CN9901233

III DATA EVALUATION

Evaluation of Complete Neutron Nuclear Data for $^{58,60,61,62,64,Nat}Ni$

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Introduction

Ni is a very important structure material in nuclear fusion engineering. The natural nickel consists of five stable isotopes. The neutron nuclear data were evaluated for $^{58,60,61,62,64,Nat}Ni$ in the energy range 10^{-5} eV to 20 MeV. The data includes total, elastic, non-elastic, total inelastic, inelastic cross sections to 33 discrete levels, inelastic continuum, (n,2n), (n,3n), (n,n'α)+(n,αn'), (n,n'p)+(n,pn'), (n,p), (n,d), (n,t), (n,α), (n,2p) 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 evaluation is based on both experimental data measured up to 1995 and calculated data with program UNF. The evaluated data will be adopted into CENDL-3 in ENDF/B-6 format.

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

Table 1 Discrete levels of Ni isotopes (Abundance %)

^{58}Ni (68.077)		^{60}Ni (26.223)		^{61}Ni (1.14)		^{62}Ni (3.634)		^{64}Ni (0.926)	
E_l	J^π	E_l	J^π	E_l	J^π	E_l	J^π	E_l	J^π
0.0	0^+	0.0	0^+	0.0	$3/2^-$	0.0	0^+	0.0	0^+
1.4545	2^+	1.3325	2^+	0.0674	$5/2^-$	1.1729	2^+	1.3458	2^+
2.4591	4^+	2.1586	2^+	0.2830	$1/2^-$	2.0486	0^+	2.2772	2^+
2.7755	2^+	2.2849	0^+	0.6560	$1/2^-$	2.3018	2^+		
2.9018	1^+	2.5058	4^+	0.9086	$5/2^-$	2.3364	4^+		
2.9424	0^+	2.6261	3^+	1.0152	$7/2^-$	2.8912	0^+		
3.0376	2^+	3.1197	4^+	1.996	$3/2^-$	3.0585	2^+		
3.2634	2^+	3.1240	2^+			3.1580	2^+		
3.4203	3^+	3.1860	3^+						
3.5240	4^+	3.1940	1^+						

Table 2 Binding energy of emitted final particle for ^{58,60}Ni (MeV) reaction channels

	n,γ	n,n'	n,p	n,α	n,³He	n,d	n,t
	n,2n	n,np	n,nα	n,pn	n,2p	n,αn	n,3n
^{58}Ni	0.0	8.9992	8.6045	6.1091	15.4849	14.9518	20.0716
	12.2030	8.1772	6.4082	8.5718	6.9525	9.2983	10.2672
^{60}Ni	0.0	7.8195	9.8606	6.4681	17.0036	15.1275	19.3301
	11.3882	9.5233	6.2948	7.4915	8.2757	7.6461	8.9992

1 Resonance Parameter

The resolved resonance parameters were given from 1.0^{-5} eV to 812 keV (to 812 keV for ^{58}Ni; to 450 keV for ^{60}Ni; to 70 keV for ^{61}Ni; to 600 keV for ^{62,64}Ni) based on ENDF/B-6 data, and supplemented by new data of Perey, Brusegan and Corvi for ^{58}Ni and ^{60}Ni, respectively.

2 Neutron Cross Section

The nuclear data of natural Ni for all reactions were obtained from summing the isotopic data weighted by the abundance. The comparison of experimental data with evaluated ones is shown in Fig.1 ~ 6. 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 some small structure in the energy range 812 keV ~ 6.0 MeV and become smooth in the energy range 6.0 ~ 20 MeV. The experimental data were taken from Larson, Perey, Smith and Koester[5~8]. In the energy range from 812 keV to 6.0 MeV, the data were mainly taken from Larson's corresponding experimental data. In the smooth energy range from 6.0 MeV to 20 MeV, they were fitted with spline function the experimental data for ^{Nat}Ni. The experimental data were taken from Perey, Budtz and Fedorov. In the energy range from 812 keV to 20 MeV for ^{58}Ni, from Harvey, Perey, Pedorov, Smith, Boschung and Stoler. In the energy range from 450 keV to 20 MeV for ^{60}Ni. Du to there are very few experimental data, total cross section of natural nickel was taken for ^{61,62,64}Ni.

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 non-elastic processes from the total cross section. In general, the agreement between the calculated cross section and the available experimental data of Li, Smith, Kinney, Guenther, Holmqvist, Korzh, Pasechnik, Ferrer, Bauer, Kazakova, Clarke, Hansen and Kammerdiener is good.

2.3 Non-Elastic Scattering Cross Section

Below 14.2 MeV, the non-elastic cross section was based on the experimental data of Beyster, Taylor, Pasechnik, MacGregor, Abromov, Machwe, Strizhak, Holmqvist and Poze for ^{Nat}Ni, most of which were measured by using sphere transmission method. Above 14.2 MeV, the model calculated result was used, and normalized to the experimental data 1.31 b at 14 MeV. A plot of these data and the evaluated data is shown in Fig.1.

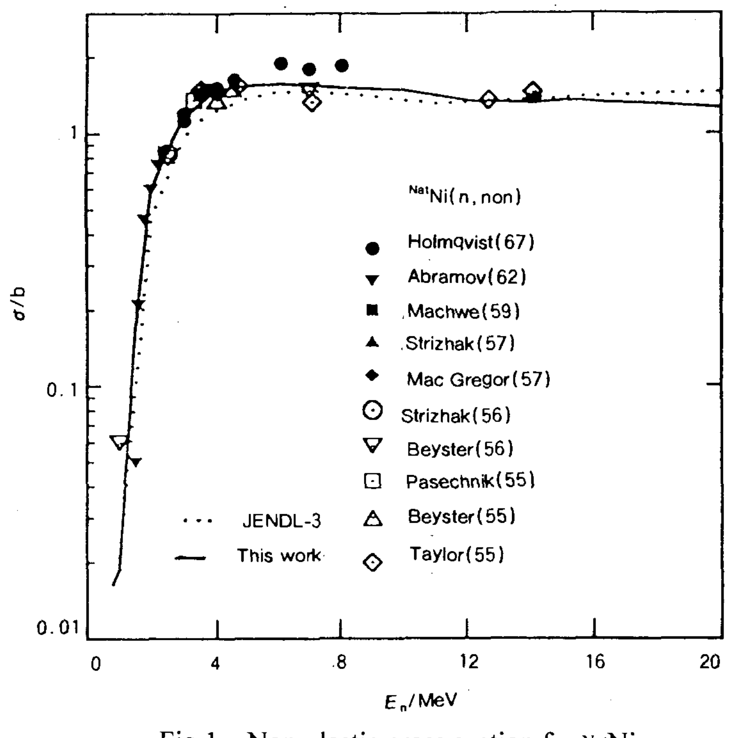

Fig.1 Non-elastic cross section for ^{Nat}Ni

2.4 Total Inelastic Cross Section

The total inelastic cross section of ^{Nat}Ni was obtained from summing the isotopic data weighted by the abundance (see Fig.2).

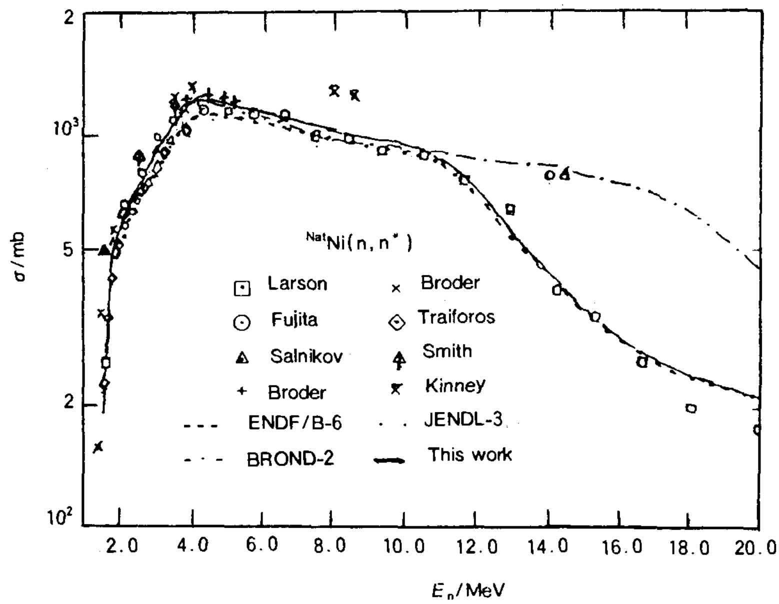

Fig.2 Total inelastic cross section for Ni

2.5 Inelastic Cross Section to the Discrete Levels and the Continuum

The inelastic scattering cross sections to 33 discrete levels were calculated by using UNF code. For 1.3325 and 1.4545 MeV levels, the data were obtained by fitting experimental data measured by Itagaki, Traiforos, Guss, Budtz, Smith, Almen, Kinney, Boschung, Rodgers, Border and Towle. For 1.1729, 2.1586, 2.2849, 2.3018, 2.4591, 2.5058, 2.6261, 2.7755, 2.9018, 2.9424, 3.0376, 3.2634 and 3.4203 MeV levels, the calculated data were normalized to the corresponding experimental value. For others, the data were taken from calculated results (see Fig.3).

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

2.6 (n,2n) Cross Section

The (n,2n) cross section of ^{Nat}Ni was obtained from summing the isotopic data weighted by the abundance (Fig.4; Ref. [2]).

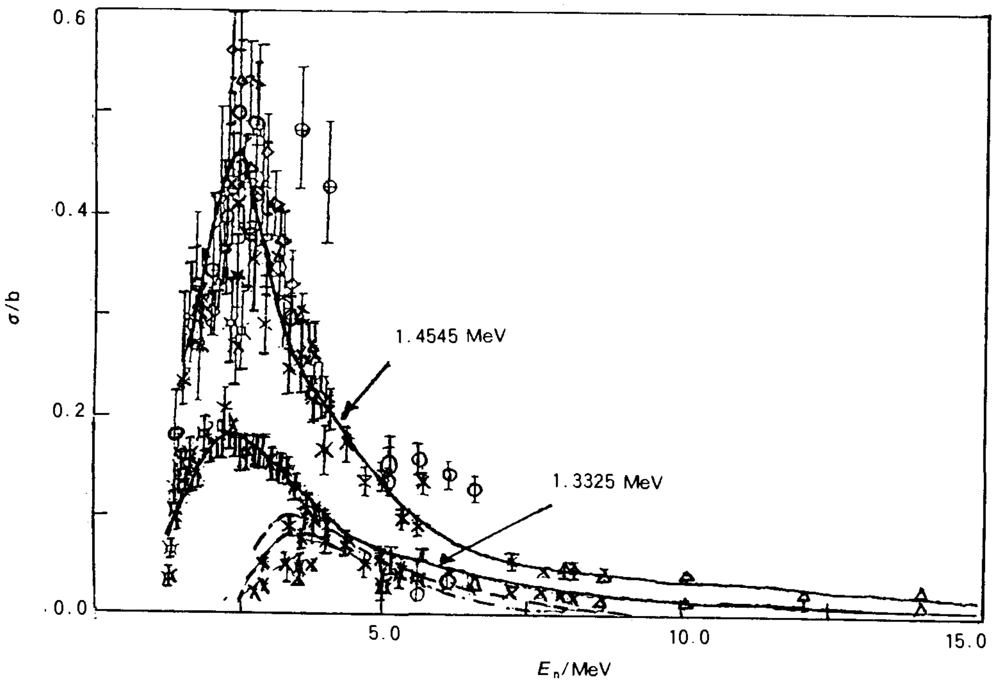

Fig.3 Inelastic cross section of Ni excited states

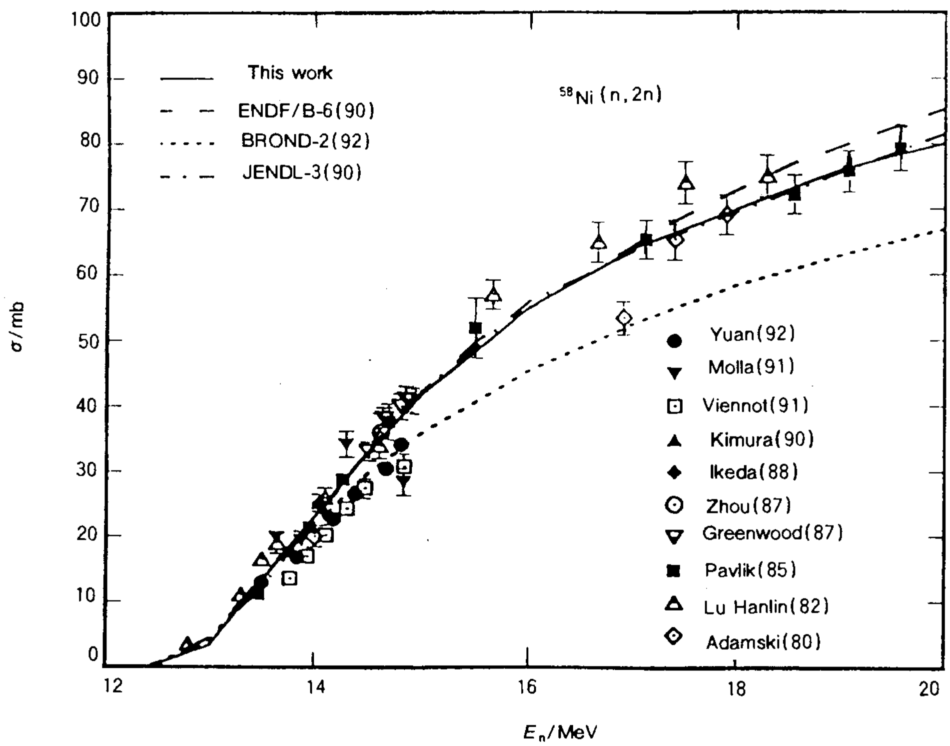

Fig.4 (n,2n) cross section for ^{58}Ni

2.7 (n,p) Cross Section

The (n,p) cross section of ^{Nat}Ni was obtained from summing the isotopic data weighted by the abundance (Fig.5 ~ 8, Ref. [3]).

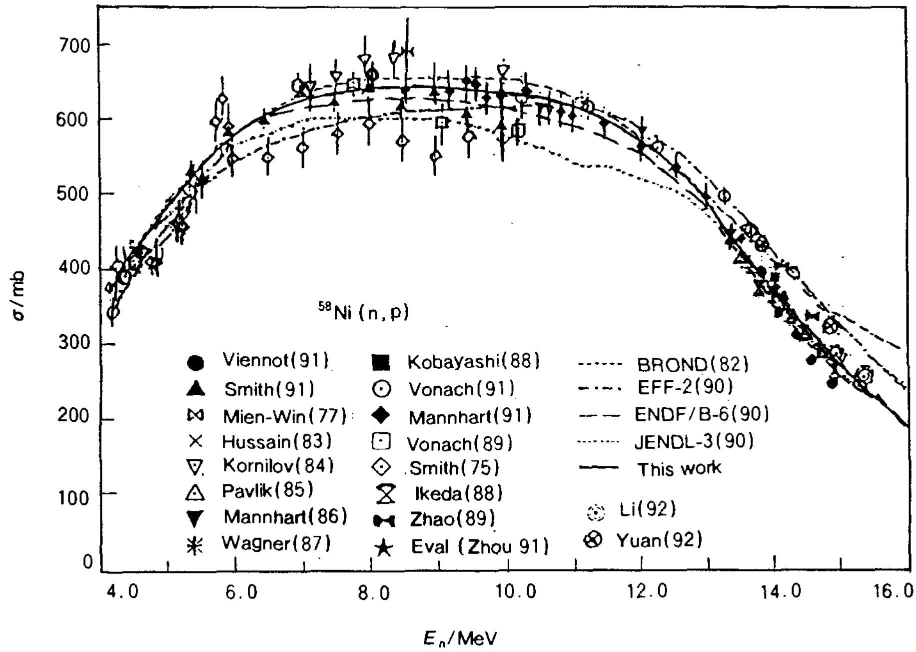

Fig.5 (n,p) cross section for ^{58}Ni

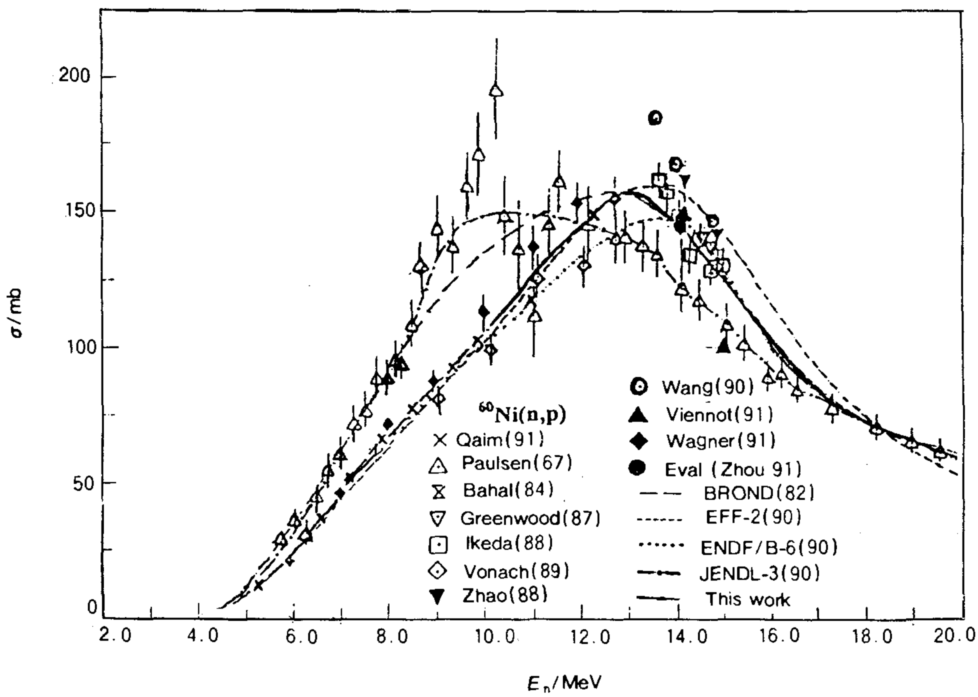

Fig.6 (n,p) cross section for ^{60}Ni

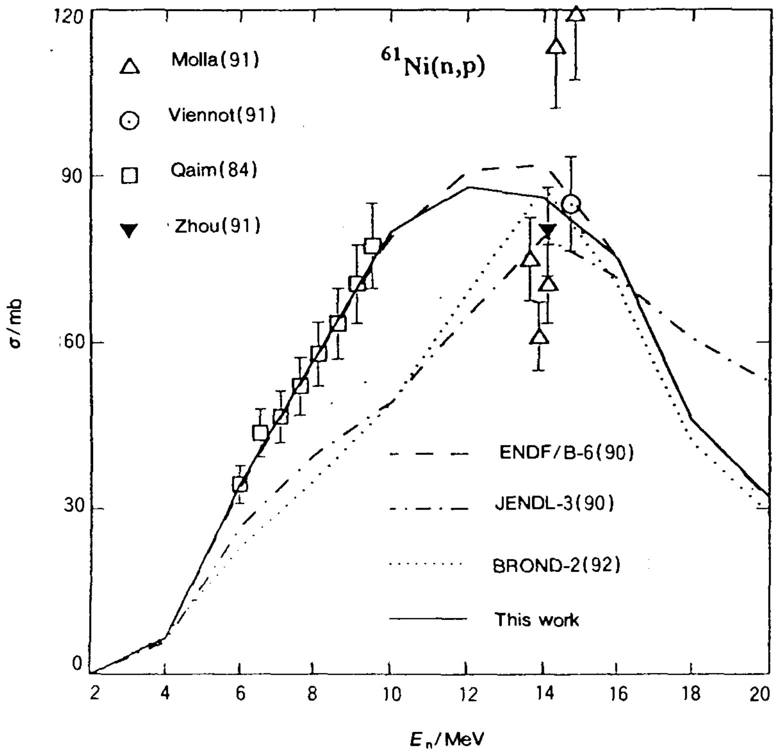

Fig.7 (n,p) cross section for ^{61}Ni

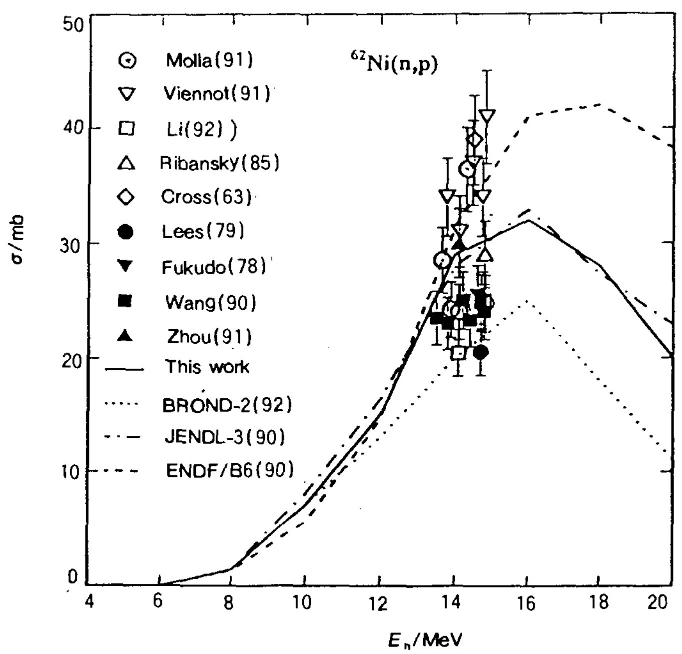

Fig.8 (n,p) cross section for ^{62}Ni

2.8 (n,α) Cross Section

The (n,α) cross section of ^{Nat}Ni was obtained from summing the isotopic data weighted by the abundance (see Fig.9, 10, Ref. [4]).

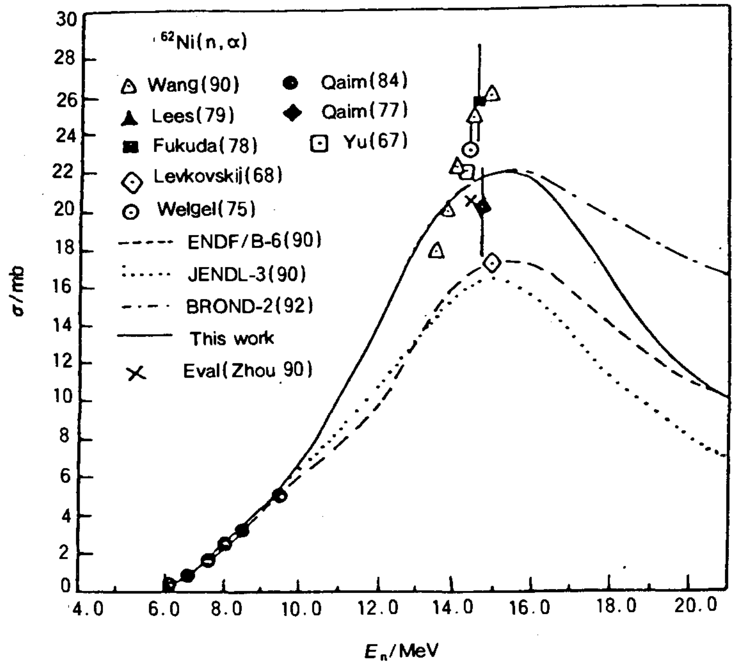

Fig.9 (n,α) cross section for ^{62}Ni

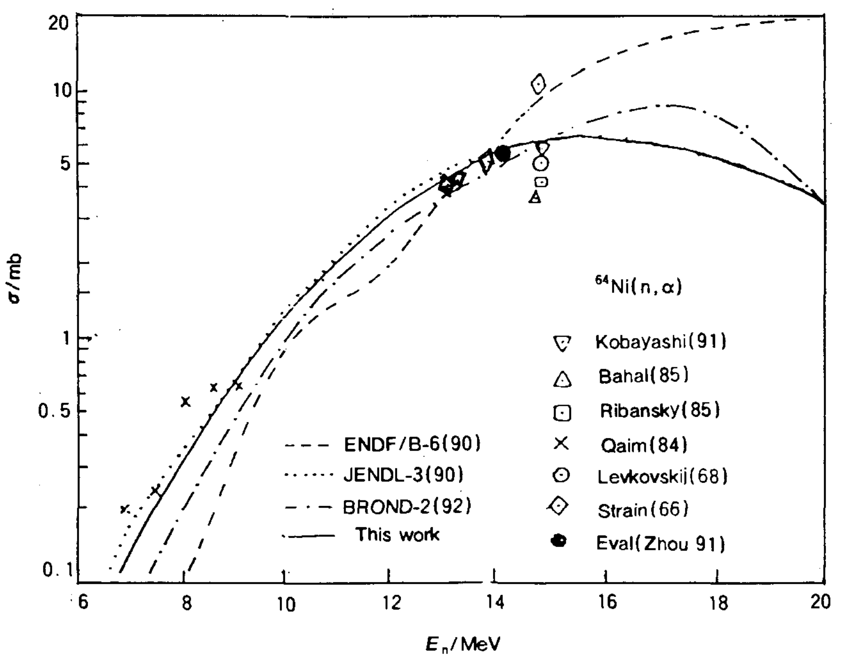

Fig.10 (n,α) cross section for ^{64}Ni

3 Secondary Neutron Angular Distributions

For elastic scattering, the experimental data measured by Qi, Hansen, Smith, Li, Kinney, Guenther, Holmgvist, Korzh, Pasechnik, Ferrer and Clarken were used to adjust the parameters in the calculations with optical model. The calculated results in good agreement with the experimental data and used for recommended data (see Fig.11, 12).

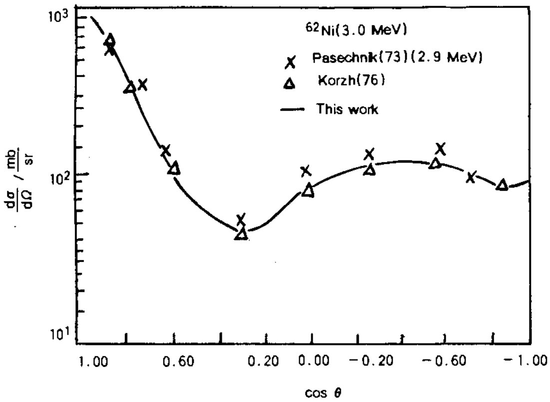

Fig.11 Elastic scatter angular distribution of 3.0 MeV for ^{62}Ni

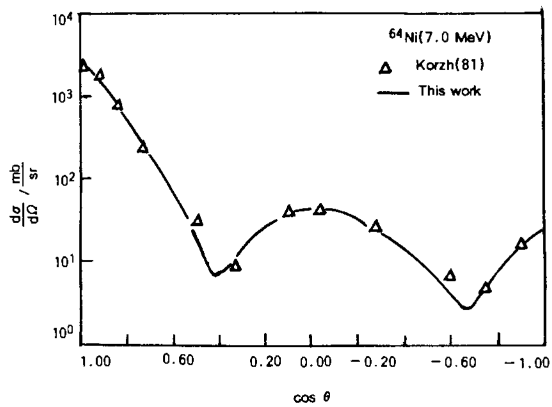

Fig.12 Elastic scatter angular distribution of 7.0 MeV for ^{64}Ni

The discrete inelastic angular distributions (MT = 51 ~ 83) were obtained from theoretical calculation results. The angular distributions for (n,2n), (n,3n), (n,n'α), (n,n'p) and continuum inelastic (MT = 16, 17, 22, 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, 22, 28, 91, 103, 104, 105, 106, 107, 111) and γ-ray production data (MF = 12,13,14,15) were taken from the calculation results (Fig.13, 14).

5 Theoretical Calculation

An automatically adjusted optical potential code (APOM)[5] was used for searching a set of optimum neutron spherical optical potential parameters. ECIS code[6] of coupled channel was used to calculate the direct inelastic scattering for excited levels as the input data of UNF[7]. UNF code, including optical model,

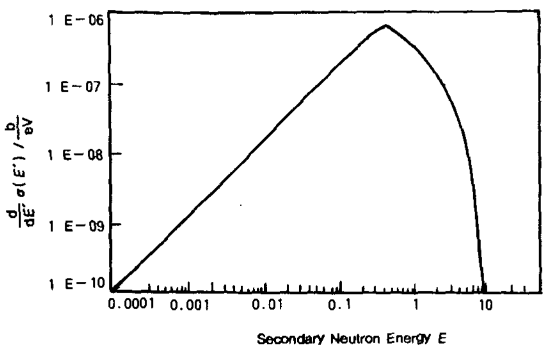

Fig.13 ^{58}Ni(n,n'p) secondary neutron spectrum at 20.0 MeV

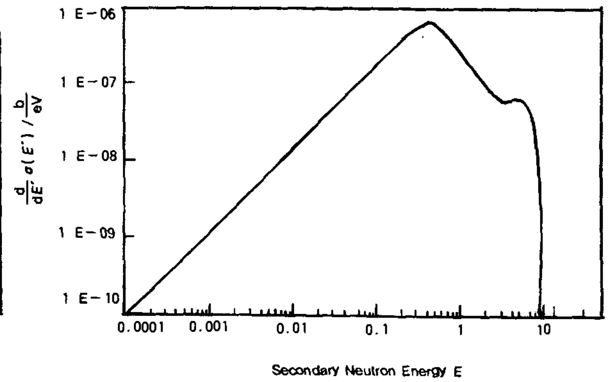

Fig.14 ^{60}Ni(n,2n) secondary neutron spectrum at 20.0 MeV

Hauser-Feshbach statistical model and exciton model, was used to calculate the data for files 3, 4, 5, 6, 12, 14, 15, which requires following input Parameters: optical potential, level density[8], giant dipole resonance and nuclear level scheme. These parameters 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 are given in Table 3, and level density parameters and pair correction parameters are given in Table 4. The giant dipole resonance parameters are shows in Table 5, the symbols CSG, EE and GG are the peak cross section, resonance energy and full width at half maximum, respectively.

Table 3 Optical potential parameters*

	Depth / MeV		Radius / fm	Diffuses / fm
Neutron	V_0 = 53.7339	W_0 = 12.3702	X_r = 1.1818	A_r = 0.7112
	V_1 = −0.1395	W_1 = −0.1642	X_s = 1.3200	A_s = 0.4340
	V_2 = −0.0155	W_2 = −1.2687	X_v = 1.3190	A_V = 0.4100
	V_3 = −17.5984	U_0 = −2.0686	X_{so} = 1.1764	A_{so} = 0.7284
	V_4 = 0.0	U_1 = 0.2659	X_c = 1.10	
	V_{so} = 3.1	U_2 = 0.0		

* Note: $V_r(E) = V_0+V_1E+V_2E(2)+V_3(A-2Z)/A+V_4Z/A(1/3)$
$W_s(E) = W_0+W_1E+W_2(A-2Z)/A$
$U_v(E) = U_0+U_1E+U_2E(2)$

Table 4 Level density parameters and pair correction values of 11 excess nuclei for $^{58,60}Ni$*

		n,γ	n,n'	n,p	n,α	n,^{3}He	n,d	n,t	n,2n	n,n'α	n,2p	n,3n
^{58}Ni	L	6.50	5.37	7.32	6.26	6.25	6.19	6.20	5.40	5.58	7.37	4.71
	P	1.0	2.35	−0.3	1.3	2.45	1.05	−0.1	1.2	2.5	1.1	2.4
^{60}Ni	L	6.91	6.36	7.75	7.37	7.27	7.20	7.32	6.50	6.25	7.81	5.37
	P	1.05	2.52	−0.3	1.1	2.62	1.22	−0.3	1.0	2.45	1.15	2.35

* Note: $L = [0.0088(S(z)+S(n))+Q_b]A$
$P = P(n)+P(z)$
$Q_b = 0.142$ or 0.12 (spherical or deformation)

Table 5 The 11 giant dipole resonance parameters of ^{58}Ni (twin peak)

CSG / b	2×0.034,0.026,2×0.047,0.026,0.047,0.034,2×0.047, 0.034, 3×0.05,2×0.04,0.05,0.04,0.05,2×0.04,0.05.
EE / MeV	2×16.3,16.37,2×16.62,16.37,16.62,16.3,2×16.62,16.3, 2×18.51,18.9,2×19.91,18.9,19.91,18.51,2×19.91,18.51.
GG / MeV	2×2.44,2.56,2×4.24,2.56,4.24,2.44,2×4.24,2.44, 2×6.37,7.61,2×4.16,7.61,4.16,6.37,2×4.16,6.37.

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 ECIS at 23 energies.

6 Concluding Remarks

Due to the new experimental data are available in last years, the evaluated data have been considerably improved, especially cross sections of total, (n,p), (n,n'p), (n,α), (n,d), total inelastic reactions and inelastic scattering to some discrete levels.

More detail please refer to Ref. [9 ~ 12] for theoretical calculation and Ref. [13 ~ 15] for evaluation.

Acknowledgments

The authors wish to thank Prof. Liu Tingjin and Liang Qichang for their much help with this work. We also thank Prof. Chen Zhenpeng for their help in the ECIS code calculation.

References

[1] Nuclear Data Sheets, 1992, 67:195; 1992,67:271; 1992, 67:523; 1991, 64: 723; 1991, 64: 815; 1991, 62: 603; 1990, 60: 337; 1983, 39: 641
[2] Ma Gonggui, et al., CNDP, 17, 74(1997)
[3] Ma Gonggui, et al., CNDP, 15, 60(1996)
[4] Ma Gonggui, et al., CNDP, 14, 53(1995)
[5] Shen Qingbiao, et al., APOM-Acode for searching optical model parameters, CNDP, 1993, 7: 43
[6] Chen Zhenpeng, Coupled channel calculation program ECIS. Communication of Nuclear Data Progress, 1995, No.13: 33
[7] Zhang Jingshang. Nucl. Sci. Eng., 1993, 114; 55 ~ 63
[8] Zhuang Youxiang,et al., A new set of level density parameters for Fermi Gas model, Chinese Physics, 1988, 8: 721
[9] Ma Gonggui, et al., J. Sichuan Univ. (Natural Science Edition), 33, 6, 677(1996)
[10] Ma Gonggui, et al., Proc. of Tenth National Conf. of Nucl. Phys.; J. Qingdao Univ. (Natural Science Edition), Supplement, Aug., 1997
[11] Ma Gonggui, et al., Atomic Energy Science and Technology(to be published)
[12] Ma Gonggui, et al., J. Sichuan Univ. (Natural Science Edition), 33, 6, 677(1996)
[13] Ma Gonggui, et al., China Nucl. Sci. and Tech. Report, CNIC-0160, 1997
[14] Ma Gonggui, et al., Evaluation of Complete Neutron Nuclear data for $^{60\sim62,64}$Ni (internal report)
[15] Ma Gonggui, et al., China Nucl. Sci. and Tech. Report (to be published)

CN9901234

Some ^{235}U Reference Fission Product Yield Data Evaluation

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Introduction

Some fission yield data are used as standards in the fission yield data measurement and evaluation, and some are used as monitor in the nuclear industry for decay heat estimation, burn-up credit study etc. All of this kind of fission yield is refered to the reference yield. Among them, the data of ^{235}U fission, especially at thermal energy, are most important ones.