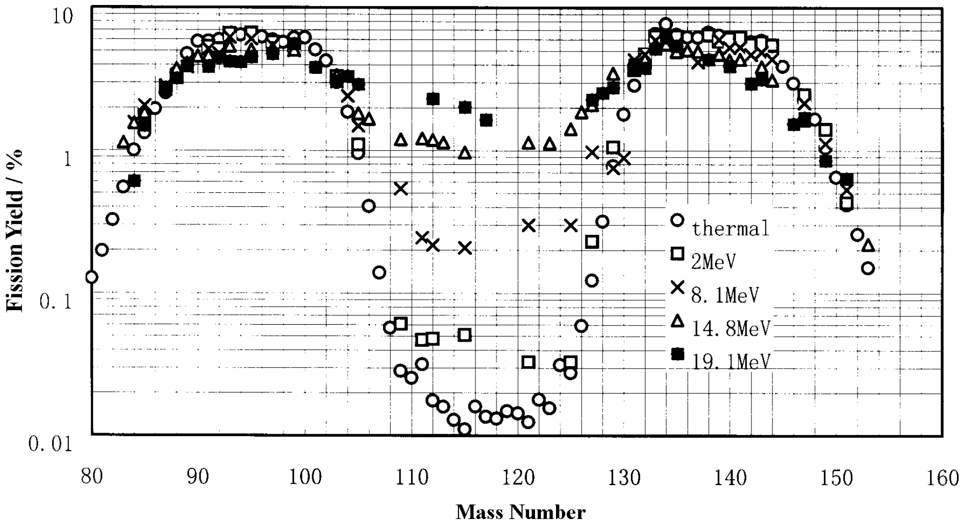

Fig. 1 Chain yields from monoenergetic-neutron-induced fission of ^{235}U

Evaluation of Complete Neutron Nuclear Data for $^{204,207}Pb$

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【**abstract**】*The complete neutron data were evaluated in the energy range from 10^{-5} eV to 20.0 MeV for ^{204}Pb and ^{207}Pb. The data include total, elastic, nonelastic, total inelastic, inelastic to 11 and 16 discrete levels, inelastic to continuum states, (n,2n), (n,3n), (n,n'p), (n,p), (n,t), (n,α) and capture cross sections. The angular distributions of secondary neutron, the double differential cross sections (DDCS), the gamma-ray production data and the resonance parameters are also included. The evaluated data were adopted into CENDL-3 in ENDF/B-6 format.*

Introduction

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

For natural lead, the data of all reaction channels are in very good agreement with the sum of the all isotopes′ data weighted by the abundance in the error range.

The level scheme is given in Table 1, selected from new data of Ref. [2].

Table 1 Levels sheme of $^{204,207}Pb$

^{204}Pb(1.4%)		^{207}Pb(22.1%)	
E_1 / MeV	J^{π}	E_1 / MeV	J^{π}
0.0	0^+	0.0	0.5^-
0.8992	2^+	0.5698	2.5^-
1.2739	4^+	0.8977	1.5^-
1.3514	2^+	1.6334	6.5^+
1.5631	4^+	2.3400	3.5^-
1.5836	0^+	2.6232	2.5^+
1.6047	3^+	2.6624	3.5^+
1.6650	2^+	2.7030	3.5^+
1.6820	1^+	2.7280	4.5^+
1.7300	0^+	3.2230	5.5^+
1.7619	1^-	3.3000	0.5^+
1.8173	4^+	3.3840	4.5^+
		3.4130	4.5^-
		3.5090	5.5^+
		3.5830	4.5^+
		3.620 0	4.5^+
		3.6340	2.5^+

1 Resonance Parameter

The resolved resonance parameters, taken from ENDF/B-6, were given from 10^{-5} eV to 0.05 MeV for ^{204}Pb and 0.475 MeV for ^{207}Pb; thermal cross sections of (n,tot), (n,n) and (n,γ) reactions are 11.857 b, 11.197 b and 0.661 b for ^{204}Pb; 11.459 b, 10.747 b and 0.712 b for ^{207}Pb, respectively.

2 Neutron Cross Section

The comparison of experimental data with evaluated ones is shown in Fig.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 is still a small structure energy range (0.475~5.0 MeV) and then smooth energy range (5.0~20.0 MeV). For ^{207}Pb in the energy range from 0.475 to 20.0 MeV, the data were mainly taken from ENDF/B-6 data; the corresponding experimental data of Koehler, Horen, Benetskij, Dukarevich and Day[3-7] for ^{207}Pb are given in Fig. 1. For ^{204}Pb in the energy range from 0.05 to 20.0 MeV, the data were mainly taken from JENDL-3.1 data; the corresponding experimental datum of Dukarevich for ^{204}Pb is given in Fig. 2.

2.2 Elastic Scattering Cross Section

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 Guenther, Tomita and Day[9~11] is good for ^{207}Pb.

2.3 Nonelastic Scattering Cross Section

This cross section is the sum of all cross sections of nonelastic channels (n,n′), (n,2n), (n,3n), (n,n′p), (n,γ), (n,p), (n,t) and (n,α) reactions.

2.4 Total Inelastic Cross Section

The total inelastic cross sections were taken from the calculations (see Fig. 3~4).

2.5 Inelastic Cross Section to the Discrete Levels and the Continuum

The inelastic scattering cross section to 16 discrete levels were calculated by using UNF code. For 0.5697, 0.8977, 1.6334 and 2.34 MeV levels of ^{207}Pb, the experimental data measured by Almen-Ra., Cranberg and Kinney[12~14], were used to normalize the corresponding model calculated results. The plots of these data and the evaluated data are shown in Figs. 3-1, 3-2. For other levels, the data were taken from calculated results. The inelastic scattering cross section to 11 discrete levels of ^{204}Pb were calculated by using UNF code.

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

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

For (n,2n) reaction of ^{207}Pb, the experimental data were measured by Frehaut[15] in the energy range from 7.41 to 14.76 MeV, The evaluated data were obtained by spline function fitting experimental data. Above 14.76 MeV, calculated data were nomalized to fitting value of the experimental data at 14.0 MeV (see Fig. 5).

For (n,2n) reaction of ^{204}Pb, the experimental data were measured by Filatenkov, Lu Hanlin, Ikeda, Kobayashi, Ryves, Decowaki, Maslov, Drushinin, Dilg and Vaughn[16~25] in the energy range from 10.1 to 19.2 MeV. The evaluated data were obtained by spline function fitting experimental data (see Fig. 6).

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

2.7 (n,p), (n,n'p), (n,α), (n,γ) Cross Sections

The cross sections were all taken from the model calculations (Fig. 7 for ^{207}Pb (n,γ) reaction).

2.8 (n, t) Cross Section

For ^{204}Pb (n,t) cross section, the calculated data were normalized to fit value of the experimental data of Qaim and Woo[26,27] at 14.6 MeV (see Fig. 8).

The ^{207}Pb (n,t) cross section was taken from the model calculation.

3 Secondary Neutron Angular Distributions

For elastic scattering angular distribution, the experimental data measured by Guenther, Tomita and Day were used to adjust the optical model parameters in the calculations. The calculated results in good agreement with the experimental data for ^{207}Pb (see Figs. 9~10).

The discrete level inelastic angular distributions were obtained from theoretical calculation results for both ^{207}Pb(MT=51~86) and ^{204}Pb (MT=51~11).

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

The double differential cross section (MF=6, MT = 16, 17, 22, 28, 91, 103, 105, 107) and γ-ray production data (MF=12,13,14,15) were all taken from the calculation results for both ^{207}Pb and ^{204}Pb.

5 Theoretical Calculation

An automatically adjusted optical potential code (APOM)[28] was used for searching a set of optimum neutron spherical optical potential parameters. DWUCK code was used to calculate the direct inelastic scattering for excited levels taken as the input data of UNF. UNF code, including optical model, Hauser-Feshbach statistical model and exciton model, was used to calculate the data of files 3, 4, 6, 12, 13, 14, 15. The input parameters are optical potential, level density, giant dipole resonance[29] and nuclear level scheme. These patameters were adjusted on the basis of experimental data in the neutron energy range from 1 keV to 20 MeV.

5.1 Optical Model, Level Density and Giant Dipole Resonance Parameters

Optical potential parameters used are given in Table 2. The level density and pair correction parameters are given in Table 3, 4. The giant dipole resonance parameters are shown in Table 4. The symbols CSG, EE and GG in Table 5 are the peak cross section, resonance energy and full width at half maximum, respectively.

5.2 The Coupled Channel Calculation

The legendre Coefficients (L. C) of direct elastic scattering to ground state and direct inelastic scattering to excited states were calculated with coupled channel code DWUCK at 12 energies by Shen Qingbiao in the required input format of UNF.

Table 2 Neutron optical model potential parameters*

Depth / MeV		Radius / fm	Diffuseness / fm
V_0=46.945	W_0=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_0=-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: $V_r(E)=V_0+V_1E+V_2E^2+V_3(A\text{-}2Z)/A+V_4Z/A(1/3)$;
$W_s(E)=W_0+W_1E+W_2(A\text{-}2Z)/A$;
$U_v(E)=U_0+U_1E+U_2E^2$.

Table 3 Level density parameters and Pair correction values of 11 excess nuclei*

		n,γ	n,n'	n,p	n,α	n,^{3}He	n,d
^{204}Pb	*L*	7.73	10.1	7.34	13.97	11.03	9.64
	P	0.85	1.32	0.25	0.83	1.25	0.72
^{207}Pb	*L*	3.62	4.57	3.24	7.28	5.622	4.18
	P	1.18	0.60	0.58	1.14	0.71	0.0

		n,t	n,2n	n,n'α	n,2p	n,3n	
^{204}Pb	*L*	12.6	13.02	12.9	8.75	11.94	
	P	0.3	0.9	1.69	0.78	1.76	
^{207}Pb	*L*	5.86	6.25	8.75	4.69	7.73	
	P	0.61	1.21	0.78	1.11	0.85	

*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 4 The 11 giant dipole resonance parameters (single peak)

^{204}Pb	CSG / b	0.481,0.541,0.541,0.481,0.645,0.541, 0.645,0.541,0.645,0.645,0.645,
	EE / MeV	13.56,13.72,13.72,13.56,13.63,13.72, 13.63,13.72,13.63,13.63,13.63,
	GG / MeV	3.96,4.61,4.61,3.96,3.94,4.61,3.94, 4.61,3.94,3.94,3.94,
^{207}Pb	CSG / b	0.65,0.481,0.481,0.54,0.481,0.54, 0.481,0.481,0.645,0.54,0.481
	EE / MeV	13.63,13.6,13.6,13.72,13.6,13.72, 13.6,13.6,13.63,13.72,13.6
	GG / MeV	3.94,3.96,3.96,4.61,3.96,4.61,3.96, 3.96,3.94,4.61,3.96,

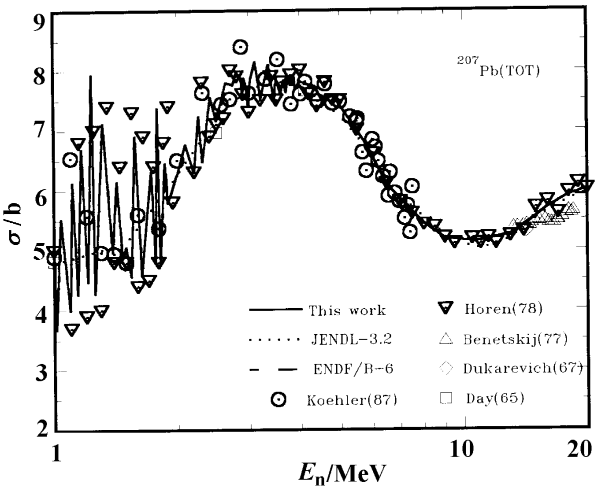

Fig. 1 Total cross section for ^{207}Pb

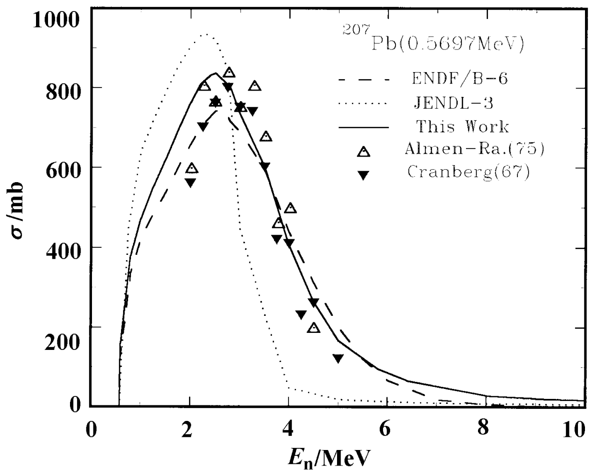

Fig. 3-1 Inelastic cross section for ^{207}Pb excited states

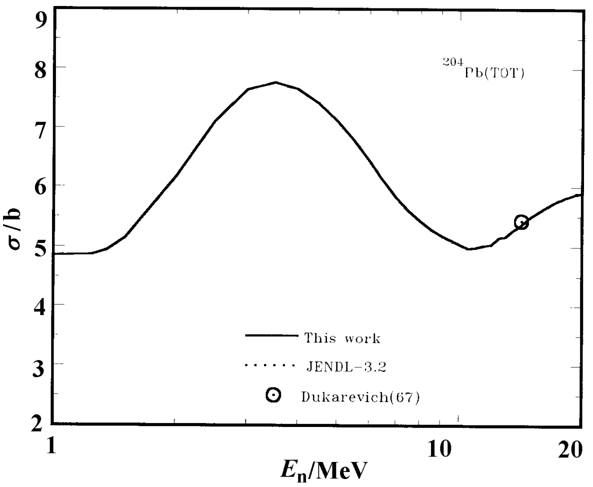

Fig. 2 Total cross section for ^{204}Pb

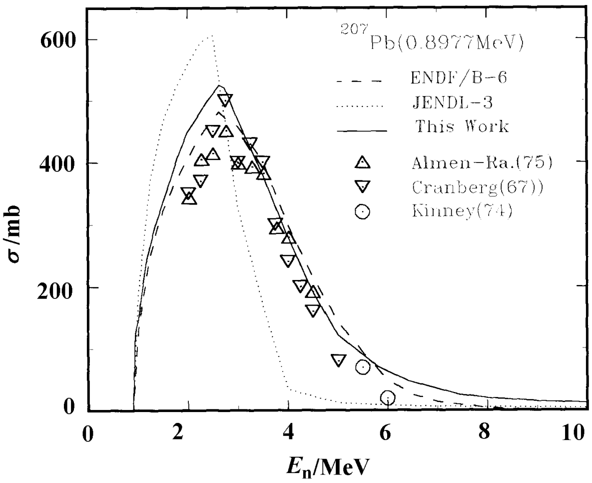

Fig. 3-2 Inelastic cross section for ^{207}Pb excited states

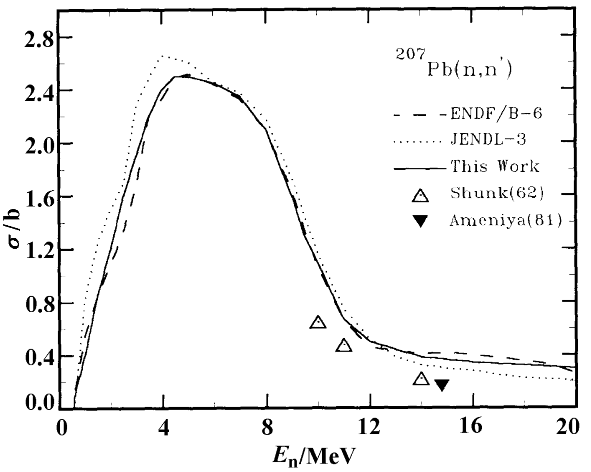

Fig. 3 Inelastic cross section for ^{207}Pb

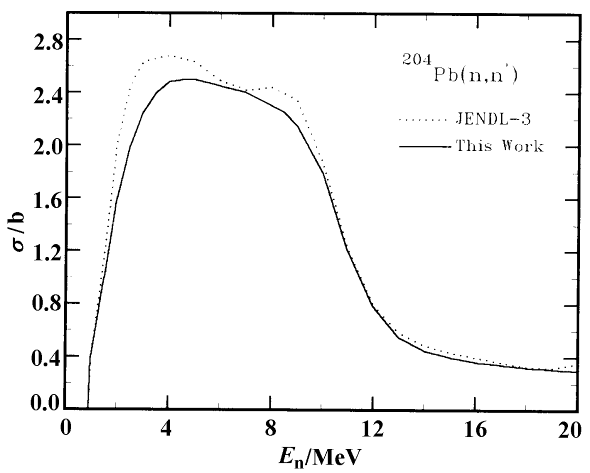

Fig. 4 Inelastic cross section for ^{204}Pb

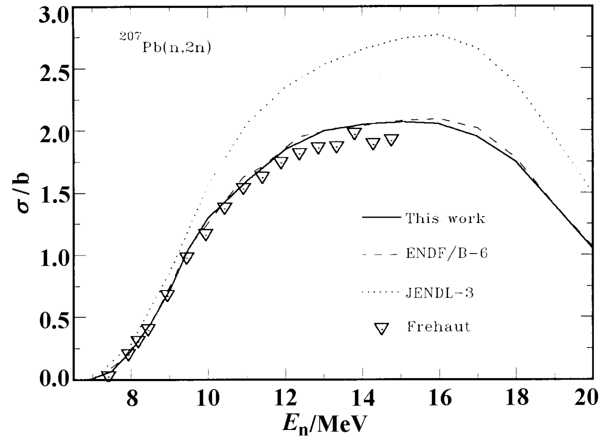

Fig. 5 (n,2n) cross section for ^{207}Pb

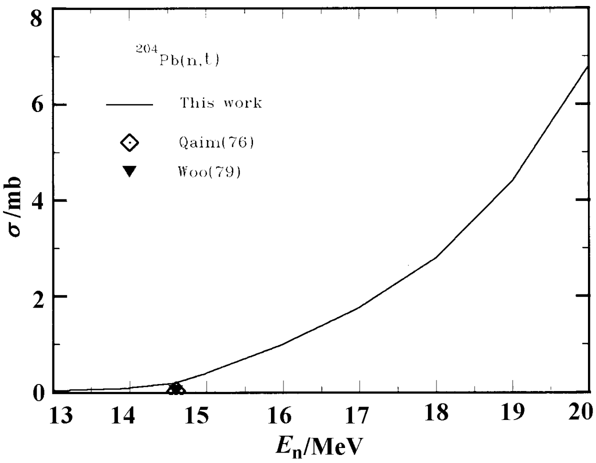

Fig. 8 (n,t) cross section for ^{204}Pb

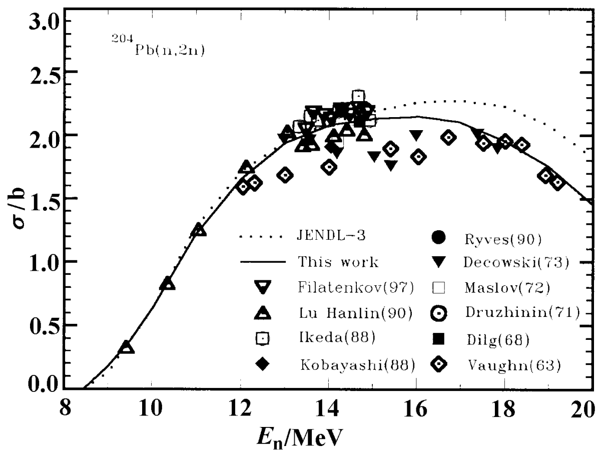

Fig. 6 (n,2n) cross section for ^{204}Pb

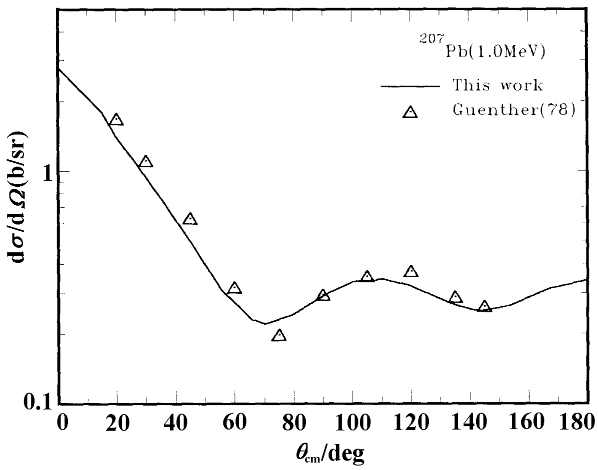

Fig. 9 Elastic scatter angular distribution of ^{207}Pb

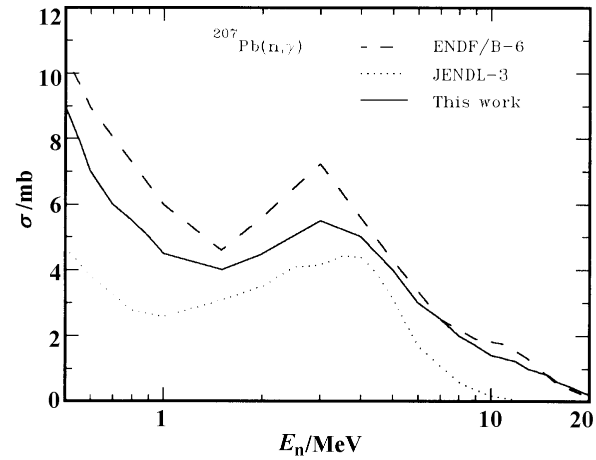

Fig. 7 (n,γ) cross section for ^{207}Pb

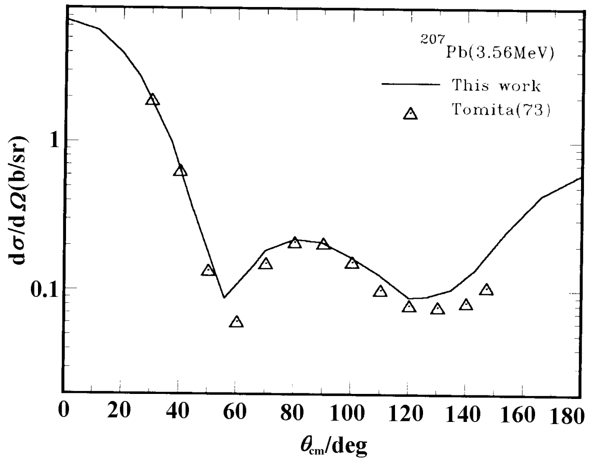

Fig. 10 Elastic scatter angular distribution of ^{207}Pb

6 Concluding Remarks

Due to the new experimental data have been available in last years, the evaluated data were considerably improved, especially for the cross sections of (n,2n) reaction and inelastic scattering to some discrete levels.

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References

[1] ZHANG Jingshang. Nucl. Sci. Eng., 1993, 114; 55~63
[2] Nuclear Data Sheets, 43, 383, 1984; 61, 93, 1990; 47,797,1986; 63,723,1991; 50,719,1987
[3] R.Koehler et al. Phys. Rev., C35,1646(1987)
[4] D.J.Horen et al. Phys. Rev., C18,722(1978)
[5] B.A.Benetskij et al. 77Kiev 2,47(1977)
[6] Ju.V.Dukarevich et al. Nucl. Phys., A92(2),433(1967)
[7] R.B.Day et al. EXFOR 12191.1010(1965)
[8] D.J.Horen et al. Phys. Rev., C29,2126(1984)
[9] P.T.Guenther et al. Nucl. Sci. Eng., 65,174(1978)
[10] Y.Tomita et al. EXFOR 20304.002(1973)
[11] R.B.Day et al. EXFOR 12191.009(1965)
[12] E.Almen-Ra. et al. Atomnaya Energiya, 503(1975)
[13] L.Cranberg et al. Phys. Rev.,159,969(1967)
[14] W.E.Kinney et al. ORNL-4909(1974)
[15] J.Frehaut et al. BNL-NCS-51245(1980)
[16] A.A.Filatenkov et al. EXFOR 41240.069(1997)
[17] LU Hanlin et al. C. Nucl. Phys., 12,269(1990)
[18] Y.Ikeda et al. JAERI-1312(1988)
[19] K.Kobayashi et al. 88MITO,261(1988)
[20] T.B.Ryves et al. ANE 17,107(1990)
[21] P.Decowaki et al. Nucl. Phys., A204,121(1973)
[22] G.N.Maslov et al. EXFOR 40136.001(1972)
[23] A.A.Drushinin et al. EXFOR 40171(1971)
[24] W.Dilg at al. Nucl. Phys., A118,9(1968)
[25] F.J.Vaughn et al. EXFOR 12223.002(1963)
[26] S.M.Qaim EY AL. Nucl. Phys., A257(2),233(1976)
[27] T.W.Woo et al. 79KNOX, 853(1979)
[28] SHEN Qingbiao et al. CNDP, No.7, 43(1993)
[29] ZHUANG Youxiang et al. Chinese Physics, 8, 721-727(1988)

Evaluation of Nuclear Fission Barrier Parameters for 17 Nuclei

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As we know well that modern nuclear installations and applications have reached a high degree of sophistication. The effective safe and economical design of these technologies require detailed and reliable design calculations. The accuracy of these calculations is largely determined by the accuracy of the basic nuclear and atomic input parameters. In order to meet the needs on high energy fission cross section, fission spectra in waste disposal, transmutation, radioactive beams physics and so on, 17 nuclei fission barrier parameters were collected from the literature based on different experiments and