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SHIELDING BENCHMARK TEST OF SODIUM AND IRON CROSS SECTIONS IN JENDL-3T

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Abstract The integral tests of sodium and iron cross sections in JENDL-3T have been performed by analyzing the following shielding benchmark experiments: 1) Broomstick experiment at ORNL, 2) the neutron transmission experiment of thick sodium cylinder and iron block at the ORNL TSF reactor, 3) ASPIS deep penetration experiment with iron slabs, 4) KFK leakage spectrum measurement from iron spheres, 5) KUR angle-dependent neutron spectrum measurement in iron sphere. The analyses are made by several neutron transport codes such as ANISN, DIAC, DOT-3.5 and MCNP, with more than 100 energy groups. Group constants are generated by the cross section processing systems, PROF-GROUCH-G2/B and RADHEAT-V4. In this study, it is confirmed that the iron and sodium data in JENDL-3T are applicable to the shielding analysis. Particularly, for the sodium experiments, JENDL-3T gives better results than JENDL-2 and ENDF/B-IV. However, the reevaluation for total and inelastic scattering cross sections of iron is necessary in the energy range from 0.8 to 3 MeV.

(integral test, shielding, neutron, transmission, sodium, iron, benchmark experiment, JENDL-3T, PROF-GROUCH-G2/B, RADHEAT-V4)

Introduction

In the present work, integral tests of the cross sections of sodium/1/ and iron/2/ in JENDL-3T/3/ have been performed by analyzing shielding benchmark experiments. The selected experiments are two experiments/4,5/ for sodium and five/4-8/ for iron.

The analyses were carried out by using ANISN (1D Sn), DIAC (1D Sn) and DOT-3.5 (2D Sn) transport codes with more than 100 groups. The group cross sections were generated from evaluated nuclear data library by using the cross section processing code systems, PROF-GROUCH-G2/B/9/ and RADHEAT-V4/10/ developed at JAERI. The Bondarenko-type self-shielding factors were employed for calculation of effective macroscopic cross sections. Point Monte Carlo calculations were also made by MCNP using cross sections processed by NJOY. The calculated results were compared with the experimental data and with those calculated by using the other files of ENDF/B-IV and JENDL-2.

Calculation and results

Broomstick experiment

The experiment/4/ was performed by measuring the spectra of fast neutrons transmitted through a cylindrical sample of sodium or iron with 4 inches diameter, irradiated by neutron beam from the TSR-II reactor of ORNL. This experiment was made in a good geometry so that uncollided flux could be estimated analytically. Then, the present analyses were made for the 60.6 cm long sodium and the iron samples 20.3 cm and 30.5 cm in length by calculating the uncollided neutron spectrum with the use of point-wise total cross sections.

Figure 1 compares the calculated neutron spectra with the experimental data in the energy range from 0.8 MeV to 11 MeV in the case of sodium sample. Agreement was obtained for all evaluated data; the C/E values are 1.24±0.19 for JENDL-2 and 3T, and 1.22±0.22 for ENDF/B-IV. Above 6 MeV, ENDF/B-IV shows better agreement than JENDL.

As for iron, the spectrum calculated with JENDL-3T agreed with the experimental data from 1.2 MeV to 11 MeV within 25% difference in case of the 20.3 cm length, but it was harder than the experiment. This tendency was slightly extended in the case of 30.5 cm sample; the neutron fluxes was underestimated by 30% in the energy region between 1 and 3 MeV. The average C/E values are as follows:

Length	JENDL-3T	ENDF/B-IV
20.3 cm	0.96±0.16	0.95±0.09
30.5 cm	0.94±0.25	0.99±0.18

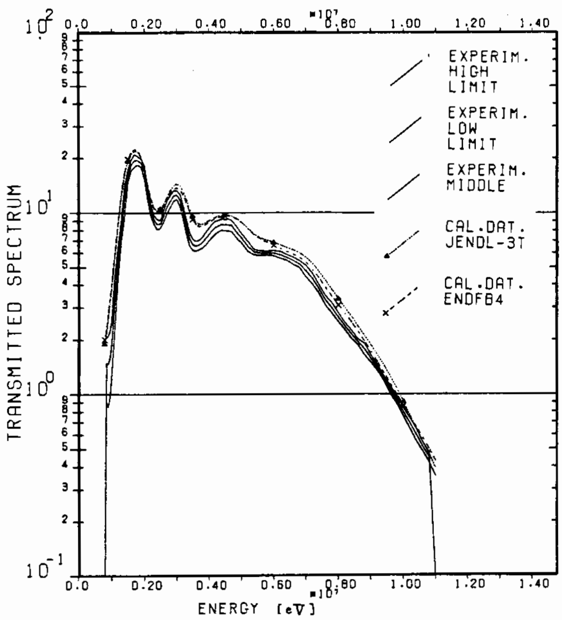

Fig. 1 Calculated and experimental transmitted spectrum and their C/E profile of sodium sample in Broomstick experiment.

ORNL neutron transmission experiment

The neutron transmission measurements were performed for five different combinations of sodium cylinders contained in aluminum tank, 11 ft in diameter and 5 - 15 ft in overall length/5/, and for six combinations of 5 ft by 5 ft iron slabs with thickness of 1.5 -36 inches/6/, by using the beam source from the TSR reactor. Neutron fluxes were measured behind of the samples. The present analyses were made for two thick sodium samples of 304.7 (10 ft) and 455.8 cm (15 ft) in length, and for five geometries of 10.3 - 92.9 cm-thick iron. Calculations of neutron fluxes in samples were carried out by DOT-3.5 with 100-group and P5-S48 approximation for RZ model. The neutrons at the detector behind the sample were estimated by using the SPACETRAN code.

Figure 2 shows the calculated and measured neutron spectra at 12 ft behind the 10 ft sodium sample. The calculated results in case considering the impurity of hydrogen with the reported maximum content in the sodium are slightly larger than the measured data: the C/E value is 1.0 - 1.3. The C/E values for the Bonner ball response are ranged from 0.75 to 0.97 for the 10 ft sample, and 0.74 - 1.05 for the 15 ft.

Figure 3 shows the NE213 spectra above 800 keV for 31.1 cm iron. Generally good agreement between the calculation and the experiment was obtained, though the neutron fluxes were underestimated in the energy range between 1 MeV and 3 MeV. The C/E values of the integrated neutron fluxes were 0.88 for 15 degree in polar angle and 0.83 for 45 degree. On the other hand, as for the spectrum measured by the Benjamin spectrometer below 1 MeV, which is not plotted in the figure, JENDL-3T overestimated by about 40%. Table 1 shows the C/E values of the Bonner ball responses.

Table 1 C/E values of Bonner ball responses in ORNL transmission experiment for iron.

thickness	angle	3"BB	6"BB	10"BB
30.8 cm	15°	0.98	1.32	1.23
	45°	1.07	1.30	1.22
62.0 cm	15°	0.96	1.25	1.11
	45°	1.05	1.34	1.16
92.9 cm	15°	0.94	1.17	0.98
	45°	1.11	1.43	1.22

ASPIS deep penetration experiment

The experiments were made with a large thin disc source of natural uranium converter, driven by the source reactor NESTOR/7/. The iron sample is 140 cm in thickness. Neutron spectra and fluxes were measured up to 115 cm depth in the iron shield. Analyses were carried out for the axial attenuation measurements by DOT-3.5 with 121 groups and P5-S48 approximation, and by MCNP with 147,000 histories.

Figure 4 gives the DOT-3.5 results for the axial traverse of reaction rates, compared with the experimental data. In general, good agreement is observed for all detectors, but the calculations show steeper gradient for threshold detector than the experiment. The C/E values for each detector are summarized as follows:

detector	JENDL-3T	ENDF/B-IV
Au(n,γ)/Cd cover	1.2 - 1.0	1.1 - 1.0
Rh103(n,n')Rh103m	1.2 - 0.5	1.4 - 0.6
In115(n,n')In115m	1.1 - 0.6	1.1 - 0.9
S32(n,p)P32	1.3 - 0.8	1.1 - 0.6

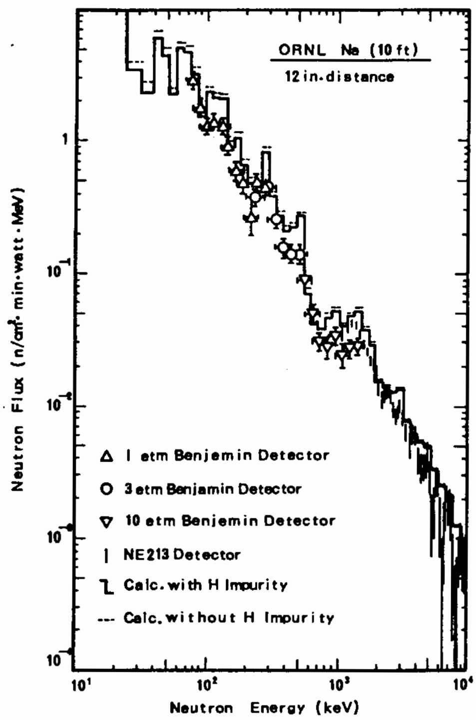

Fig. 2 Neutron spectra at 12" behind 10 ft sodium in ORNL experiment.

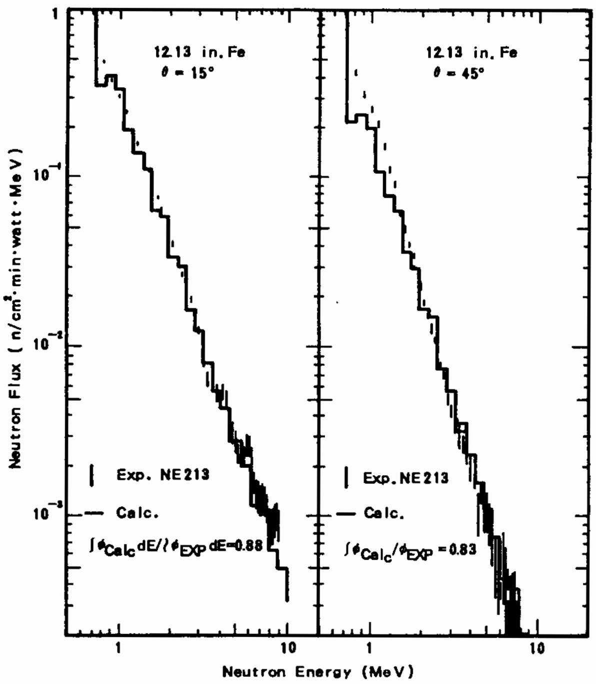

Fig. 3 Neutron spectra calculated and measured with the NE213 in ORNL 31.1 cm iron experiment.

JENDL-3T has a tendency giving smaller C/E values than ENDF/B-IV. The difference is obvious for In-115(n,n').

Figure 5 shows neutron spectra at 57 cm depth. JENDL-3T gives good agreement with the experimental data. Particularly, the result with JENDL-3T explained well neutron spectrum around the 24 keV window, while ENDF/B-IV result shows an overshooting at the peak and the valley. Fast neutron spectrum above 700 keV was underestimated by JENDL-3T, while it was well reproduced at 22 cm depth. At the deeper penetration, huge underestimation appeared.

KFK experiment

The leakage neutron spectrum measurements were performed for six different iron spheres of diameters of 15 - 40 cm/8/. The sphere contained a Cf-252 source in the central channel. In the analyses, the 100-group calculations were carried out by DIAC with the S16 approximation using a sphere model having a shell source at the center.

Figure 6 shows the results for the iron of 35 cm diameter. Calculation with JENDL-3T agrees with the experiment as well as that with ENDF/B-IV does. For all geometries, the integrated neutron flux was over-estimated by 8-11% between 63 keV and 5.2 MeV. Below 50 keV where the spectrum was not measured, the discrepancy between JENDL-3T and ENDF/B-IV is observed in the figure.

KUR experiment

The experiments of measuring angle-dependent neutron spectrum in iron sphere 60 cm in diameter and rectangular parallelepiped assembly of 90 x 100 x 100 cm were performed with a time-of-flight technique/9/. The photo-neutron source of a lead target bombarded by 30 MeV electron beam was used. The analyses were done by using ANISN with 100 groups and the P5-S32 approximation.

Figure 7 compares the present calculated neutron spectrum with the measured values and those calculated/9/ using JENDL-2 and ENDF/B-IV at r=22.5 cm and at 90 degree to radial direction in the assembly. The calculated result was normalized to the experimental data around 200 keV. For JENDL-3T, good agreement between the calculation and the experiment is observed.

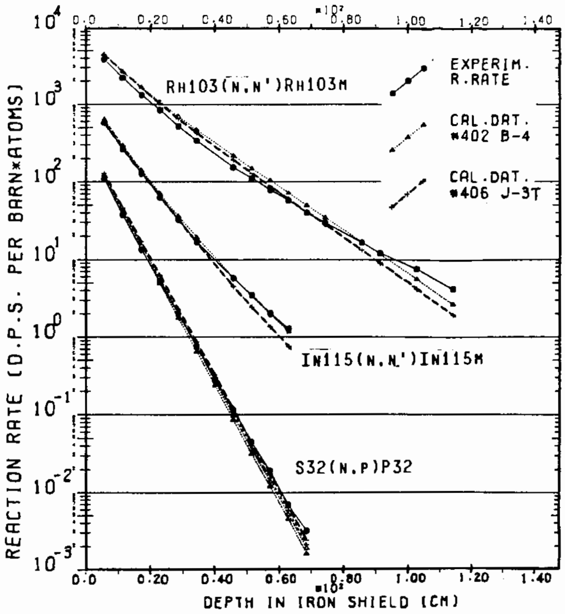

Fig. 4 Comparison of axial traverses of reaction rates calculated with DOT-3.5 and measured in ASPIS experiment.

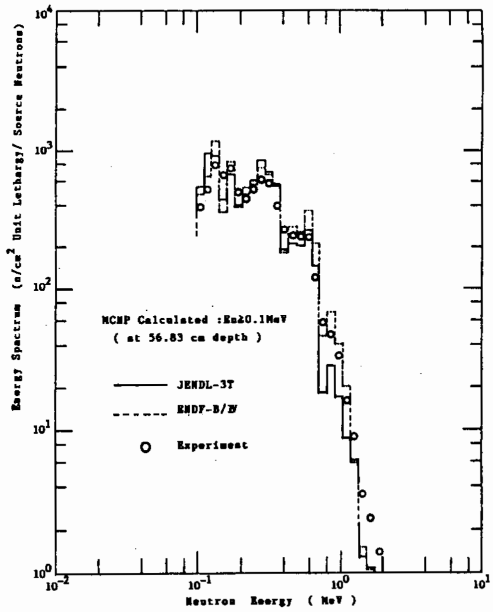

Fig. 5 Neutron spectra calculated by MCNP and measured at 57 cm depth in ASPIS experiment.

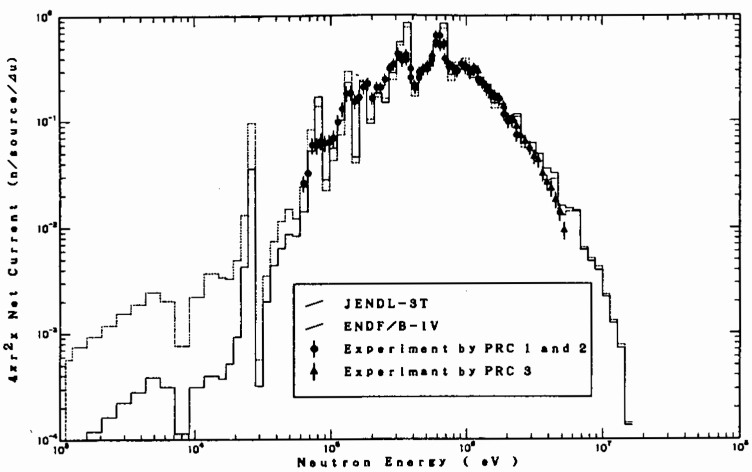

Fig. 6

Leakage neutron spectra from 35 cm diameter iron in KFK experiment.

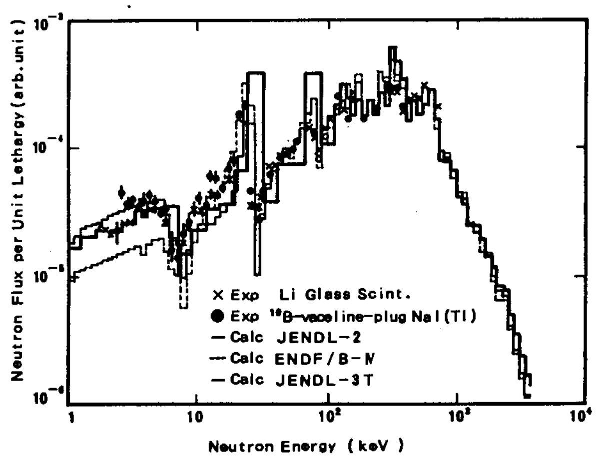

Fig. 7 Angle-dependent neutron spectra at r=22.5 cm and at 90 degree in parallelepiped rectangular iron assembly in KUR experiment.

Discussion

Sodium cross section

Table 2 compares the average C/E values for the Bonner ball response calculated with the different libraries. The JENDL-3T result is the closest to unity. As a result, JENDL-3T is considered to be the most reliable data to calculate the neutron fluxes, at least in the energy region below 10 keV neutrons of which gave a dominant contribution to the Bonner ball responses.

In the analysis of the Broomstick experiment, JENDL-3T gave about 20% higher transmission from 2 to 10 MeV. The overestimation was also observed in the calculated neutron spectrum behind the 10 ft sodium experiment as shown in Fig. 4. However, these overestimation can be diminished by modification of total cross section less than a few percent. In addition, there are ambiguities in sodium density and some calculation errors. Accordingly, no modification is required so far.

Table 2 Average C/E values of Bonner ball responses in ORNL transmission experiment for 10 ft sodium.

detector	JENDL-3T	JENDL-2	ENDF/B-IV
Cd-BB	1.0	0.7	0.8
3" BB	1.1	0.8	0.9
6" BB	1.05	0.9	0.9
10" BB	1.0	0.9	0.85

N.B. Calculation without impurity hydrogen.

Iron cross section

The result of integral test for JENDL-3T was the same as JENDL-2. Therefore, its reliability is as good as that of JENDL-2. Additionally, it is noted that the neutron spectrum around the 24 keV window was excellently well described.

However, some problems in JENDL-3T can be pointed out from the present work. First, underestimation of neutron flux in the energy region from 1 to 3 MeV was observed in the results for deep penetration in the Broomstick, the ORNL transmission, and also the ASPIS experiments. It suggests that total cross section at these energies may be too large. Second, the discrepancy of spectra remained below 1 MeV in the ORNL and the ASPIS experiments may suggest a necessity of modifying a partition of elastic and inelastic scattering cross sections.

Conclusion

From the study, applicability of sodium and iron data in JENDL-3T to shielding calculations has been confirmed. At the same time, some problems still remained in iron data are also pointed out. Those are as follows: total cross section from 1 to 3 MeV is rather large and partial inelastic scattering cross sections should be checked. By considering these feedback informations in the cross section evaluation, applicability of the forth coming official version, JENDL-3, will be improved.

Authors are grateful to T. Nakagawa at Nuclear Data Center of JAERI for his kind advises to nuclear data processing.

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