EVALUATED NEUTRON NUCLEAR DATA FILE FOR COPPER

Zou Yiming Ma Gonggui Wang Shiming

(INSTITUTE OF NUCLEAR SCIENCE AND TECHNOLOGY OF SICHUAN UNIVERSITY, CHENGDU)

ABSTRACT

A comprehensive evaluated neutron nuclear data file and theoretical calculation for copper are described.

This complete data contain neutron cross sections, angular distribution and energy distribution of secondary neutrons in the energy region from 10^{-5} eV to 20 MeV.

INTRODUCTION

Natural copper consists of two isotopes, ^{63}Cu and ^{65}Cu.

Below 20 MeV considered neutron induced reaction Q values of the isotopes are listed in Table 1.

Table 1 Reaction Q value (MeV) of $^{63,65}Cu$

Reactions	^{63}Cu (69.1%)	^{65}Cu(30.9%)
(n,n)	0.0	0.0
(n,n′)	−0.6697	−0.7710
(n,2n)	−10.841	−9.9045
(n,3n)	−19.200	−17.820
(n,α)	7.9159	7.0670
(n,p)	0.7165	−1.3488
(n,n′p)	−6.1245	−7.4446
(n,t)	−8.2389	−8.6219
(n,n′t)	−16.058	−15.463
(n, ^{3}He)	−9.5278	−12.262
(n,n′ ^{3}He)	−18.863	−20.661
(n,d)	−3.9000	−5.2200
(n,n′d)	−14.500	−14.879
(n,α)	1.7149	−8.2939
(n,n′α)	−5.7765	−6.7703

The present evaluation was based on experimental data available up to June 1989 and theoretical calculation with MUP−2[1] code. It contains neutron cross sections, angular distributions and energy spectra of secondary neutron for mentioned above mentioned reactions. Comparing with CENDL−1, the evaluated neutron cross sections have considerabely improved for charged particle emission reaction due to the theoretical calculation code had been improved. The present evaluated neutron cross sections are in essentially in agreement with ENDF / B−6[8] and JENDL−3[103].

1 THEORETICAL CALCULATION AND THE PARAMETERS

In this calculation, AUJP[3] and MUP−2[1] were used.

Original optical potential parameters were taken from the work of Xu Dingan[4], nuclear level informations of ^{63}Cu and ^{65}Cu were taken from Refs. [5, 6] respectively, and level density parameters were taken from Ref. [7].

The adjusted optical model parameters are given as following: (MeV or fm)

$$V = 55.563 - 0.457E + 0.0018E^2 - 27.039(N-Z)/A$$

$$r_0 = 1.19, \quad a_0 = 0.75$$

$$W_d = 16.08 - 0.353E - 35.47\,(N-Z)\,/\,A, \quad \text{or zero},$$
$$r_w = r_d = 1.41, \quad a_w = a_d = 0.26$$
$$V_{so} = 3.41, \quad r_{so} = 1.19, \quad a_{so} = 0.75$$

The level density parameters are :

^{63}Cu

PZ	0.0	1.20	−0.10	1.30	0.0
PN	−0.18	1.30	−0.15	1.32	−0.2
SZ	−17.10	−16.57	−14.75	−14.40	−14.00
SN	17.25	16.38	15.80	14.98	14.45

^{65}Cu

PZ	0.0	1.20	−0.10	1.30	0.0
PN	−0.10	1.50	−0.18	1.30	−0.15
SZ	−17.10	−16.57	−14.75	−14.40	−14.00
SN	18.05	17.55	17.25	16.38	15.80

The giant dipole resonance parameters are given in the following:

^{63}Cu

SAO	0.050	0.250	0.075	0.032	0.034	0.026	0.034	0.026	0.0	0.0	0.0	0.050	0.050	0.050	0.050	0.050
GM	6.89	6.89	6.89	2.44	2.44	2.56	2.44	2.56	6.89	6.89	6.89	6.37	6.37	7.61	6.37	7.61
EG	16.70	16.70	16.70	16.30	16.30	16.37	16.30	16.37	16.70	16.70	16.70	18.51	18.51	18.90	18.51	18.90

^{65}Cu

SAO	0.050	0.075	0.075	0.034	0.034	0.026	0.034	0.026	0.0	0.0	0.0	0.050	0.050	0.050	0.050	0.050
GM	6.89	6.89	6.89	2.44	2.44	2.56	2.44	2.56	6.89	6.89	6.89	6.37	6.37	7.61	6.37	7.61
EG	16.70	16.70	16.70	16.30	16.30	16.37	16.30	16.37	16.70	16.70	16.70	18.51	18.51	18.90	18.51	18.90

Preequilibrium parameters are :

DK = 380 (for ^{63}Cu), 130 (for ^{65}Cu).

The calculated total, elastic scattering and non−elastic scattering cross sections are in agreement with the evaluated experimental data, as illustracted in Table 2.

The calculated total inelastic scattering cross section, discrete level inelastic scattering cross section, (n,γ) and (n,2n) cross sections are essentially in agreement with the evaluated experimental data.

Table 2 The comparison between calculated and measured data

(MeV)	tot			n,n			non		
	eval.	cal.	err.	eval.	cal.	err.	eval.	cal.	err.
1.0	3.43	3.65	6.6	3.18	3.41	7.1	0.248	0.234	6.0
1.5	3.09	3.22	4.2	2.45	2.61	7.0	0.64	0.61	5.0
2.0	3.00	3.08	2.7	2.10	2.13	1.5	0.90	0.94	4.4
2.5	3.13	3.10	1.0	1.95	1.94	0.5	1.18	1.16	2.0
3.0	3.30	3.22	2.4	1.92	1.91	0.5	1.38	1.30	6.0
4.5	3.70	3.64	1.6	2.12	2.14	0.9	1.58	1.50	5.0
6.0	3.80	3.76	1.1	2.20	2.27	3.2	1.60	1.49	6.2
7.0	3.75	3.72	0.8	2.16	2.25	4.2	1.59	1.47	7.5
8.0	3.67	3.65	0.5	2.09	2.17	3.8	1.58	1.47	7.0
10.0	3.40	3.44	1.2	1.85	1.93	4.3	1.55	1.51	2.6
12.0	2.20	3.17	0.9	1.70	1.67	1.8	1.50	1.50	0.0
14.5	2.90	2.86	1.4	1.44	1.39	3.5	1.46	1.46	0.0
17.0	2.66	2.66	0.0	1.22	1.23	0.8	1.44	1.44	0.0
20.0	2.47	2.56	3.6	1.07	1.14	7.5	1.40	1.40	0.0

err. = [|cal. − eval.| / eval.] × 100

2 RECOMMENDED NEUTRON CROSS SECTIONS

2.1 Total Cross Sections

Below 99.5 keV, the resonance parameter of ^{63}Cu and ^{65}Cu were given. They were taken directly from Hetrick, Fu, Larson[8].

Below 1 MeV, there are considerable structure in the experimental data. So in this energy regions, the better resolution experimental data were recommended respectively. From 35 to 100 keV, the data of Garg[9] were used; from 100 keV to 1 MeV, the data of Whalen[10] were used. In this energy range, the new data of Poenitz[11], which are averaged cross section over 50 keV energy range and have higher precision (about 2.5%), are in good agreement with these data.[9, 10].

Above 1 MeV, the data become smooth. The normal polynomial fitting result of 13 groups[10~22] was used, including the data of Poenitz[11] above 1 MeV and the new measured average cross section of Guenther[12] over 200 keV intervals.

The data of Morales[23] measured in 1987, due to no detail information and seriously disagreement with others[17, 20, 21], were abandoned.

The present evaluated total cross sections are in agreement with that of CENDL–1 and JENDL–3[103]; and are also in agreement with ENDF / B–6[8], except somewhat higher in the energy region 0.2~2.0 MeV, as illustracted Fig. 1.

2.2 Elastic Scattering Cross Sections

The recommended elastic scattering cross sections were obtained by subtracting the non–elastic cross sections from the evaluated total cross sections. The calculated cross section was compared with the available experimental data. In the energy region between 0.2~ 14 MeV, the cross section is in agreement very well with the available measurements [25~29]. Between 4~ 8 MeV, the calculated curve was slighly higher than the measured data of Holmqvist[30].

2.3 Non–elastic Scattering Cross Sections

There are more experimental results from threshold to 20 MeV. The new data[31, 32] near 14 MeV, measured with spherical shell and anti–spherical method with higher precision (about 2.0%), are in very good agreement with the others[35, 38, 40, 42]. The normal polynomial fitting of the experimental data [31~42] was used as recommended data.

The evaluated data are in good agreement with ENDF / B–6 and JENDL–3, except ENDF / B–6 is higher above 15 MeV, as illustrated in Fig.2. Meanwhile ENDF / B–5[24] is about 6% higher than the others from 5 to 12 MeV.

2.4 Inelastic Scattering Cross Sections

(1) Discrete Inelastic Scattering Cross Sections

The discrete inelastic scattering cross sections include 7 leves of ^{63}Cu and 5 leves of ^{65}Cu. The excitation energy and spin parity of the levels are listed in Table 3, taken from Refs. [5, 6].

Table 3 (1) Energy levels of ^{63}Cu

Level	Energy (MeV)	Spin Parity	Level	Energy (MeV)	Spin Parity
1	0.0	1.5^-	5	1.4120	2.5^-
2	0.6697	0.5^-	6	1.5470	1.5^-
3	0.9621	2.5^-	7	1.8610	3.5^-
4	1.3270	3.5^-	8	2.0110	1.5^-

Table 3(2) Energy levels of ^{65}Cu

Level	Energy (MeV)	Spin Parity	Level	Energy (MeV)	Spin Parity
1	0.0	1.5^-	4	1.482	3.5^-
2	0.771	0.5^-	5	1.623	2.5^-
3	1.116	2.5^-	6	1.725	1.5^-

There are more experimental data for lower 4 levels (0.6697, 0.7710, 0.9621 and 1.1160) and they are in agreement with the calculated results.

The calculated results were taken as the recommended discret level inelastic scattering cross sections. In order to keep up the total inelastic scattering cross section, the discrete inelastic scattering cross sections were somewhat adjusting in the energy region below the threshold of the continuum inelastic scattering cross sections.

The recommended discrete inelastic cross sections were in agreement with measured data [43~47], ENDF / B–6 andJENDL–3, as illustrated in Fig. 7.

The recommended total inelastic cross section was obtained by subtracting sum of the cross sections of the other reactions from the evaluated non–elastic cross section, and are in very good agreement with ENDF / B–5, ENDF / B–6 and JENDL–3. The comparasion between the evaluations and measured data [12, 45, 48, 49] is shown in Fig. 4.

(2) Continuum Inelastic Scattering Cross Section

Continuum inelastic scattering cross section was obtained by subtracting the sum of the discrete inelastic scattering cross sections from the total inelastic scattering cross section.

2.5 (n,2n) Cross Sections

From threshold to 13.5 MeV, the only experimental data of Frehaut[50] was used. From 13.5 to 20 MeV, the (n,2n) cross section was taken from the evaluation[51] of (n,2n) cross sections for isotopes.

Both ^{63}Cu (n,2n) and ^{65}Cu (n,2n) cross sections have been used as standards, therefore many sets of experimental data are available. The evaluation[51] was based on measurements[52~60] for ^{63}Cu, and measurements [52, 56, 62~67] for ^{65}Cu. The newer experimental data of ^{63}Cu[61] and ^{65}Cu [68~71] is in very good agreement with the evaluation[51].

The recommented (n,2n) cross sections are in agreement with ENDF / B–5, ENDF / B–6 and JENDL–3. Between 12 MeV and 13.5 MeV the three evaluations are somewhat higher than the experimental data[50]. Above 17 MeV the data of JENDL–3 appear somewhat lower than the others and the data of Zhou[51], as illustrated in Fig 5.

2.6 (n,3n) Cross Section

The (n,3n) cross section was taken from the model calculation due to lack of experimental data.

2.7 Capture Cross Section

From 35 keV to 1 MeV, the normal polynomial fitting of the data of Stavisskij[72], Diven[73] and Voignier[74]was taken. Between 1 to 3 MeV, the data of Voignier[74] was used. From 3 to 20 MeV the linear interpolation and the extrapolation were made in log– log scales, through the measured data[75] near 14 MeV.

The evaluatedcrosssections are in very good agreement with ENDF / B–6 and JENDL–3, except the above 3 MeV, as illustrated in Fig.3.

2.8 (n,p) and (n,n′p) Cross Sections

(1) (n,p) cross sections

One set of experimental data[76] for ^{63}Cu and ^{65}Cu near 14 MeV was abandoned, because the data for ^{65}Cu is about 50% higher than the others [68, 77, 78].

The calculated (n,p) cross section for ^{65}Cu are in agreement with available experimental data[68,77~79].

The evaluated (n,p) cross section was teken from the calculation, and are in agreement with which obtained by subtracting the evaluated (n,d) cross section from the data of Colli[80] at 14.1 MeV.

(2) (n,n′p) cross sections

The recommented (n,n′p) cross section was taken from model calculation, and normalized to a new measured data[82] which is almost the average value of the two sets of discrepance data[80, 81] at 14.1 MeV.

2.9 (n,α) and (n,n′α) Cross Sections

(1) (n,α) cross sections

The cross sections for the natural element were obtained from evaluated cross sections for the isotopes.

The (n,α) cross section for ^{63}Cu was taken from the data of Winkler[83] below 8 MeV, above that the exciting curve of Paulsen[84] was normalized to the weighted average value of the data[85~88].

The (n,α) cross section for ^{65}Cu was taken from the model calculation.

(2) (n,n′α) cross sections

There are only a few experimental results for ^{65}Cu. The model calculation are in agreement with the experimental data[89, 90], and are somewhat higher than that of Santry[79]. The (n,n′α) cross section were obtained from the model calculation.

2.10 (n, ^3He) and (n,n′ ^3He) Cross Sections

There are no experimental data for these reactions, and the calculated results are very small. Therefore, these processes was ignored.

2.11 (n,t) and (n,n′t) Cross Sections

The (n,t) cross section was taken from the calculation, due to lack of experimental data.

The (n,n′t) cross sections was ignored, due to lack of experimental data and very small calculated values.

2.12 (n,d) and (n,n′d) Cross Sections

There are only one set of experimental data[91] at 14.8 MeV. It is in agreement with the calculation result. Therefore, the calculation results were used.

The (n,n′d) cross section was directly taken from the calculation results, due to lack of experimental data.

3 ANGULAR DISTRIBUTION OF SECONDARY NEUTRON

The angular distributions of secondary neutrons, from elastic scattering and inelastic scattering to discrete levels, were given by Legendre coefficients in the center–of–mass system. The angular distributions of secondary neutrons for (n,n′ continuum), (n,2n), (n,3n), (n,n′p) (n,n′d) and (n,n′α) process were assumed isotropic.

The experimental data of elastic scattering angular distributions scattered in the energy range from 0.05 to16 MeV. For adjusting optical potential parameters, the following data were used: from 0.05 to 1.5 MeV, Lane[92] and Smith[26]; from 1.7 to 10 MeV, Tsukada[93] Holmqvist[30], Galloway[94], Bucher[95], Galloway[96],Gorlov[97], Anikin[98, 99]. and Guenther[12]; from 11 to 16.1 MeV, Bucher[95] Coon[27], Anderson[100], Begum[101] and Li Jingde[102].

The angular distributions of elastic scattering neutrons were taken from the calculation. They are in agreement with the experimental data, as illustrated in Fig. 6.

4 THE ENERGY DISTRIBUTION OF SECONDARY NEU TRON

The energy distributions of secondary neutrons from (n,n′ continuum), (n,2n), (n,3n) (n,n′p) (n,n′d) and (n,n′α) process were taken from the calculations.

5 SUMMARY

The recommended total, non–elastic, (n,γ) and (n,2n) cross sections were completely based on the experimental data. The evaluated total inelastic cross section and charged particle emition cross section are in agreement with the available experimental data.

The present evaluation is considerably different from that of CENDL–1, due to new experimental data and improved MUP–2 code, as the following:

(1) Nonelastic scattering cross sections of the present evaluation is about 14% higher than CENDL–1 between 0.85 to 2 MeV due to use of new experimental data.
(2) Below 13.5 MeV, the present (n,2n) cross sections become about 25% less than that of CENDL–1 due to use of Frehaut's data.
(3) The present evaluated particle emition cross sections are comparable with experimental data, and considerably different from CENDL–1, due to using improved MUP–2 code.

The present evaluated cross section are essentially in agreement with ENDF / B–6 and JENDL–3, but there are following differences :

(1) The present total cross sections are slightly higher than ENDF / B–5 and ENDF / B–6 in the energy region from 0.2 to 2 MeV.
(2) The evaluated non–elastic cross section of ENDF / B–5 from 3 to 12 MeV and that of ENDF / B–6 above 17 MeV are somewhat higher.
(3) The recommended (n,2n) cross sections of ENDF / B–6 are somewhat lower above 17 MeV.
(4) The evaluated (n,γ) cross section of ENDF / B–6 appears somewhat higher, and that of JENDL–3 appears lower above 3 MeV.

In order to improve the present evaluation, new measured data are needed, these data include :

(1) measurements of the charged particle emition cross sections for natural element.

(2) measurements of precise differential elastic scattering from 4 to 8 MeV.

ACKNOWLEDGMENTS

The authors are very grateful to Profs. Liang Qichang, Liu Tingjin for their much help in this work, in the meantime, also the same to Prof. Cai Dunjiu et al. of CNDC.

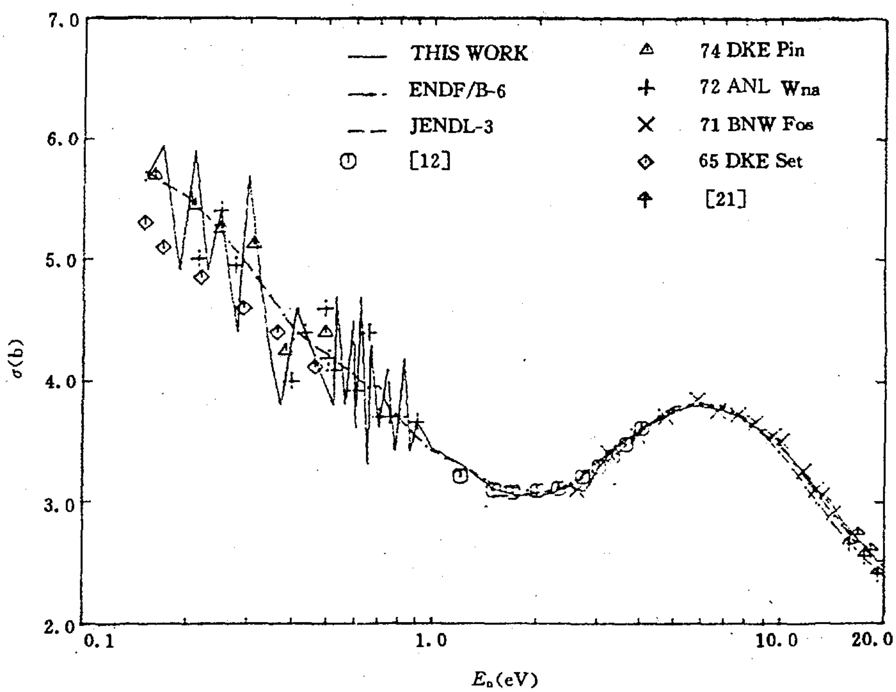

Fig. 1 Neutron total cross section of Cu

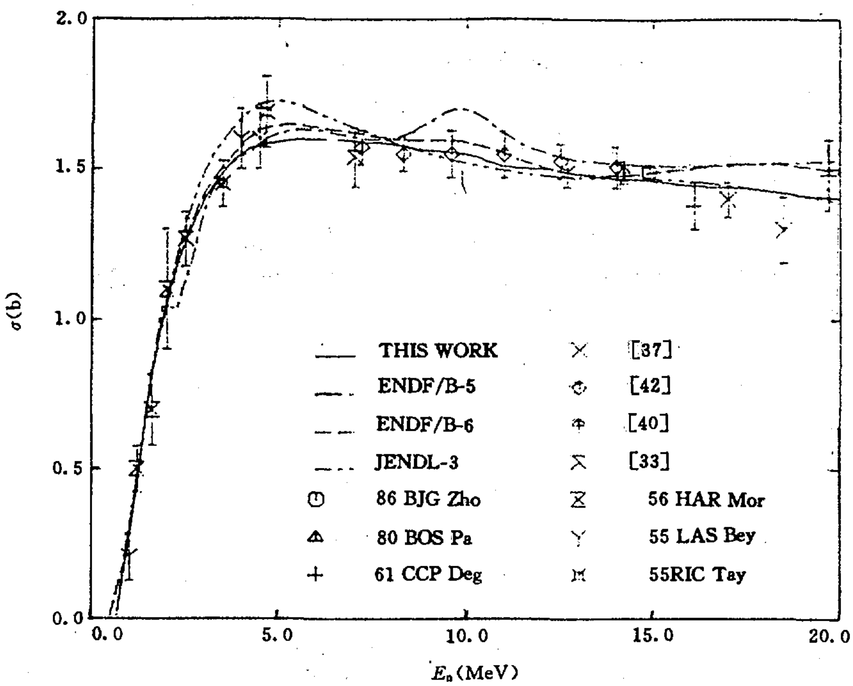

Fig. 2 Neutron nonelastic cross section of Cu

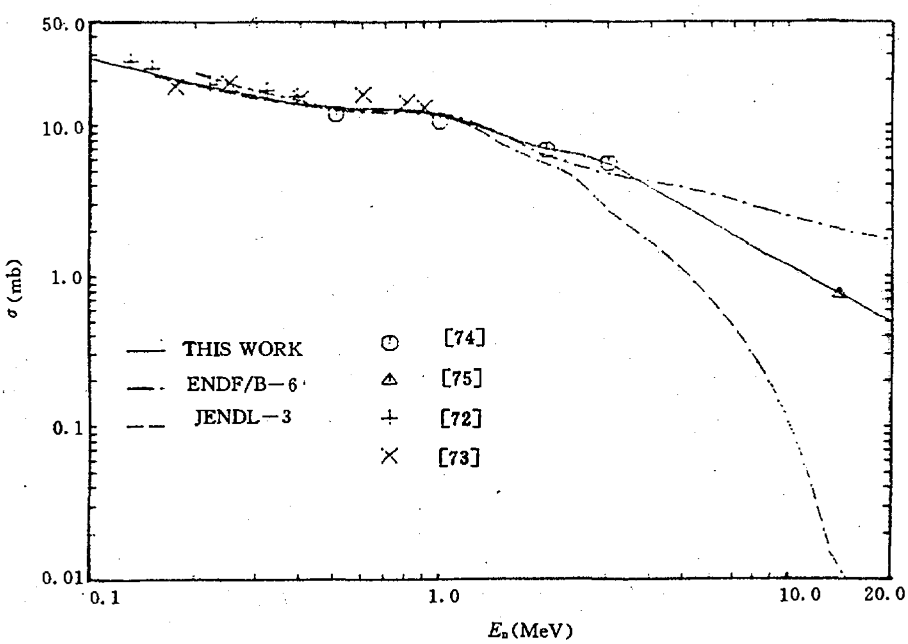

Fig. 3 Neutron capture cross section of Cu

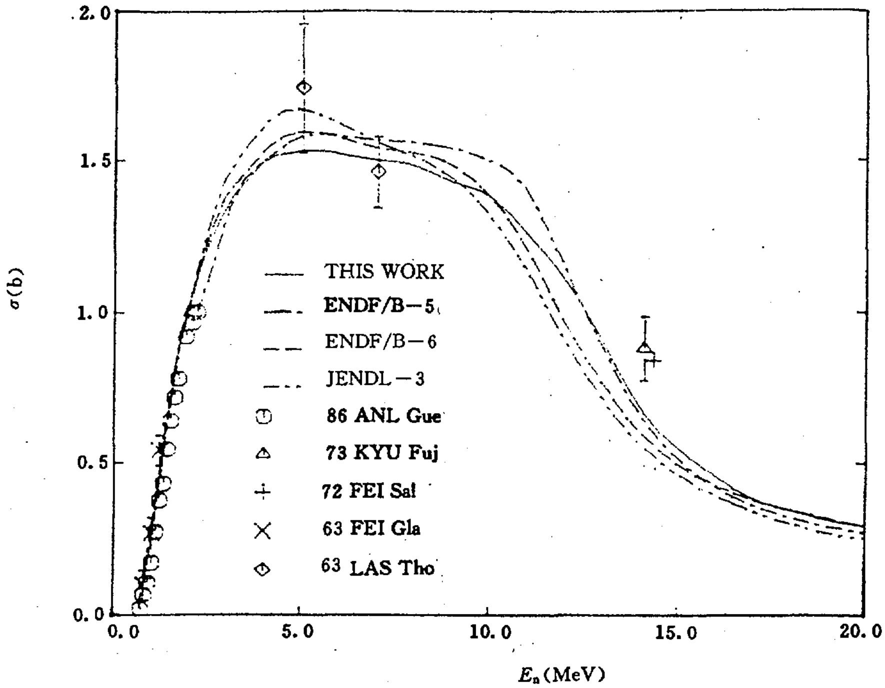

Fig. 4 Neutron total inelastic cross section of Cu

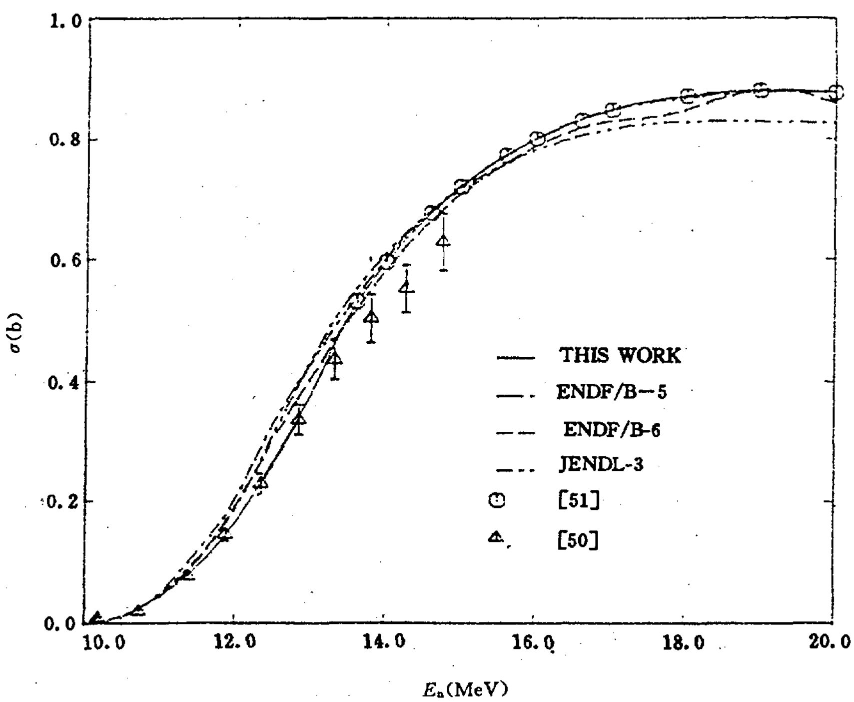

Fig. 5 (n,2n) cross section of Cu

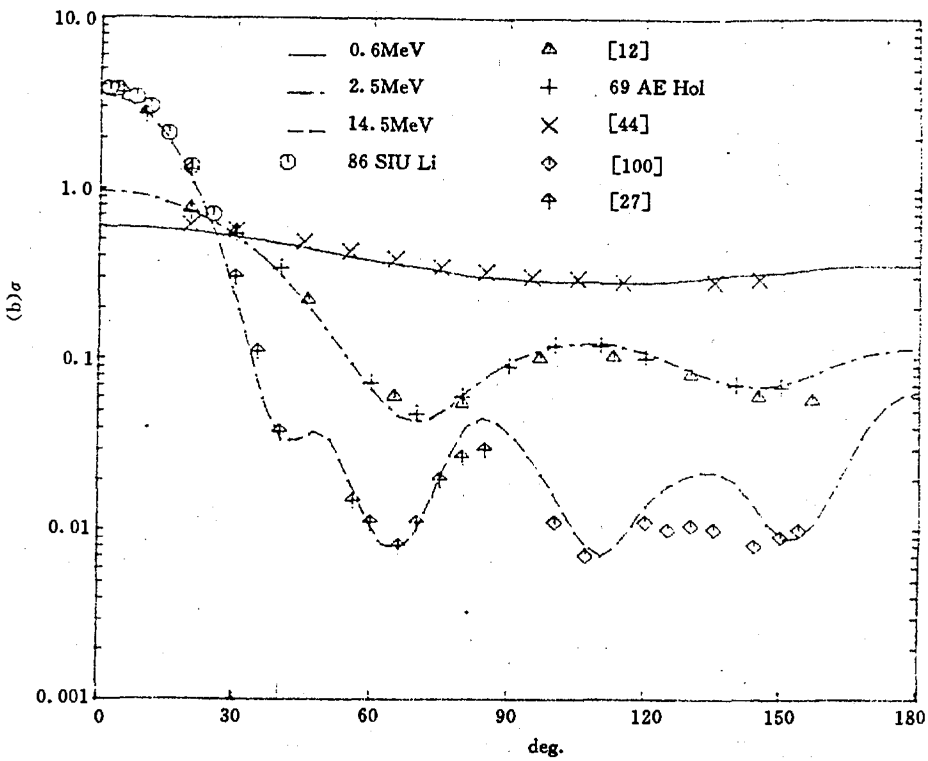

Fig. 6 Differential elastic scattering cross section of Cu

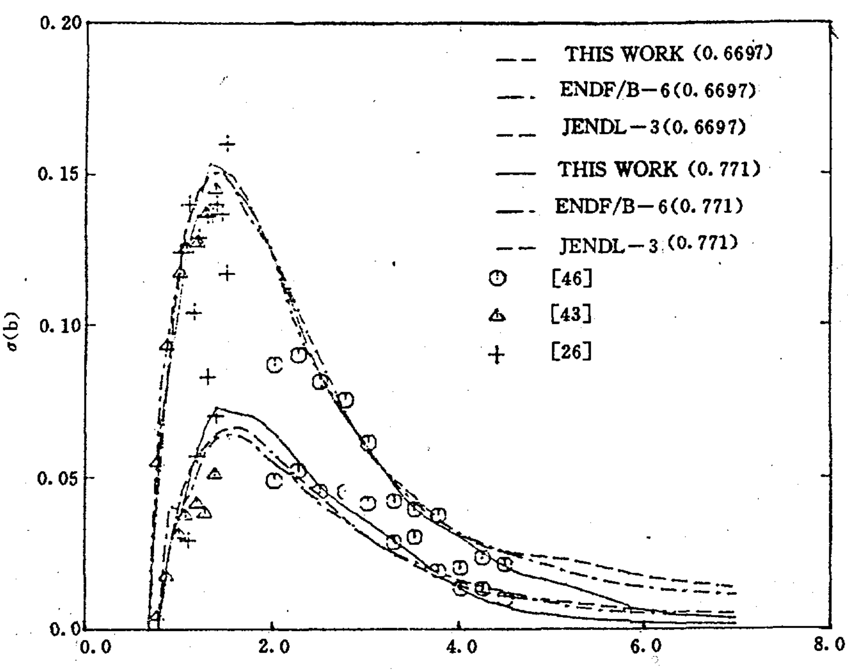

Fig. 7 Inelastic scattering to 0.6697 MeV, 0.7710 MeV levels cross sections

REFERENCES

[1] Yu Ziqiang, Cai Chonghai et al., Thoretical calculation program MUP–2 for medium and heavy nuclei, inter report (1986)
[2] Liu Shirui, Chinese Evaluated Nuclear Data Library, Version 1 (CENDL–1), CNDC–85010 p. 189(1986)
[3] Zhou Hongmo, Yu Ziqiang et al., Auto–parameter ajusting optical model calculation program AUJP, inter report (1978)
[4] Xu Dingan , Theoretical Calculation of the Neutron Reaction Data for Cu Induced by $E_n < 20$ MeV Neutron, CNDC–85011, p. 105(1986)
[5] R. L. Auble, Nuclear Data Sheets, 28, 559(1979)
[6] N. J. Ward et al., Nuclear Data Sheets, 47, 135(1986)
[7] Su Zongdi et al., Chinese Journal of Nuclear Physics Vol. 8, No. 3, 199(1986)
[8] Hetrick Fu Larson, ENDF / B–6 (1990)
[9] J. B. Garg et al., EANDC (US)–54, (1964)
[10] J. F. Whalen et al., ANL–7710, 12(1971)
[11] W. P. Poenitz et al., ANL–NDM–80(1983)
[12] P. Guenther et al., Nucl. Phys., A, 448, 280(1986)
[13] D. W. Miller et al., Phys. Rev., 88, 83(1952)
[14] J. H. Coon et al., Phys. Rev., 88, 562(1952)
[15] N. Nereson et al., Phys. Rev., 89, 775(1953)
[16] J. C. Albergotti et al., Nucl. Phys., 82, 652(1966)
[17] R. B. Day et al., Phys. Rev., 92, 358(1953)
[18] M. Mazari et al., Phys. Rev., 100, 972(1955)
[19] W. K. Robinson et al., J. Phys., 37, 482(1969)
[20] J. M. Peterson et al., Phys. Rev., 120, 521(1960)
[21] P. H. Bowen et al., Nucl. Phys., 22, 640(1961)
[22] D. G. Foster et al., Phys. Rev., C3, 576(1971)
[23] J. R. Morales et al., P. INDC (CHL)–002(1987)
[24] C. Y. Fu, ORNL–TM–8283 (ENDF / B–5 Description) (1982)
[25] A. Langsdorf jr et al., Phys. Rev., 107, 1077(1957)
[26] A. B. Smith et al., Phys. Rev., B, 135, 76(1964)
[27] J. H. Coon et al., Phys. Rev., 111, 250(1958)
[28] El–Kadi et al., Nucl. Phys., A390, 509(1982)
[29] Kinney et al., ORNL–4908 (1974)
[30] B. Holmqvist et al., AE–430 (1971)
[31] Pal Bharati, Nucl. Instru. Metherds, 171, 347(1980)
[32] Zhong Wenguang et al., Chinese Journal of Nucl. Phys., 8(3), 251(1986)
[33] J. R. Beyster et al., Phys. Rev., 104, 1319(1956)

[34] J. R. Beyster et al., Phys. Rev., 98, 600(1955)
[35] H. L. Taylor et al., Phys. Rev., 100, 174(1955)
[36] V. G. Degtyarev et al., Atomnaja Energija, 11, 397(1961)
[37] T. W. Bonner et al., Phys. Rev., 113, 1088(1959)
[38] Lu Zuyin, Chinese Journal of Atomic Energy, 6, 480(1964)
[39] A. Chatterjee et al., Phys. Rev., 161 (4), 1181(1967)
[40] M. H. Macgregor et al., Phys. Rev., 108, 726(1957)
[41] M. H. Macgregor et al., Phys. Rev., 111, 1155(1958)
[42] W. P. Ball et al., Phys. Rev., 110, 1392(1958)
[43] B. Holmqvist et al., AE–150 (1964)
[44] A. S. Smith et al., Phys. Rev., B135, 76(1964)
[45] H. Glazkov et al., Atomnaja Energija, 15, 416(1963)
[46] E. Almen–Ramstrom AE–503 (1975)
[47] W. E. Kinney et al., ORNL–4908 (1974)
[48] D. Thomson, Phys. Rev., 129, 1649(1963)
[49] I. Fujita et al., Journal of Nuclear science and Technology, 9, 301(1973)
[50] J. Frehaut et al., Symposium on neutron cross section from 10~ 15 MeV, BNL, Upton, N. Y. 399(1980)
[51] Zhou youpu, Evaluation of reacted cross sections, Inter repot hsj–81157 (bp) (1982)
[52] R. N. Glover et al., Nucl. Phys., 29, 309(1962)
[53] H. Liskien et al., J. Nucl. Energ., Section A / B, 19, 73(1965)
[54] M. Bormann et al., Z. Physik, 166, 477(1962)
[55] J. M. Ferguson et al., Phys. Rev., 118, 228(1960)
[56] M. Bormann et al., Nucl. Phys., A130, 195(1969)
[57] R. A. Jargis, J. Phys., G4, 445(1978)
[58] D. R. Koehler et al., AOMC–RR–62–1(1962)
[59] J. L. Fowler et al., Phys. Rev., 77, 787(1950)
[60] L. A. Rayburn, Phys. Rev., 130, 731(1963)
[61] F. GHanbari et al., Annals of Nucl. Energy, 13, 301(1986)
[62] H. K. Vonach et al., 2nd Conf. on Neutron Cross Section and Techn., Washington V2, D. CH–7 Mark, P. 885(1968)
[63] W. Mannkart et al., Z. Physik, Sect., A272, 279(1975)
[64] R. J. Prestwood et al., Phys. Rev., 121, 1438(1961)
[65] D. C. Santry et al., Can. J. Phys., 44, 1183(1966)
[66] A. Paulson et al., Nukleonik, 7, 117(1965)
[67] M. Bormann et al., Z. Physik, 174, 1(1963)
[68] J. W. Meadows et al., Inter. Conf. on Nucl. Data for Basic and Applied Science, Santa Fe, New Mexico, 1, 123(AD01) (1985)
[69] G. Winker, Annals of Nucl. Energy., 10 (11), 601(1983)

[70] J. Cstkai, Int. Conf. on Nucl. Data for Science and Technology, Antwerp, 414 Sep.(1982)
[71] P. N. Ngoc et al., 5th All Union conference on neutron Physcis, Kiev, 1,259, Sep. (1980)
[72] U. Ya. Stavisskij et al., Atomnaja Energija, 15 (4), 323(1963)
[73] B. C. Diven et al., Phys. Rev., 120, 556(1960)
[74] J. Voignoer et al., Nncl. Scie. and Eng., 93, 43(1986)
[75] Budnar et al., INDC(YUG)−6 (1979)
[76] S. M. Qaim et al., Nucl. Phys., A283, 269(1977)
[77] P. Pepelnik et al., NEANDC(E)−262U (5), 32(1985)
[78] Gupta et al., Pramana, (India) 24, 637(1985)
[79] D. C. Santry et al., Can. J. Phys., 44, 1183(1965)
[80] L. Colli et al., Nuovo Cimento, (Italy) 13, 730(1959)
[81] D. L. Allan et al., Nucl. Phys., 10, 348(1959)
[82] Joensson et al., Arkiv for Fysik, 39, 295(1969)
[83] G. Winkler et al., Nucl. Scie. and Eng., 76, 30(1980)
[84] A. Paulsen et al., Nukleonik, 10, 91(1967)
[85] L. R. Greenwood, DOE−ER−0046−21, 15(1985)
[86] O. Y. Artemev et al., Atomnaja Energija, 49 (3), 195(1980)
[87] Garuska et al., INR−1871 / I / PL / A, 15(1980)
[88] G. Winkler et al., Nucl. Scie. and Eng., 67 (2), 260(1978)
[89] Ryves et al., Metrologia, 14 (3), 127(1978)
[90] Qaim et al., EUR−5182E, 939(1974)
[91] S. M. Grimes et al., Phys. Rev., C19, 2127(1979)
[92] R. O. Lane et al., Ann. Phys., 12, 135(1961)
[93] K. Tsukada et al., 2nd IAEA Conf. on Nucl. Data for Reactors, Helsiki, Finland, 2, 305 June (1970)
[94] R. B. Galloway et al., Nucl. Phys., A318, 173(1979)
[95] W. Bucher et al., Phys. Lett., B58, 277(1975)
[96] R. B. Galloway et al., Nucl. Phys., A212, 182(1973)
[97] G. V. Gorlov et al., Jadernaja Fizika, 8(6), 1086(1968)
[98] G. V. Anikin et al., Jadernaja Fizika, 12 (6), 1121(1970)
[99] Anikin et al., Atomnaja Energija, 60, 54(1986)
[100] J. D. Anderson et al., Phys. Rev., 115, 1010(1959)
[101] A. Begum et al., Nucl. Phys., A332, 349(1979)
[102] Li Jingde et al., Chinese J. Nucl. Phys., 10, 46(1988)
[103] N. Yamamuro, T. Kawakita, JENDL−3 (1990)