Integral Test for JENDL High Energy File

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As activities of the Intermediate and High Energy Nuclear Data Integral Test Working Group in the Japanese Nuclear Data Committee, integral tests of JENDL High Energy File (JENDL-HE) have started. Processing method of JENDL-HE with the NJOY code has been established. As a result of benchmark tests for the ^{56}Fe data in JENDL-HE with the two neutron incident experiments conducted at TIARA and RCNP, calculations with JENDL-HE agreed excellently with the experimental data. The data were found to be adequate for nuclear design calculations as far as the energy range tested, below 68-MeV, was concerned.

1. Introduction

Evaluation of JENDL High Energy File (JENDL-HE) for the first priority nuclides is going to be completed in the early 2001. The data have been strongly required for many applications for intermediate and high energy fields. The JAERI/KEK project for high-intensity proton accelerator is one of such applications. The data in JENDL-HE are therefore needed to be validated urgently before they are used practically in nuclear design calculations for the accelerator facilities. Under this situation, the Intermediate and High Energy Nuclear Data Integral Test Working Group* has been organized since May 2000 in the Japanese Nuclear Data Committee. This report summarizes a part of results obtained so far by the Working Group.

2. Needs for JENDL-HE

Since no evaluated cross section data for higher energy, i.e., up to 3 GeV, have been available, intranuclear cascade Monte Carlo calculation codes such as NMTC/JAM [1] and MCNPX [2] are used for design calculations for the accelerator facilities. We encountered the following difficulties in the calculations.

(1) Bulk shielding calculations have to deal with attenuation of neutron fluxes by ~ 15 orders of magnitude as shown in Fig. 1. The calculations are very tough for the Monte Carlo codes to obtain results with good statistics although they are feasible. Deterministic calculation codes with a multigroup cross section library are suitable for such the bulk shielding calculations.

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(2) The point estimator in Monte Carlo codes requires total and neutron scattering cross section data. Since no evaluated cross section data beyond 150 MeV are available, use of the point estimator is limited to 150 MeV.

(3) The intranuclear cascade model is adequate for medium- and heavy-mass nuclei, but not for light nuclei such as Be, B, C, N and O. Use of evaluated cross section data will improve calculations for the light nuclei.

(4) At present, no activation cross section library beyond 150 MeV is available.

When the JENDL-HE up to 3 GeV will be available, these difficulties will be solved.

3. Production of Cross Section Data for Transport Calculation Codes

The JENDL-HE files provided by evaluators, i.e., ^{1}H, ^{56}Fe and all the isotopes for Ca, Ti, Cr and Cu, were processed by the NJOY-99.24 code [3] into ACE-type cross section data for the MCNP code [4]. The new ACE-type format that included outgoing particle distributions and a new cumulative angle distributions was adopted. In the processing, several invalid data in JENDL-HE files were found, and most of them were corrected. One problem still remained that energy-angle distributions of secondary particles were represented in the laboratory system below 250 MeV while in the center-of-mass system above 250 MeV. The representation was not allowed in the ENDF-6 format, but not easy to correct. Hence, the problem was avoided temporarily by giving patches for both the NJOY and MCNP codes.

Multi-group cross section data for deterministic transport calculation codes were also produced successfully by NJOY.

4. Benchmark Problems and Analysis

The Working Group has selected benchmark experiments for validation of JENDL-HE as listed in Table 1. This report deals with neutron incident experiments, and the TIARA and RCNP experiments on iron [5, 6] indicated in bold letters in Table 1 are the only experiments for which cross section data are provided for the calculations.

The MCNP-4C code [4] was used for neutron transport calculations. Since the cross section data for iron was given only for the main isotopes of iron, i.e., ^{56}Fe, other three isotopes of iron were replaced by ^{56}Fe. Calculations with the LA-150 library [7] were also performed for comparisons.

5. Results and Discussion

Figure 2 compares calculated neutron spectra for the RCNP experiment with the experimental data. The MORSE calculation [5] with HILO86 library is also plotted for comparisons. Results by

Table 1 Benchmark experiments selected for the benchmark test of JENDL-HE.

Facility / Institute	Material	Energy	Remarks
TIARA / JAERI	**Fe**, PE, Concrete	**43, 68 MeV**	**n-incident [5]**
RCNP / Osaka Univ.	C, **Fe**, Pb	**65 MeV**	**n-incident [6]**
AGS / BNL	Hg/Pb/Fe	1.9, 12, 24 GeV	p-incident
TIARA / JAERI	C, Al, Cu, Pb	68 MeV	p-incident, TTY
WNR / LANL	C, Al, Fe	113, 256 MeV	p-incident, TTY
Proton Synchrotron / KEK	W, Pb	0.5, 1.5 GeV	p-incident
Synchrophasotron / JINR	Pb	2, 2.5 GeV	p-incident

JENDL-HE and LA-150 are close to each other, and they agree well with the experimental data. Although the spectrum by LA-150 is slightly larger than that by JENDL-HE in the energy range below 50 MeV for the 40 cm iron case, it is difficult to judge which calculation is better than the other.

Results for the TIARA experiment with 68-MeV and 43-MeV p-Li neutrons are shown in Figs. 3 and 4, respectively. Although both the JENDL-HE and LA-150 calculations predict adequately the measured neutron flux spectra, results by JENDL-HE are better than those by LA-150 as a general trend. The only significant discrepancy in the shape of neutron spectrum between JENDL-HE and LA-150 is found in the valley of neutron flux at about 5 MeV below the neutron peak. Although the spectrum by JENDL-HE follows adequately the experimental spectrum, that by LA-150 has a tiny peak at the valley. There would be a problem in the energy distributions for secondary neutrons in LA-150.

Figure 5 and 6 shows ratios of calculated to experimental neutron fluxes (C/E values). The left-hand-side figures in Figs. 5 and 6 indicate C/E values of neutron fluxes on the incident neutron beam axis as a function of penetration thickness. The LA-150 calculations tend to overestimate neutron fluxes as penetration thickness increases. This indicats that there are some problems in total or elastic/nonelastic scattering cross sections in LA-150. The JENDL-HE calculations give better agreements with the experimental data. Especially, neutron fluxes for the 68-MeV experiment are predicted excellently, i.e., ± 20 %, up to 130 cm thickness in the iron shield in which neutron fluxes attenuate by approximately 6 orders of magnitude.

The right-hand-side figures in Figs. 5 and 6 show C/E values of neutron fluxes as a function of offset distance from the neutron beam axis, and these results are suitable for testing angular distributions of secondary neutrons. The C/E curves almost flat regardless of the offset distance. This suggests that the angular distributions of secondary neutrons in both JENDL-HE and LA-150 are adequate.

6. Summary

As a result of benchmark tests for the ^{56}Fe data in JENDL-HE with the two neutron incident experiments, calculations with JENDL-HE agreed excellently with the experimental data. The data were found to be adequate for nuclear design calculations as far as the energy range tested, below 68-MeV, was concerned.

From a standpoint of the shielding design for the JAERI/KEK Project, it is expected that data for the three minor isotopes of iron (^{54}Fe, ^{57}Fe and ^{58}Fe) and for elements included in concrete (e.g., O, Al and Si) will be available as soon as possible.

Acknowledgments

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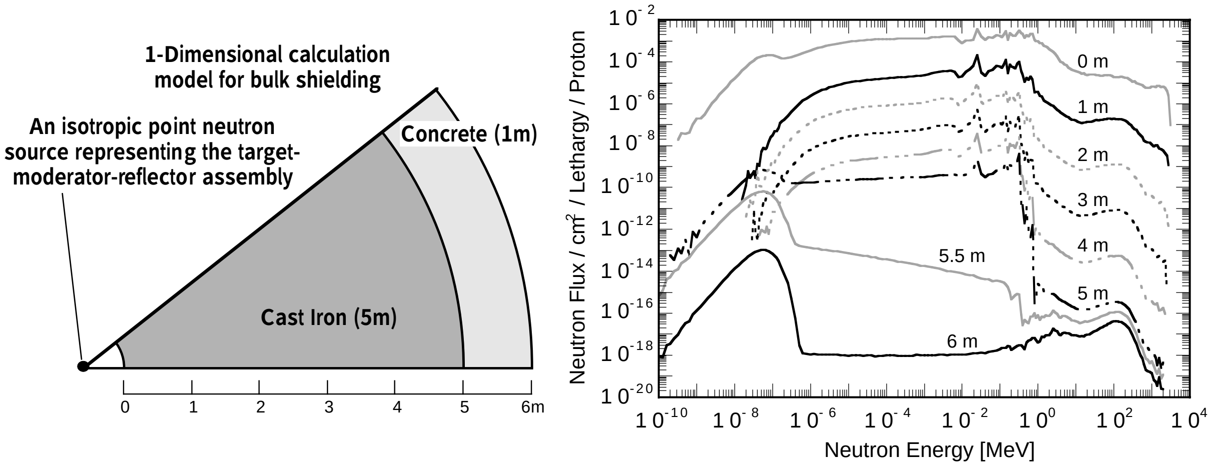

Fig. 1 An example of the bulk shielding calculation for a 3-GeV proton beam driven spallation neutron source by Monte Carlo calculation codes: calculation model (left) and calculated neutron spectra (right).

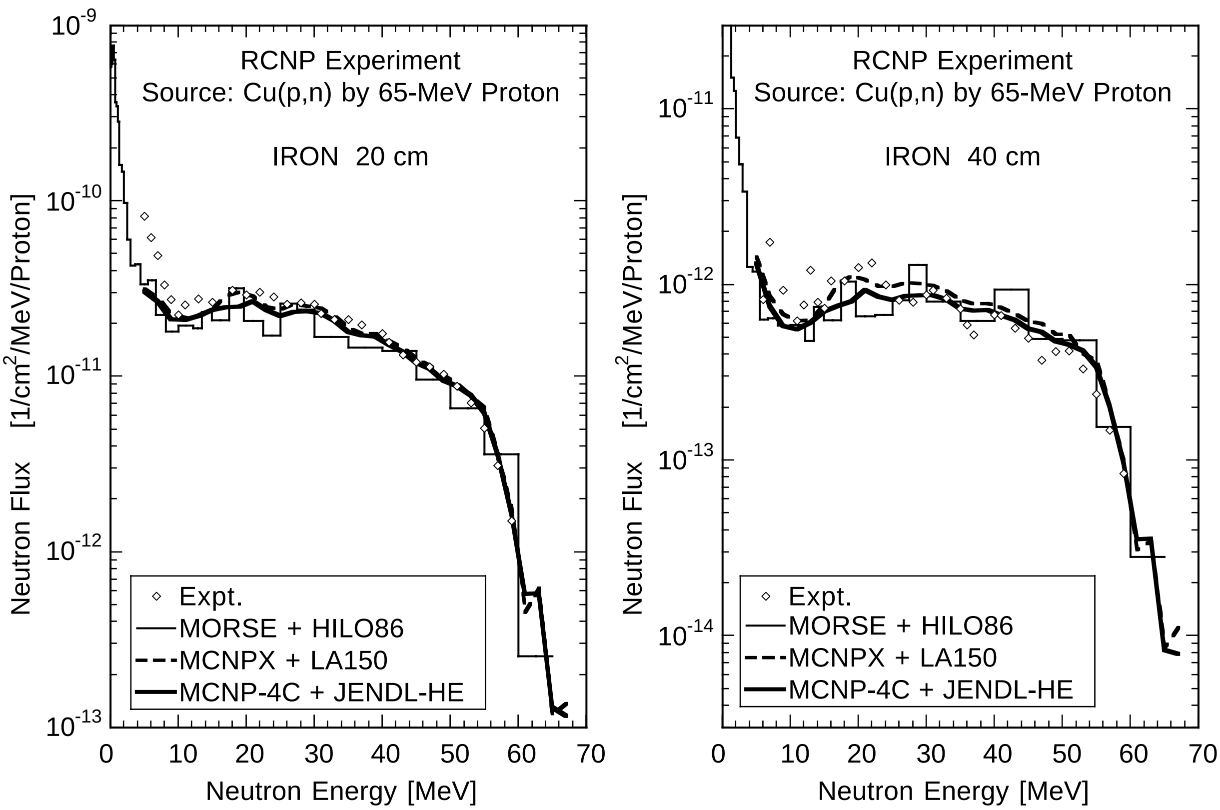

Fig. 2 Neutron flux spectra for the RCNP shielding experiment on iron for 20 cm and 40 cm thicknesses with a white neutron source produced by 65-MeV proton bombardment on a copper target.

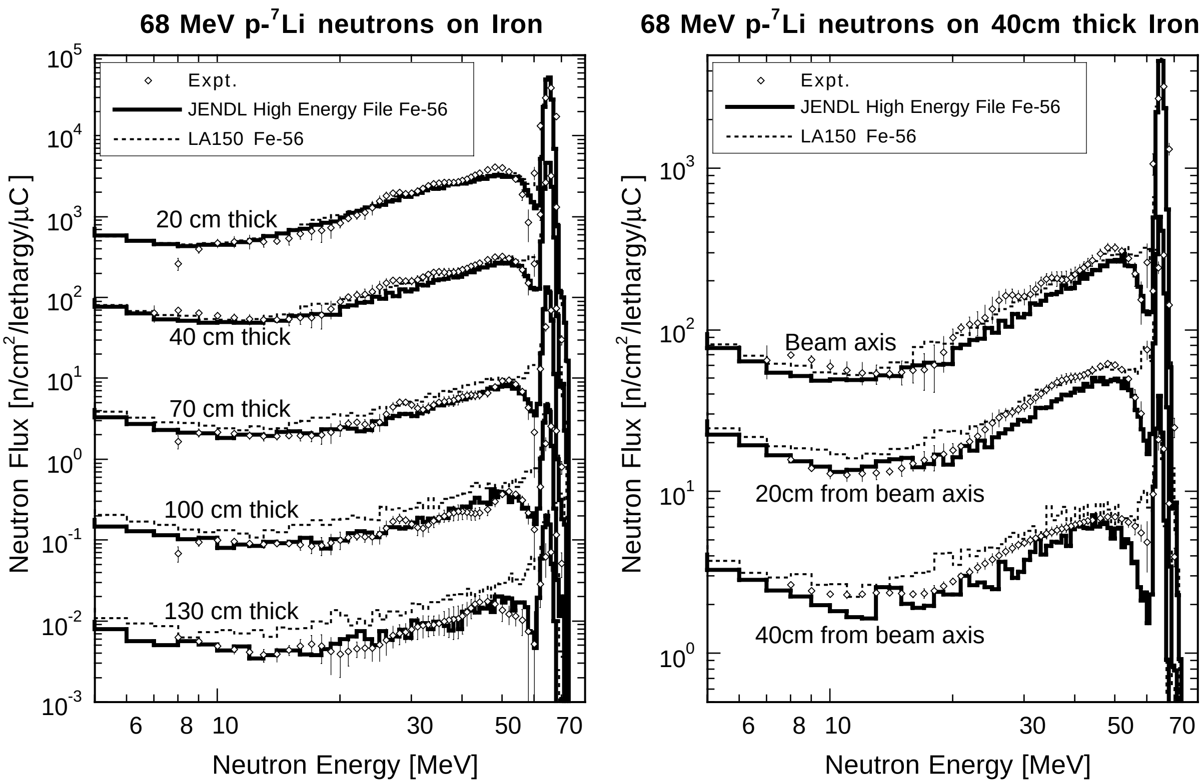

Fig. 3 Neutron flux spectra for the TIARA shielding experiment on iron with 68-MeV p-^{7}Li neutrons as a function of penetration thickness (left) and offset distance (right).

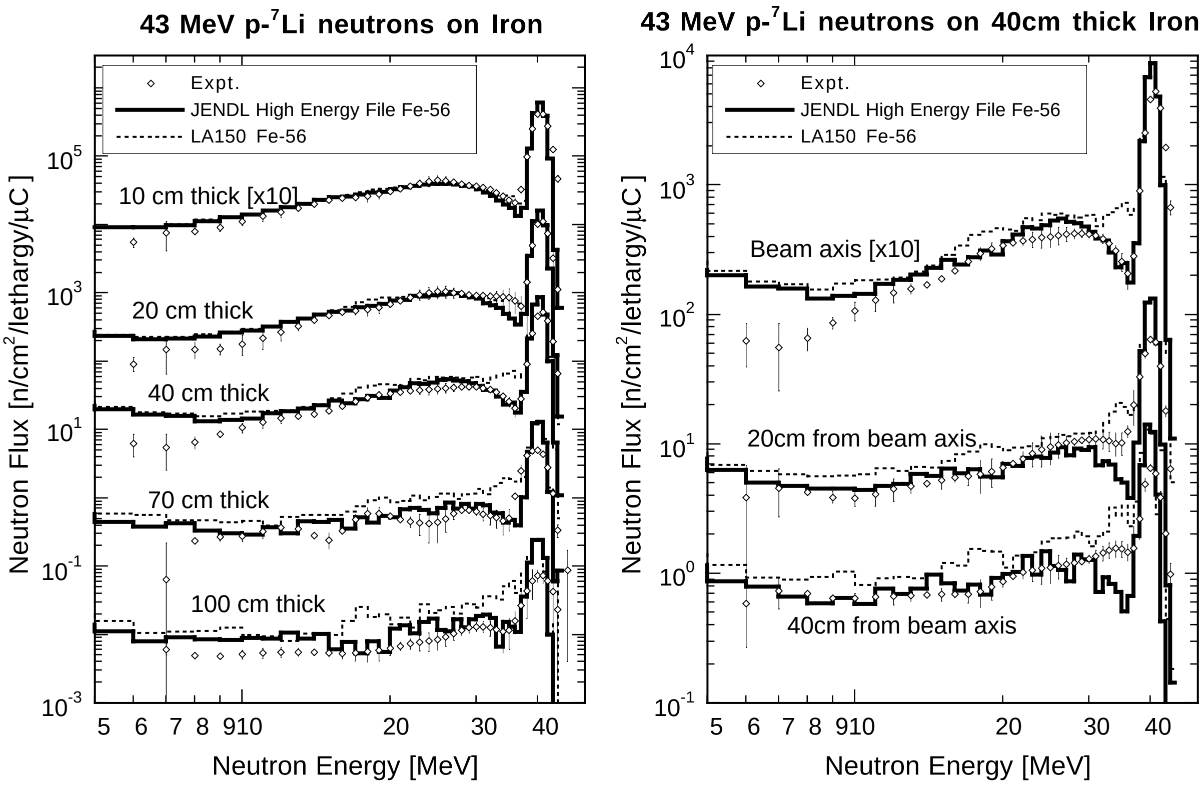

Fig. 4 Neutron flux spectra for the TIARA shielding experiment on iron with 43-MeV p-^{7}Li neutrons as a function of penetration thickness (left) and offset distance (right).

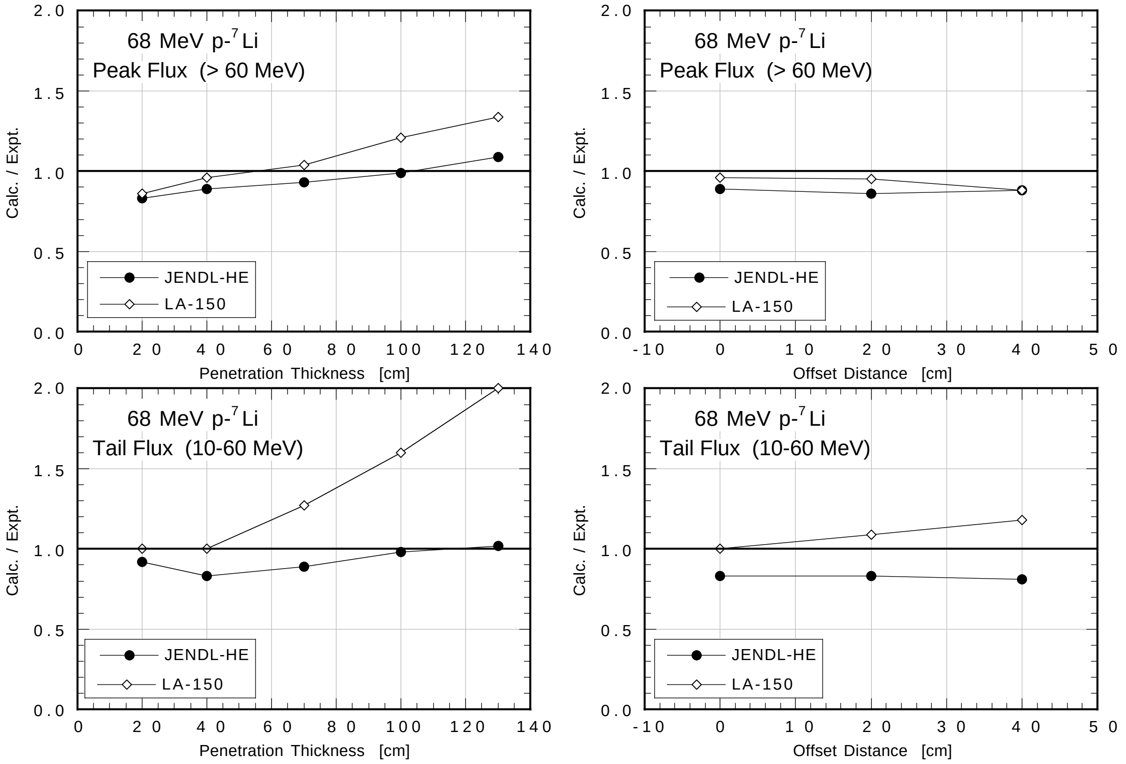

Fig. 5 C/E values for integral neutron fluxes for the TIARA shielding experiment on iron with 68-MeV p-^{7}Li neutrons: penetration thickness dependence (left) and offset distance dependence (right), and peak neutron flux above 60 MeV (top) and tail neutron flux between 10-60 MeV (bottom).

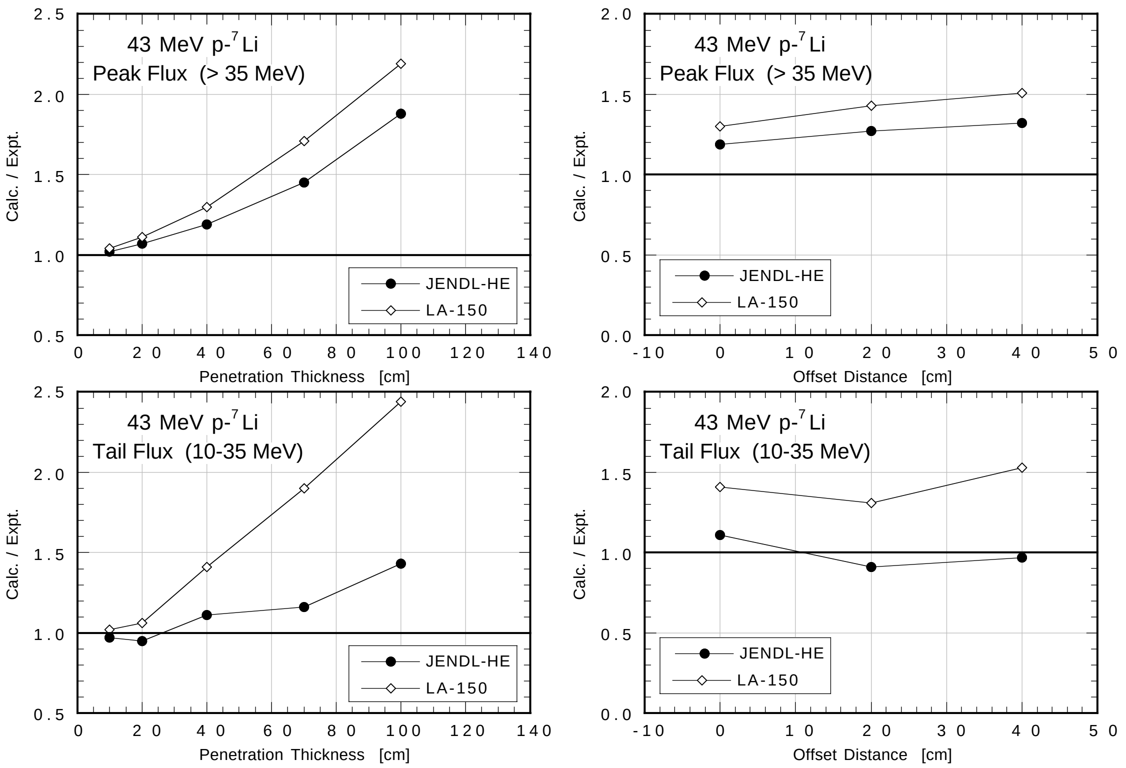

Fig. 6 C/E values for integral neutron fluxes for the TIARA shielding experiment on iron with 43-MeV p-^{7}Li neutrons: penetration thickness dependence (left) and offset distance dependence (right), and peak neutron flux above 35 MeV (top) and tail neutron flux between 10-35 MeV (bottom).