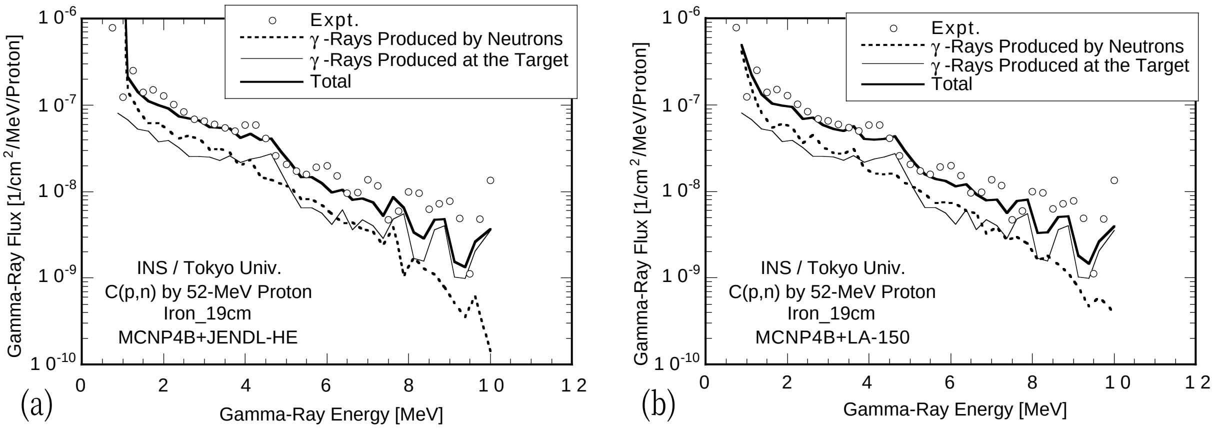


Fig. 5 Neutron spectra measured in the TIARA concrete shield experiment compared with calculations by JENDL-HE, LA-150 and 100XS.



(a) (b)

Fig. 6 Gamma-ray spectrum measured behind the iron shield of 20 cm in the RCNP experiment compared with the calculations by (a) JENDL-HE and (b) LA-150.



(a) (b)

Fig. 7 Gamma-ray spectrum measured behind the iron shield of 19 cm in the INS experiment compared with the calculations by (a) JENDL-HE and (b) LA-150.

data. Gamma-rays observed have two origins: gamma-rays produced by neutron interactions in the iron shield, and gamma-rays produced at the target by high energy proton bombardment on the targets. The former component is obtained by the neutron-gamma-ray coupled calculations with source neutrons while the latter component is obtained by just gamma-ray transport calculations with source gamma-rays. Since what we should test here is secondary gamma-ray production cross section data, we are interested in only the former component. Those experiments, the RCNP experiment especially, are not very suitable for our purpose because the latter component is strong. Nevertheless, the general agreements between the measured and calculated gamma-ray spectra suggests that there is no serious problem in the gamma-ray production cross section data of iron in JENDL-HE and LA-150.

## 5. Concluding Remarks

Benchmark tests of the preliminary version of JENDL-HE with the MCNP code have been continued. A problem in JENDL-HE is pointed out that the angular distribution of elastically scattered neutrons by iron-56 is too emphasized toward 0 degree. Good results are obtained in the analyses of concrete shield experiments and iron secondary gamma-ray experiments. Problems found through the tests are expected to be considered in revision of JENDL-HE.

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