Evaluation of Complete Neutron Nuclear Data for ^{206}Pb

Ma Gonggui Luo Xiaobing

(Institute of Nuclear Science and Technology, Sichuan University, 610064)

Abstract

The following neutron data are given for ^{206}Pb in the energy range from 10^{-5} eV to 20.0 MeV. The evaluated neutron nuclear data included total, elastic, noelastic, total inelastic, inelastic cross sections to 15 discrete levels, inelastic continuum, (n,2n), (n,3n), (n,n'p), (n,p), (n,t), (n,α) and capture cross sections. The angular distributions of elastic and discrete in elastic scattering neutron, the double differential cross sections (DDCS) of secondary neutron, the gamma-ray production data and the resonance parameters are also included. The evaluated data will be adopted into CENDL-3 in ENDF/B-6 format.

Introduction

Lead is a very important structure material in nuclear fusion engineering. Its complete neutron nuclear data were evaluated based on both experimental data measured up to 1999 and theoretical calculated data with program UNF[1]. The evaluated data will be adopted into CENDL-3 in ENDF/B-6 format[MAT=3822] and will be utilized in the various fields of nuclear engineering.

The level scheme are given in Table 1, which was selected from the new data presented in Ref.[2]. The binding energy of emitted final particle are given in Table 2.

Table 1 Inelastic discrete levels (Abundance 24.1%) for ^{206}Pb

E_l / MeV	J^π	E_l / MeV	J^π	E_l / MeV	J^π	E_l / MeV	J^π
0.0	0^+	1.4668	2^+	1.9977	4^+	2.3790	4^+
0.8031	2^+	1.6840	4^+	2.1479	2^+	2.3842	6^-
1.1660	0^+	1.7035	1^+	2.2002	7^-	2.3914	4^+
1.3405	3^+	1.7842	2^+	2.3150	0^+	2.4240	2^+

Table 2. Binding energy of emitted final particle(MeV) ^{206}Pb

reaction channels	n, γ n,2n	n,n′ n,n′p	n,p n,n′α	n,α n,pn′	n,^{3}He n,2p	n,d n, αn′	n,t n,3n
	0.0	6.7414	7.4922	−0.3956	12.6913	11.7715	13.0546
	8.0809	7.2547	−1.1445	6.5039	7.2500	5.9925	6.73396

1 Resonance Parameter

The resolved resonance parameters were given from 10^{-5} eV to 0.9 MeV, taken from ENDF/B-6 data. Thermal cross sections of (n,tot), (n,n) and (n,γ) reactions are 11.266 b, 11.237 b and 29.0 mb, respectively.

2 Neutron Cross Section

The comparison of experimental data with evaluated ones are shown in Figs. 1~10. It can be seen that the present evaluation is in agreement with the experimental data.

2.1 Total Cross Section

Above the resolved resonance region, there are still a energy range (0.9~5.0 MeV) with some small structure and then smooth energy range (5.0~20.0 MeV). In the energy range from 0.9 to 20.0 MeV, the data were mainly taken from corresponding experimental data of Horen, Benetakij, Foster Jr, Carlson, Bukarevich and Miller[3~8]. A plot of these data and the evaluated data is shown in Fig. 1.

2.2 Elastic Scattering Cross Section

Above the resolved resonance region, the elastic scattering cross section was obtained by subtracting the sum of cross sections of all the non-elastic processes from the total cross section. In general, the agreement between the evaluated cross section and the available experimental data of Abdel, Elemad, Holmqvist, Bostrorn, Landan and Walt[9-14] is good, as shown in Fig. 2.

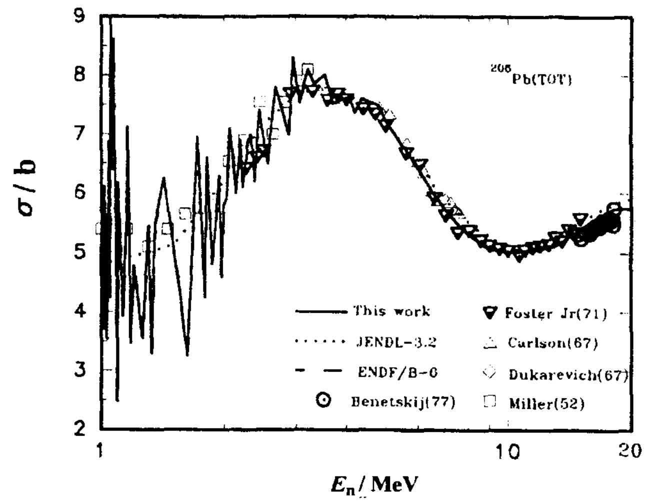

Fig. 1 Total cross section for ^{206}Pb

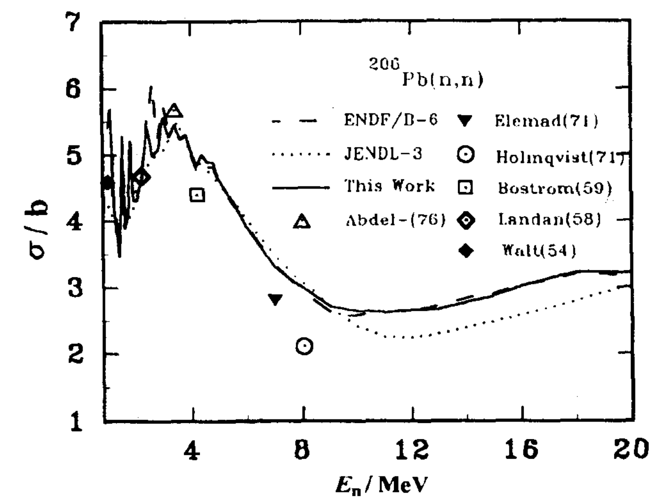

Fig. 2 Elastic cross section for ^{206}Pb

2.3 Nonelastic Scattering Cross Section

This cross section is the sum of all cross sections of (n,n′), (n,2n), (n,3n), (n,n′p), (n, γ), (n,p), (n,t) and (n, α) reactions. The agreement between the evaluated cross section and the available experimental data of Haas[15] and Walt is good, as shown in Fig. 3.

2.4 Total Inelastic Cross Section

The calculated results were adopted and normalized to the experimental data by Thomson[16] at 7.0 MeV (see Fig. 4).

2.5 Inelastic Cross Section to the Discrete Levels and the Continuum

The inelastic scattering cross section to 15 discrete levels were calculated by using UNF code. For 0.8031, 1.166, 1.3405 and 1.4668 MeV levels, there are some the experimental data measured by Almen-Ra., Konobeevskij and Cranberg[17~19]. The model calculated results were normalized to these measured data. A plot of these data and the evaluated data is shown in Fig. 4-1 and 4-2. For 1.684~2.4359 MeV levels, respectively.

The continuum part was obtained by subtracting the cross section of inelastic scatteringe to 15 discrete levels from the total inelastic.

2.6 (n,2n) and (n,3n) Cross Section

For (n,2n) reaction, the experimental data were measured by Frehaut[20] in the energy range from 8.44 to 14.76 MeV. The evaluated data were obtained by fitting experimental data with spline function. Above 14.76 MeV, calculated data were nomalized to fitting value of the experimental data at 14.0 MeV (see Fig. 5).

For (n,3n) reaction, the data were taken from the calculated results(see Fig. 6).

2.7 (n,p) and (n,n'p) Cross Section

For (n,p) reaction, the experimental datum were measured by Belovitckij[21] at 14.5 MeV. The calculated data was normalized to this datum (see Fig. 7).

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

2.8 (n, α) Cross Section

The model calculated results were normalized to the experimental data by Filatenkov, Grallert, Maslov and Yu-Wen Yu[22~25] at 14.5 MeV (see Fig. 8).

2.9 Capture Cross Section

The evaluated data of capture cross section from 10^{-5} eV to 0.9 MeV were given by the resonance parameters and the background. From this energy up to 20.0 MeV, the cross section was taken from the model calculation due to lack of the experimental data (see Fig. 9).

3 Secondary Neutron Angular Distributions

For elastic scattering, there are some experimental data measured by Schreder, Ferrer, Guenther[26~28]. The calculated results are in good agreement with the experimental data and used as recommended data (see Fig. 10-1, 10-2).

The discrete inelastic angular distributions (MT=51~65) were obtained from theoretical calculation results. the angular distributions for (n,2n),(n,3n),(n,n'p) and continuum inelastic (MT = 16, 17, 28, 91) were assumed to be isotropic.

4 The Double Differential Cross Section and γ-Ray Production Data

The double differential emission cross section (MF=6, MT=16, 17, 28, 91, 103, 105, 107) and γ-ray production data (MF=12, 13, 14, 15) were taken from the calculation results (see Fig. 11).

5 Theoretical Calculation

UNF code, including optical model, Hauser-Feshbach statistical model and exciton model, was used to calculate the data for files 3, 4, 6, 12, 13, 14, 15, which requires following input parameters: optical potential, level density, giant dipole resonance[29] and nuclear level scheme. These patameters were adjusted on the basis of experimental data concerned in the neutron energy range from 1 keV to 20 MeV.

An automatically adjusted optical potential code (APOM)[30] was used for searching a set of optimum neutron spherical optical potential parameters. DWUCK code was used to calculate the direct inelastic scattering cross sectiona for excited levels as the input data of UNF.

5.1 Optical Model, Level Density and Giant Dipole Resonance Parameters

Optical potential parameters used are given in Table 3. The level density and pair correction parameters are given in Table 4. The giant dipole resonance parameters are shown in Table 5, the symbols CSG, EE and GG are the peak cross section, resonance energy and full width at half maximum, respectively.

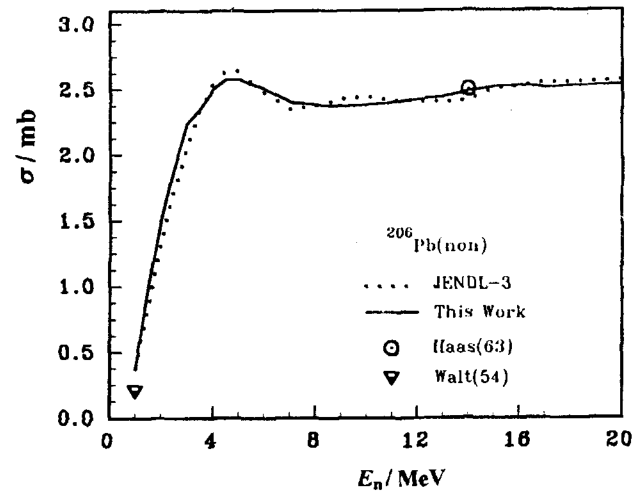

Fig. 3 Non-elastic cross section for ^{206}Pb

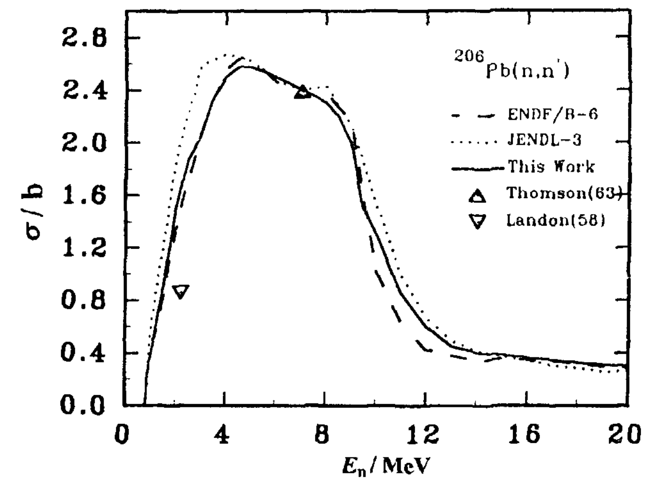

Fig. 4 Inelastic cross section for ^{206}Pb

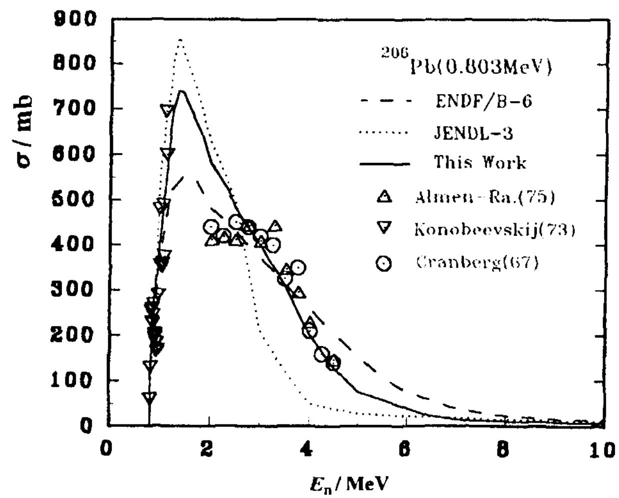

Fig. 4-1 Inelastic cross section for ^{206}Pb excited states

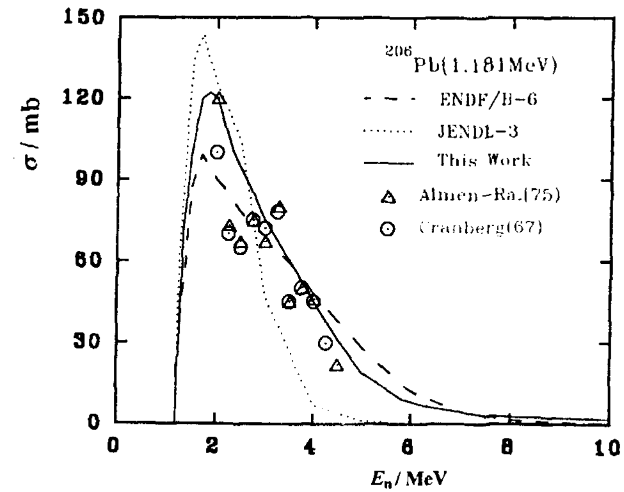

Fig. 4-2 Inelastic cross section for ^{206}Pb excited states

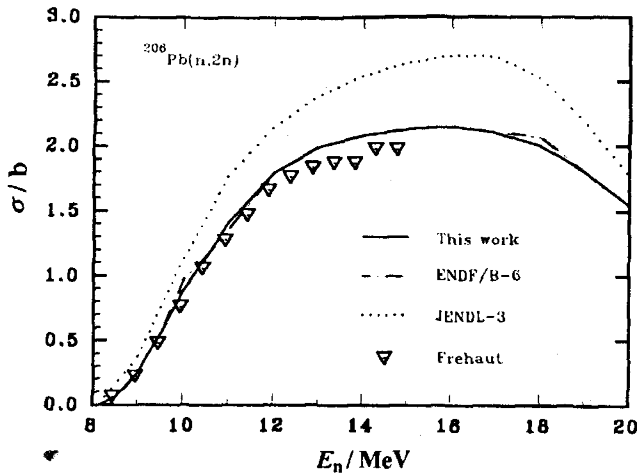

Fig. 5 (n,2n) cross section for ^{206}Pb

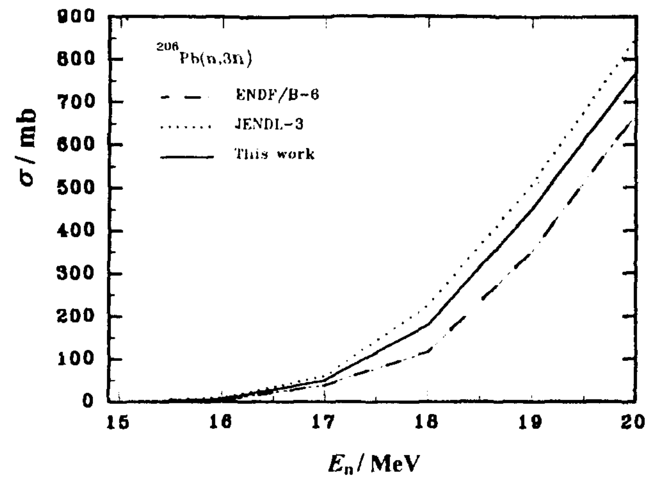

Fig. 6 (n,3n) cross section for ^{206}Pb

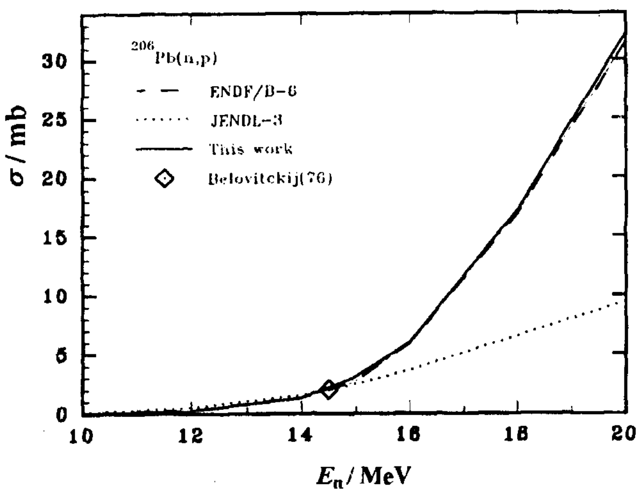

Fig. 7 (n,p) cross section for ^{206}Pb

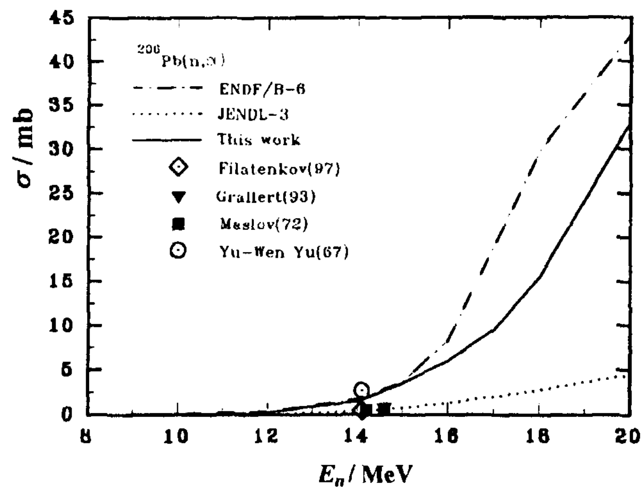

Fig. 8 (n, α) cross section for ^{206}Pb

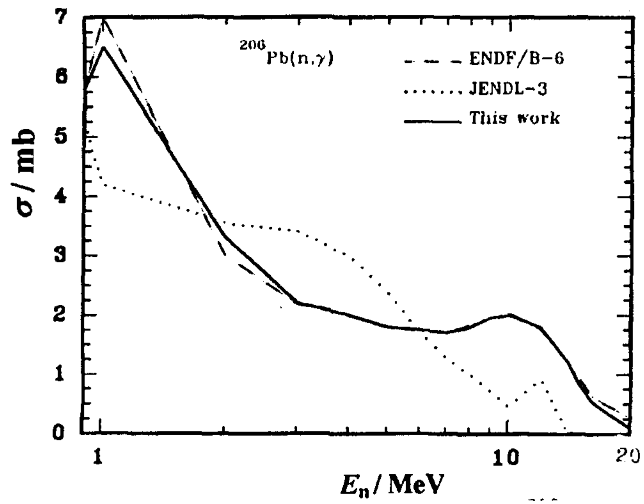

Fig. 9 (n, γ) cross section for ^{206}Pb

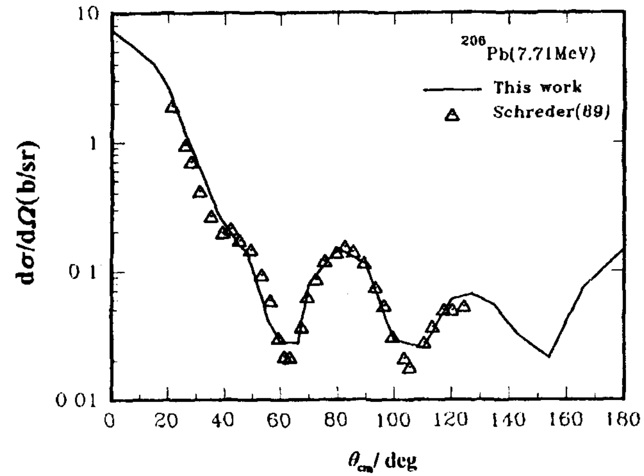

Fig. 10-1 Elastic scatter angular distribution of ^{206}Pb

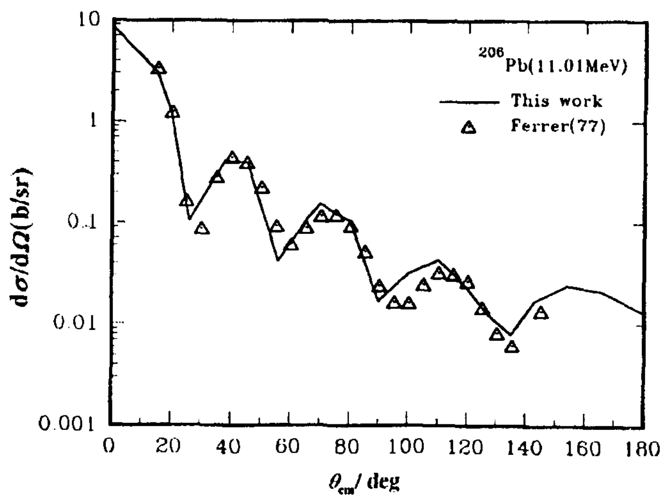

Fig. 10-2 Elastic scatter angular distribution of ^{206}Pb

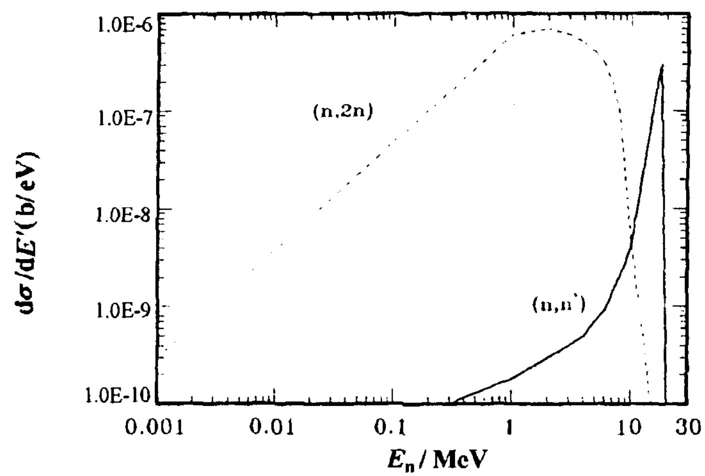

Fig. 11 (n,2n) and (n,n') continuous neutron spectra for ^{206}Pb at 20.0 MeV

5.2 Direct Inelastic Calculation

The direct elastic scattering to ground state and direct inelastic scattering to excited states were calculated with code DWUCK at 19 energies by Shen Qingbiao in the required input format of UNF.

Table 3 Optical model potential parameters*

	Depth/MeV		Radius/fm	Diffuseness/fm
Neutron	V_o=46.945	W_o=3.805	X_r=1.24715	A_r=0.64
	V_1=-0.232	W_1=0.4151	X_s=1.24	A_s=0.48
	V_2=-0.00	W_2= 0.00	X_v=1.24	A_v=0.48
	V_3=0.00	U_o=-0.0	X_{so}=1.24715	A_{so}=0.64
	V_4=0.0	U_1=0.0	X_c=1.22	
	V_{so}=6.0	U_2=0.0		

* Note: $V_r(E)=V_o+V_1E+V_2E(2)+V_3(A-2Z)/A+V_4Z/A(1/3)$;
$W_s(E)=W_o+W_1E+W_2(A-2Z)/A$;
$U_v(E)=U_o+U_1E+U_2E(2)$.

Table 4 Level density parameters and pair correction values of 11 residual nuclei*

	n, γ	n,n'	n,p	n, α	n, ^{3}He	n,d	n,t	n,2n	n,n'α	n,2p	n,3n
L	4.57	6.25	4.18	8.75	7.28	5.86	7.34	7.73	11.03	5.62	10.05
P	0.60	1.21	0.0	0.78	1.14	0.61	0.25	0.85	1.25	0.53	1.32

* Note: $L=[0.00880(s(z)+s(n))+Q_b]A$; $P=p(n)+P(z)$;
Q_b=0.142 or 0.12 (spherical or deformation).

Table 5 The 11 giant dipole resonance parameters(single peak)

CSG/b	0.481, 0.541, 0.541, 0.645, 0.541, 0.481, 0.541, 0.481, 0.645, 0.541, 0.481,
EE/MeV	13.56, 13.72, 13.72, 13.63, 13.72, 13.56, 13.72, 13.56, 13.63, 13.72, 13.56,
GG/MeV	3.96, 4.61, 4.61, 3.94, 4.61, 3.96, 4.61, 3.96, 3.94, 4.61, 3.96,

6 Concluding Remarks

Due to the new experimental data have been available for recent years, the evaluated data have been considerably improved, especially for cross sections of total, (n,2n), elastic angular distributions and inelastic scattering to some discrete levels.

Acknowledgments

The authors, would like to thank Profs. Liu Tingjin and Liang Qichang for their helps with this work, also to thank Profs. Shen Qingbiao for his helps with the DWUCK code calculation.

References

[1] Zhang Jingshang. Nucl. Sci. Eng., 114, 55-63 (1993)

[2] Nuclear Data Sheets, 61,93,1990; 75,678,1995; 71,88,1994; 50,719,1987; 43,383,1984

[3] D.J.Horen et al., Phys. Rev., C20,478(1979)

[4] R.E.Benetskij et al., 77Kiev 2,44(1977)

[5] D.G.Foster Jr et al., Phys. Rev., C3,576(1971)

[6] A.D.Carlson et al., Phys. Rev., 158,1142(1967)

[7] Ju.V.Dukarevich et al., Nucl. Phys., A92(2),433(1967)

[8] D.W.Miller et al., Phys. Rev., 88,83(1952)

[9] M.Abdel-Harith et al., ZFK-315,12(1976)

[10] M.A.Etemad et al., Atomnaya Energiya, 482(1973)

[11] B.Holmqvist et al., Atomnaya Energiya, 430(1971)

[12] H.H.Landon et al., Phys. Rev., 112,1192(1958)

[13] M.Walt et al., Phys. Rev., 93,1062(1954)

[14] N.A.Bostrom et al., WADC-TN-59-107(1959)

[15] G.M.Haas et al., Phys. Rev., 132,1211(1963)

[16] Thomson et al., Phys. Rev., 129,1649(1963)

[17] E.Almen-Ramstrom et al., Atomnaya Energiya, 503(1975)

[18] E.S.Konobeevskij et al., IZV 37(8),1714(1973); EXFOR 40215

[19] L.Cranberg et al., Phys. Rev., 159, 969(1967)

[20] J. Frehaut et al., 80BNL, 399(1980)

[21] G.E.Belovitckij et al., 75Kiev 4,209(1976)

[22] A.A.Filatenkov et al., INDC(CCP)-402(1997)

[23] A.Grallert et al., INDC(NNDS)-286,131(1993)

[24] G.N. Maslov et al., YK-9,50(1972)

[25] Yu-Wen Yu et al., Nucl. Phys., A98,451(1967)

[26] G.Schreder et al., Phys. Rev., C39,1768(1989)

[27] J.C.Ferrer et al., Nucl. Phys., A275,325(1977)

[28] P.T.Guenther et al., Nucl. Sci. Eng., 65,174(1978)

[29] Zhuang Youxiang et al., Chinese Physics, 8, 721-727(1988)

[30] Shen Qingbiao et al., CNDP, No.7, 43(1993)

The Experimental Data Evaluation for Natural Hf and Its Isotopes

Wang Tingtai
(Zhengzhou University, 450052)
Liu Tingjin
(China Nuclear Data Center, CIAE, 102413)
Liu Jianfeng
(Zhengzhou University, 450052)

Most of the experimental data were retrieved from EXFOR experimental neutron library, the data for natural Hf and its isotopes were evaluated in the incident neutron energy region up to 20 MeV.

1 General Method of the Evaluation

1.1 The Retrieval of Experimental Data in EXFOR Format

The experimental data were retrieved directly from EXFOR master experimental neutron data library. The retrieval can be done according to the