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MEASUREMENT AND ANALYSIS OF NEUTRON SPECTRA FROM CHROMIUM SLAB FOR 14MeV NEUTRON SOURCE

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Abstract: Neutron energy spectra scattered by a chromium slab were measured with a 14 MeV neutron source in order to assess the accuracy of chromium cross sections. The measurement was performed by the time-of-flight method for 6 scattering angles. The neutron energy spectra between 2 and 15 MeV were obtained and compared with calculated spectra. The calculation was carried out with a continuous energy Monte Carlo code MCNP using JENDL-3PR1 and ENDF/B-IV cross section libraries. Generally the spectra calculated using JENDL-3PR1 showed good agreement with the measurement, but the result suggested the cross sections and secondary angular distributions of elastic and inelastic scattering in JENDL-3PR1 should be changed for better agreement.

(chromium, neutron spectra, 14 MeV neutron source, cross section, JENDL-3PR1, ENDF/B-IV, time-of-flight, Monte Carlo)

Introduction

Chromium is a major component of structural and shielding materials for fusion reactors such as stainless steel; the accuracy of neutron cross sections of chromium is important to evaluate nuclear performance of fusion reactors. Neutron cross sections of chromium were re-evaluated for the 3rd version of JENDL as JENDL-3PR1, but the assessment of the evaluation has not thoroughly been accomplished compared with other important elements. In the present study, benchmark data for the assessment of chromium cross sections were obtained by measuring neutron spectra scattered by a chromium slab. Analysis of the measurement was also carried out using JENDL-3PR1 and ENDF/B-IV nuclear data libraries, and the result was compared with the measured neutron spectra.

Experimental Method

Measurement was performed using a D-T neutron source facility, OKTAVIAN at Osaka university. Fast neutrons were produced by T(d,n)He reaction in a Ti-T target with a 300 KeV Cockcroft-Walton type accelerator. The angular distributions of source neutron energy and yield were determined experimentally by the method described in Ref. 1. The average source neutron energy was 14.1 MeV.

The experimental arrangement is shown in Fig. 1. A chromium slab was placed at 6 positions (25, 45, 68, 112, 135 and 155 degree in scattering angle) along the detector axis and neutron spectra were measured by the time-of-flight (TOF) method. A NE213 scintillator of 25.4 cm diameter and 5.04 cm thickness was used for TOF spectra measurement. Another NE213 scintillator of 5.08 cm diameter and 5.08 cm thickness was used for source monitoring, and the measured data were normalized to one monitor count. The electronic system used was almost the same as presented in Ref. 2. The sample used was a chromium slab of 20 cm x 20 cm width, 5 cm thickness and 7.18 g/cm^3 density. Efficiency curve of the main detector was determined as a function of neutron energy by two experiments: TOF measurement of neutrons scattered by a polyethylene ring and that of fission neutrons from ^{252}Cf source.

Since a small collimator prepared for a small sample was used in the measurement and the detector could not see the whole sample surface through the collimator, the geometric efficiency of the detector depended on neutron flight path from the sample. Mapping of the efficiency was made by traversing a ^{252}Cf neutron source on the

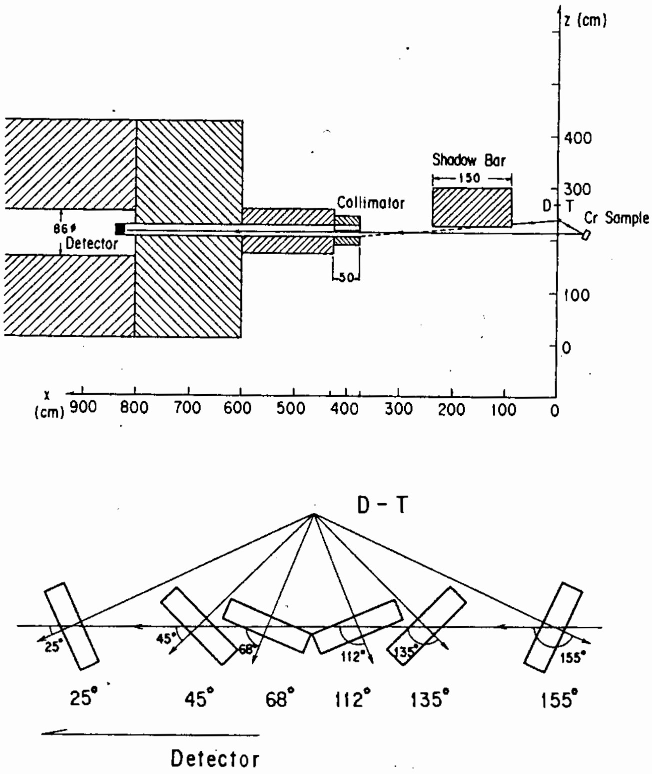

Fig. 1 Experimental arrangement

sample. Fig. 2 shows an example of the mapped relative efficiency for the sample position of 45 and 135 degree. These figures were used in the Monte Carlo calculation to collect point tally.

The measurement of source spectrum was also carried out without the sample and the shadow bar to determine the absolute neutron yield. In this measurement, detector counts (C_s) normalized by the source monitor counts (M_s) are given by the following relation:

$$\frac{C_s}{M_s} = G_s P(\Omega)\frac{S_d}{r^2} \qquad (1)$$

where G_s , $P(\Omega)$, S_d and r are the detector efficiency to source neutron, the angular distribution of source neutron yield per monitor count, the area of the detector and the distance between the target and the detector, respectively. In the measurement of scattered neutron spectra, normalized detector counts (C_i/M) are given by the following relation:

$$\frac{C_i}{M} = G_i \phi_i S_d \qquad (2)$$

where G_i and ϕ_i are the detector efficiency and the neutron flux of the i-th energy bin for a unit neutron source, respectively. In the present study, experimental result was obtained in the form of neutron flux measured with the sample relative to that measured without the sample, which is expressed by the following equation:

$$\frac{C_i/MG_i}{C_s/M_sG_s} = \phi_i \frac{r^2}{P(\Omega)} \qquad (3)$$

Since the normalized flux is obtained in the analysis, it is necessary to multiply the calculational result with a factor of $r^2/P(\Omega)$ before comparing with the experimental result.

Uncertainties in the measured spectra came from counting statistics (3%), uncertainties in the detector efficiency (5%), and the monitoring statistics (5%).

Calculational Method

Calculation was performed using a continuous energy Monte Carlo code MCNP/3/. The sample, the shadow bar and the collimator shown in Fig. 1 were modeled in the analysis, where the latter two were assumed to be made of pure iron. The chromium cross sections required for the calculation were prepared by processing the nuclear data in JENDL-3PR1/4/ (MAT=2400) and ENDF/B-IV/5/ (MAT=1191) using the NJOY code system/6/.

Since the sample occupied only a small solid angle around the neutron source, the source direction biasing was employed to improve the statistics of Monte Carlo calculation. Source neutrons were assumed to be emitted isotropicly in the present study. A point detector was placed at the center position of the main scintillator to tally the neutron flux. Since the actual detector used in the measurement had finite surface area, correction of tally weights is necessary to compare the measured and calculated data. The correction was accomplished by modifying the tally weights with the space dependent correction factor obtained from the mapping data as shown is Fig 2.

Results and Discussions

The measured and calculated neutron spectra for the 6 scattering angles are comparatively shown in Fig 3. Four peaks are observed in the measured spectra corresponding to elastic scattering and inelastic scattering to discrete levels. Generally the spectra calculated using JENDL-3PR1 agree with the measured ones.

.193	.274	.356	.428	.484	.513	.510	.461	.378	.288
.253	.360	.468	.563	.636	.674	.670	.606	.496	.376
.316	.449	.583	.701	.793	.840	.835	.755	.618	.472
.368	.523	.679	.817	.924	.979	.973	.880	.721	.550
.376	.534	.694	.835	.944	1.00	.994	.899	.736	.562
.355	.505	.656	.789	.892	.945	.939	.850	.696	.531
.314	.445	.579	.696	.787	.834	.829	.750	.614	.469
.258	.367	.477	.574	.649	.687	.683	.617	.506	.386
.194	.276	.359	.431	.488	.517	.514	.465	.381	.291
.129	.184	.239	.287	.325	.344	.342	.309	.253	.193

Fig. 2 Relative efficiency of the detector mapped in 45 and 135 degree

As for 45 and 155 degree, spectra were also calculated using ENDF/B-IV, but the calculation overestimates the measurement greatly between 6 and 12 MeV. The discrepancy seems to have come from inappropriate values assigned to inelastic scattering cross sections to discrete levels in ENDF/B-IV, which are actually much greater than those in JENDL-3PR1.

Peaks of elastic scattering are observed between 13 and 14 MeV. In this energy region, JENDL-3PR1 agrees well with the measurement in 135 and 155 degree. ENDF/B-IV agreeds well, but JENDL-3PR1 does not with the measurement in 45 degree. Direct comparison of differential data between the two libraries and Stelson's experiment/7/ reveals the cross section in JENDL-3PR1 is much greater than both ENDF/B-IV and experimental data around 45 degree. As for 68 and 112 degree, the reason of discrepancy is not certain, but it seems the hollows around the two angles observed in the differential cross section are not correctly evaluated in JENDL-3PR1.

Three peaks of inelastic scattering to discrete levels are observed between 8 and 13 MeV. The second peaks around 12.5 MeV corresponding to the 1.43 MeV level are overestimated between 45 and 112 degree by the calculation based on JENDL-3PR1. It seems the values assigned to this cross section (49 mbarn at 14 MeV) should be reduced slightly and the secondary angular distribution should be modified at the same time.

The third and fourth peaks show a similar tendency. The analysis underestimates these peaks in the forward angles but overestimates them in the backward angles. The secondary angular distributions of inelastic scattering reactions corresponding to these peaks are evaluated as functions smoothly changing with scattering angle. Judging from the above result, the anisotropy of the reactions should be emphasized toward forward direction.

In the energy range from 8 MeV down to 2 MeV, slopes originating from inelastic scattering to the continuum level are observed. Since the analysis overestimates the slopes in the backward angles, the cross section should be reduced slightly and the anisotropy of secondary neutrons should be taken into evaluation.

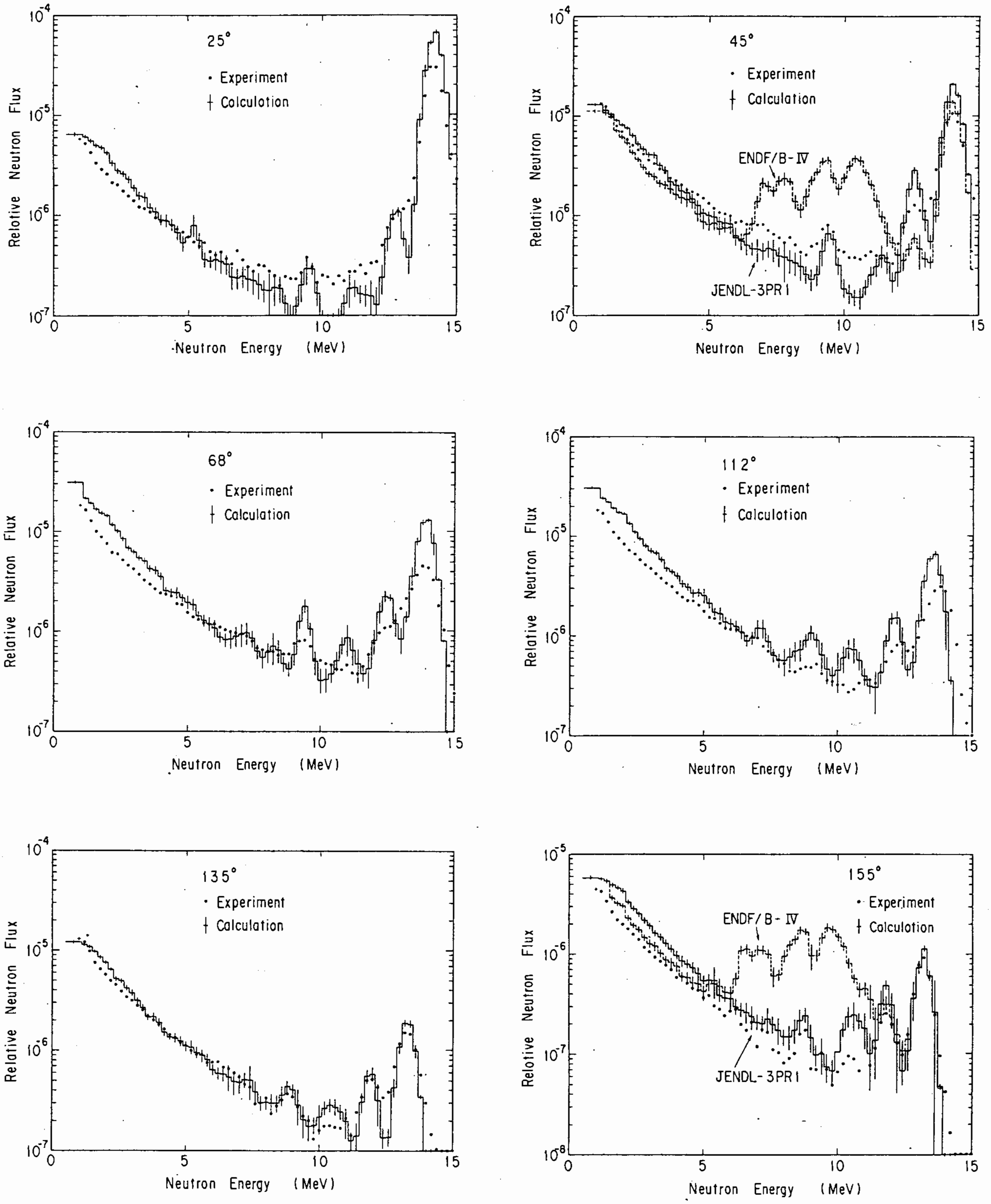

Fig. 3 Measured and calculated relative neutron spectra (with sample/without sample)

Conclusion

Neutron spectra scattered by a chromium slab were measured for the energy range between 2 and 15 MeV by the time-of-flight method. The following results were obtained by comparing neutron spectra between the measurement and the calculation performed with the MCNP Monte Carlo code:

(1) The calculation using JENDL-3PR1 generally shows good agreement with the measurement, while that using ENDF/B-IV greatly overestimates the measured spectra between 6 and 12 MeV.

(2) The calculation using JENDL-3PR1 overestimates elastic peaks in 25, 45, 68 and 112 degree probably due to inappropriate evaluation of the secondary angular distribution.

(3) The calculation using JENDL-3PR1 generally overestimates inelastic peaks in the backward angles. For better agreement, it is recommendable to reduce inelastic scattering cross sections slightly and to emphasize the anisotropy of their secondary angular distributions toward forward direction.

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