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Neutron Activation Cross Section Measurements and Evaluations in CIAE

Huang Xiaolong

China Institute of Atomic Energy
China Nuclear Data Center
P.O. Box 275 (41)
Beijing 102413
P.R. China

Lu Hanlin, Zhao Wenrong, Yu Weixiang and Han Xiaogang

China Institute of Atomic Energy
Department of Neutron Physics
P.O. Box 275 (49)
Beijing 102413
P.R. China

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Abstract

The cross sections of 28 reactions have been measured by the activation method since 1995 in CIAE. At the same time the cross sections of 40 reactions which we have measured since 1989 have been compiled and evaluated.

A brief description of experimental measurement for activation cross sections is given. The data measured after 1995 by ourselves are listed in Table 4 and our evaluations for 40 reactions are listed in Table 5, respectively. A graphical intercomparison with available experimental data is given in appendix.

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1. Introduction

The neutron activation cross sections are very useful in nuclear engineering applications, especially in fission and fusion reactors, and nuclear physics studies. For example, they are basic nuclear data needed to evaluate gas production and radiation damage in fusion devices and also are used to confirm predictions of nuclear reaction theory. Meanwhile they can be used as threshold detectors to measure neutron spectra of reactors or some neutron fields. As developing of nuclear technology and nuclear engineering, more accurate data including measurements and evaluations are required.

At present an abundance of neutron activation cross sections has been measured, and several sets of evaluated results such as ENDF/B-6 have been given. But among them, there are large discrepancies. First, there are some reactions which haven't been measured in some neutron energy region, for example, $^{58}\text{Ni}(\text{n},\text{np+pn+d})^{57}\text{Co}$ and $^{181}\text{Ta}(\text{n},2\text{n})^{180\text{m}}\text{Ta}$ reactions, etc. Second, for some reactions, such as $^{58}\text{Ni}(\text{n},\text{p})^{58}\text{Co}$, $^{64}\text{Zn}(\text{n},\text{p})^{64}\text{Cu}$, there existed a sharp disagreement between measurements of different experiments, especially in above 15MeV neutron energy region. On the other hand, among the available evaluated data, there also existed large discrepancies, for example, $^{176}\text{Hf}(\text{n},2\text{n})^{175}\text{Hf}$ reaction. Some evaluated data are in agreement but in fact they are wrong due to erroneous measurements.

In this case, it is necessary to measure and evaluate some reactions so as to check and improve the existing data and to provide more reliable and accurate results. Since 1995, we have begun to collect and measure the neutron activation cross sections for some reactions. And at the same time we have begun to make evaluations for some reactions.

Up to now, we have measured 28 reactions and evaluated 40 reactions, which are listed in Table 1. For each reaction, present measured and evaluated data are summarized in Table 4 and 5, respectively, and the evaluated data are plotted in figures which enclosed in appendix.

Table 1 List of measured and evaluated reactions and associated parameters[@]

Reaction	Abundance, %	Product	Half-life	E_{γ} , keV	P_{γ} , %
$^{23}\text{Na}(\text{n},2\text{n})^{22}\text{Na}$	100	^{22}Na	950.8(9) d	1274.5	99.935(15)
$^{46}\text{Ti}(\text{n},\text{p})^{46}\text{Sc}$	8.25	^{46}Sc	83.79(4) d	889.3	99.984(2)
				1120.6	99.987(1)
$^{47}\text{Ti}(\text{n},\text{p})^{47}\text{Sc}$	7.44	^{47}Sc	3.349(1) d	159.4	67.9(15)
$^{48}\text{Ti}(\text{n},\text{p})^{48}\text{Sc}$	73.72	^{48}Sc	43.67(9) h	983.5	99.987(1)
				1037.5	97.5(6)
				1312.1	99.994(1)
$^{54}\text{Fe}(\text{n},\text{p})^{54}\text{Mn}$	5.845	^{54}Mn	312.12(6) d	834.8	99.976(2)
$^{54}\text{Fe}(\text{n},\alpha)^{51}\text{Cr}$	5.845	^{51}Cr	27.701(2) d	320.1	9.86(5)
$^{56}\text{Fe}(\text{n},\text{p})^{56}\text{Mn}$	91.754	^{56}Mn	2.5785(2) h	846.8	98.87(30)
				1810.7	27.19(79)
				2113.1	14.34(40)

$^{59}\text{Co}(\text{n},\text{p})^{59}\text{Fe}$	100	^{59}Fe	44.503(6) d	1099.3 1291.6	56.5(15) 43.2(11)
$^{58}\text{Ni}(\text{n},\text{p})^{58}\text{m+gCo}$	68.077	^{58}gCo	70.86(6) d	810.8	99.45(1)
$^{58}\text{Ni}(\text{n},\text{np+pn+d})^{57}\text{Co}$	68.077	^{57}Co	271.79(7) d	122.1 136.5	85.6(2) 10.7(1)
$^{60}\text{Ni}(\text{n},\text{p})^{60}\text{m+gCo}$	26.223	^{60}Co	1925.5(5) d	1173.2 1332.5	99.857(22) 99.983(6)
$^{62}\text{Ni}(\text{n},\alpha)^{59}\text{Fe}$	3.634	^{59}Fe	44.503(6) d	1099.3 1291.6	56.5(15) 43.2(11)
$^{63}\text{Cu}(\text{n},\alpha)^{60}\text{Co}$	69.17	^{60}Co	1925.5(5) d	1173.2 1332.5	99.857(22) 99.983(6)
$^{64}\text{Zn}(\text{n},\text{p})^{64}\text{Cu}$	48.6	^{64}Cu	12.701(2) h	1345.8	0.47(1)
$^{71}\text{Ga}(\text{n},\gamma)^{72}\text{Ga}$	39.892	^{72}Ga	13.95(5) \$ h	834.0	95.6(1)
$^{85}\text{Rb}(\text{n},2\text{n})^{84}\text{m+gRb}$	72.165	^{84}gRb	32.85(11) d	881.6	68.9(9)
$^{93}\text{Nb}(\text{n},2\text{n})^{92}\text{mNb}$	100	^{92}mNb	10.15(2) d	934.4	99.07(4)
$^{92}\text{Mo}(\text{n},\text{p})^{92}\text{mNb}$	14.84	^{92}mNb	10.15(2) d	934.4	99.07(4)
$^{109}\text{Ag}(\text{n},2\text{n})^{108}\text{mAg}$	48.161	^{108}mAg	426(8) y	433.9 614.3 722.9	90.5(6) 89.8(19) 90.8(19)
$^{132}\text{Ba}(\text{n},2\text{n})^{131}\text{Ba}$	0.101	^{131}Ba	11.50(6) d	123.8 496.3	29.0(3) 46.8(5)
$^{134}\text{Ba}(\text{n},2\text{n})^{133}\text{mBa}$	2.417	^{133}mBa	38.9(1) h	275.9	17.5(1)
$^{134}\text{Ba}(\text{n},2\text{n})^{133}\text{Ba}$	2.417	^{133}Ba	10.51(5) y	356.0	61.9(1)
$^{136}\text{Ba}(\text{n},\alpha)^{133}\text{mXe}$	7.854	^{133}mXe	2.19(1) d	233.2	10.0(3)
$^{136}\text{Ba}(\text{n},2\text{n})^{135}\text{mBa}$	7.854	^{135}mBa	1.196(2) d	268.0	15.6(3)
$^{137}\text{Ba}(\text{n},\text{p})^{137}\text{Cs}$	11.23	^{137}Cs	11015(20) d	661.7	85.1(2)
$^{138}\text{Ba}(\text{n},\alpha)^{135}\text{Xe}$	71.70	^{135}Xe	9.14(2) h	249.8	90.2(2)
$^{140}\text{Ce}(\text{n},2\text{n})^{139}\text{Ce}$	88.48	^{139}Ce	137.64(2) d	165.9	79.9(1)
$^{151}\text{Eu}(\text{n},2\text{n})^{150}\text{gEu}$	47.8	^{150}gEu	36.9(9) y	334.0 439.4 584.3	96.0(30) 80.4(30) 52.6(25)
$^{153}\text{Eu}(\text{n},2\text{n})^{152}\text{m2+gEu}$	52.2	^{152}gEu	13.524(2) y	121.8 1408.0	28.4(1) 20.9(1)
$^{159}\text{Tb}(\text{n},\gamma)^{160}\text{Tb}$	100	^{160}Tb	72.3(2) d	1178.0	14.9(3)
$^{159}\text{Tb}(\text{n},2\text{n})^{158}\text{Tb}$	100	^{158}Tb	180(11) y	184.4 944.0	72.6(9) 43.9(13)
$^{169}\text{Tm}(\text{n},\gamma)^{170}\text{Tm}$	100	^{170}Tm	128.6(3) d	84.3	2.48(13)
$^{175}\text{Lu}(\text{n},2\text{n})^{174}\text{m+gLu}$	97.41	^{174}mLu	142(2) d	67.1 111.8 176.7 272.9 992.1	7.25(21) 0.298(11) 0.470(19) 0.550(25) 0.546(21)
				76.5	5.93(28)

				1241.9	5.14(13)
$^{176}\text{Hf}(n,2n)^{175}\text{Hf}$	5.206	^{175}Hf	70(2) d	89.4 343.4 433.0	2.40(17) 84(3) 1.44(4)
$^{180}\text{Hf}(n,\gamma)^{181}\text{Hf}$	35.1	^{181}Hf	42.39(6) d	482.0	80.6(5)
$^{181}\text{Ta}(n,2n)^{180m}\text{Ta}$	99.988	^{180g}Ta	8.152(6) h	93.4 103.6	4.34(10) 0.78(19)
$^{185}\text{Re}(n,2n)^{184m+g}\text{Re}$	37.4	^{184g}Re	38.0(5) d	641.9	1.94(6)
$^{185}\text{Re}(n,2n)^{184m}\text{Re}$	37.4	^{184m}Re	169(8) d	104.7 920.9	10.1(5) 8.14(38)
$^{187}\text{Re}(n,2n)^{186m}\text{Re}$	62.6	^{186m}Re	$2.0(5)\times 10^5$ y	137.2*	8.83(30)
$^{187}\text{Re}(n,2n)^{186g}\text{Re}$	62.6	^{186g}Re	89.22(1) h	137.2	8.83(30)
$^{182}\text{W}(n,n'\alpha)^{178m2}\text{Hf}$	26.498	$^{178m2}\text{Hf}$	31(1) y	325.6 495.0 574.0	94.1(3) 68.9(2) 83.8(3)

Notes: @, taken from Ref.115. \$, present measurement . *, from subsequent decay of ^{186g}Re .

2. Brief description of measurements

In present work the conventional activation method was used to measure the neutron activation cross sections. Table 1 gives the relevant reactions and information for present investigation.

The neutron sources used in our measurements were produced by various accelerators. Table 2 gives the relevant properties of these neutron sources.

The samples were natural metal plates, which were machined to disks or slips, or oxide powder which was pressed into pills. In general the purity of them was better than 99.9%.

In present work all the cross sections were measured relative to standard cross sections in the whole measured energy range. This is a so-called the relative measurement method. In this way, the neutron flux can be determined by standard reactions of $^{197}\text{Au}(n,\gamma)^{198}\text{Au}$, $^{27}\text{Al}(n,\alpha)^{24}\text{Na}$, $^{93}\text{Nb}(n,2n)^{92m}\text{Nb}$, or $^{197}\text{Au}(n,2n)^{196}\text{Au}$ which cross sections are known well. Meanwhile throughout the irradiation, the neutron flux as a function of irradiation time was recorded continually. It was used to make correction for the influence of neutron flux fluctuation.

The radioactivities of reaction products were measured by Ge(Li) or HPGe detector. Their efficiencies were calibrated quite carefully using a set of standard point γ -ray sources. During the measurement, the counting was done at a distance of 18cm between samples and face of detector for most reactions so that the effects of γ -ray cascade in the detectors was avoided. Meanwhile γ -ray self-absorption in the samples was measured to correct the attenuation of γ -ray in samples.

As mentioned above, in the neutron energy range below 20MeV, four neutron sources, e.g $T(d,n)^4\text{He}$, $D(d,n)^3\text{He}$, $T(p,n)^3\text{He}$ and $^7\text{Li}(p,n)^7\text{Be}$ reactions, are usually used in activation cross section measurement. Theoretically these neutron sources are monoenergetic neutrons at a certain neutron energy region, but in practice there still

exist several kinds of low energy neutrons due to some unavoidable factors in experiment. For instance, the contributions of low energy neutrons(most of them are scattering neutrons) are rather small for ^7Li -p and T-p neutron sources, unless the proton energy is over 2.38 and 7.08MeV, when the interference reactions such as $^7\text{Li}(\text{p},\text{n})^7\text{Be}^*$ 1st and $^7\text{Li}(\text{p},\text{n})^7\text{Be}^{**}$ 2nd are open. But the conditions will be very different from T-d and D-d neutron sources, as they are usually affected by various kinds of low energy neutrons particularly for D-d neutron source.

Table 2 Frequently used neutron sources at accelerators

reaction	incident energy, MeV (effective monoenergetic range)	neutron energy, MeV (monoenergetic neutron energy range)	type of accelerators	notes
$^7\text{Li}(\text{p},\text{n})^7\text{Be}$	1.881—7 (1.881—2.37)	0.03—5.3 (0.03—0.6)	VDG Tandem HI-13	$E_p > 2.37\text{MeV}$ the $^7\text{Li}(\text{p},\text{n})^7\text{Be}^*$ 1 st (the first excite energy of ^7Be is 0.431 MeV) will be open
$\text{T}(\text{p},\text{n})^3\text{He}$	1.019—12 (1.019 — 8.35)	0.2—11.2 (0.2—7.7)	VDG Cyclo- Tandem HI-13	$E_p > 8.35\text{MeV}$ the $\text{T}(\text{p},\text{np})\text{D}$ reaction will be open
$\text{T}(\text{d},\text{n})^4\text{He}$	0.1—12 (0.1—3.71)	13—29 (13—20)	VDG Cyclo- Tandem HI-13 CCW	$E_d > 3.71\text{MeV}$ the $\text{T}(\text{d},\text{np})\text{T}$ reaction will be open
$\text{D}(\text{d},\text{n})^3\text{He}$	0.1—10 (0.1—4.45)	2—13 (2—7.8)	VDG Cyclo- Tandem HI-13 CCW	$E_d > 4.45\text{MeV}$ the $\text{D}(\text{d},\text{np})\text{D}$ reaction will be open

Usually in the energy range of 6-12MeV, D-d neutron source is used. In this case, the low energy neutrons come from: a. After a long irradiation time, the self-building D target will be formed and thus produces low energy neutrons via $\text{D}(\text{d},\text{n})^3\text{He}$ reaction. b. When the energy of incident d beam is higher than 4.45MeV, the interference reaction $\text{D}(\text{d},\text{np})\text{D}$ is open, which usually called breakup neutrons. c. The primary neutrons interact and scatter with the target, structure and cooling materials, etc. d. The low energy neutrons are produced through charged particle interaction with the target structure materials. These low energy neutrons are mixed with the primary neutron and form a continuous distribution spectrum, of which the intensity depend on incident E_d , irradiated time etc. As an example, Fig.I shows a typical neutron spectrum for D-d neutron source in 7-12MeV energy range, which has been measured by the multiple foil activation technique. The chosen threshold reactions are $^{115}\text{In}(\text{n},\text{n}')^{115m}\text{In}$, $^{58}\text{Ni}(\text{n},\text{p})^{58m+g}\text{Co}$, $^{46}\text{Ti}(\text{n},\text{p})^{46}\text{Sc}$, $^{48}\text{Ti}(\text{n},\text{p})^{48}\text{Sc}$, $^{56}\text{Fe}(\text{n},\text{p})^{56}\text{Mn}$, $^{27}\text{Al}(\text{n},\alpha)^{24}\text{Na}$, $^{54}\text{Fe}(\text{n},\text{p})^{54}\text{Mn}$, $^{54}\text{Fe}(\text{n},\alpha)^{51}\text{Cr}$, $^{181}\text{Ta}(\text{n},2\text{n})^{180m}\text{Ta}$ and $^{197}\text{Au}(\text{n},2\text{n})^{196}\text{Au}$ reactions. The experiment was carried out at HI-13 Tandem accelerator of CIAE using a new gas target and the incident energy of deuteron beam is ~8.4MeV. The neutron spectrum

was calculated using the SAND-II code. Fig. I shows that there exist several different kinds of low energy neutrons, such as D(d,np)d break-up neutrons, low energy D-d neutrons and neutrons scattered by cool water, etc. Therefore, how to deduct the effect of the low energy neutrons reasonably is one of the key questions for getting reliable results.

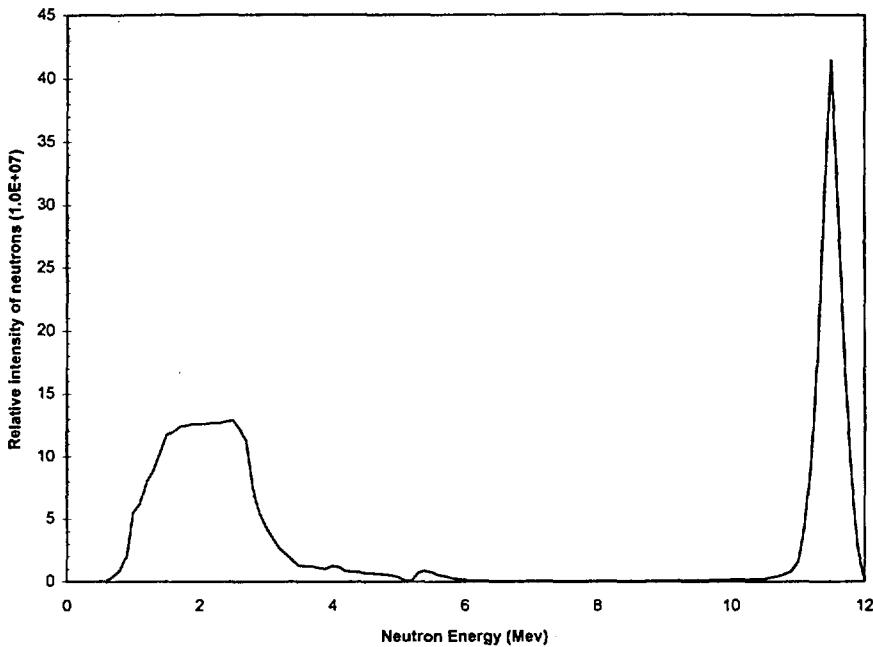


Fig. I Neutron spectra for primary neutron energy at 11.5MeV analysed with SAND-II code

For T-d neutron source, there also exist these low energy neutrons mentioned above except for the breakup neutrons. The intensity of low energy neutrons are dependent on the irradiation time of T-Ti target and incident E_d . This effect is one of the main reason for the discrepancies between the calculation and measurement, and functions the threshold of reactions. In previous measurements, all experimental data are obtained without correction for the effect of low energy neutrons because nearly all experimental researcher thought that this effect is small enough to be ignored. Present work shows that the effect can not be ignored because the contributions of low energy neutrons are rather large. Table 3 shows the measured ingredient of low energy neutrons of T(d,n) ^4He reaction in new or old(used for 120 $\mu\text{A}\cdot\text{h}$) T-Ti target measured by the time-of-flight method at 0° angle. So above 15MeV for low threshold reactions the effect must be deducted reasonably, too.

Generally the effect of low energy neutrons in present work is deducted using different method respectively in different neutron energy range. (1) In 1~6MeV energy region, a new D target was used and the irradiation time was as short as possible for D-d neutron source. (2) In 6~13MeV energy region, the investigated reaction was measured relative to a monitor reaction, which has nearly the same threshold and the similar excitation function shape with the investigated one. In this way, the influence of the low energy neutrons can be subtracted very well. If this

wasn't done easily, a group of monitors were selected with different threshold and irradiated with the investigated reaction together. Thus a relationship between the neutron flux and the thresholds can be obtained. So the neutron flux for the investigated reaction would be got using the relationship according to its threshold. The effect of the low energy neutrons was subtracted using this method for most reactions in this neutron energy range. (3) Above 15MeV energy region, the effect of low energy neutrons was deducted by irradiating a empty target, which is free from T. In addition the corrections of scattered neutrons by target materials, sample holder and sample itself, and of neutron flux attenuation due to target and sample were calculated for each reaction using a Monte Carlo program.

Table 3 Measured ingredient of low energy neutrons in T-Ti target

E_d , MeV	condition of T-Ti target	energy range of D(d,n) neutron, MeV	ratio of N_{D-d}/N_{T-d} , %	peak value of C(d,n) neutron, MeV	ratio of N_{C-d}/N_{T-d} , %
2.0	new	4.75 ~ 5.4	1.4		
2.0	old	3.0 ~ 5.4	5.2		
3.0	new	4.6 ~ 6.4	6.6	2.8	13.6
3.0	old	4.0 ~ 6.4	27.4	2.8	16.4

Present measured results for each reaction are listed in Table 4 in an order of atomic number of elements.

3. Brief description of evaluation procedure

On the basis of present measurements and systematic analysis of typical experimental data, the neutron excitation functions for 40 reactions, which have been measured by ourselves since 1989, were evaluated and recommended. The compilations were usually based on EXFOR library and some internal files.

The evaluation procedure in present work as the following steps. a. First of all the experimental conditions of the available measured data —such as neutron source, type of samples, reference reaction, etc. were analyzed physically. Then the data were adjusted by standard reaction cross section, gamma-ray branching ratios, etc. with the latest values. Finally the reliability and systematic deviations of these experimental data could be determined after evaluating the extent of all kinds of interferences semi-quantitatively or quantitatively. b. The type of used samples and the probable interference reactions were checked, when an natural sample was used. If the interference reactions weren't deducted in measurements, they should be deducted properly when evaluated. c. The evaluations were made using a program of orthogonal polynomial fit code for the sets of data or using a theoretical model program to calculate and the calculations were fitted to the measurements. d. Give the evaluated errors.

The evaluations were done in different way for different reactions. For some reactions which have enough measurements, the evaluations were performed in the

energy region of threshold-20MeV using a program of orthogonal polynomial fit for the adopted data sets. For example, $^{58}\text{Ni}(\text{n},\text{p})^{58}\text{Co}$ reaction was done in this way. For some reactions, only a few data were found and/or concentrated on about 14MeV, the evaluation was done by means of theoretical calculations. The reactions of $^{176}\text{Hf}(\text{n},2\text{n})^{175}\text{Hf}$ and etc. was finished in this way. In addition, some reaction such as $^{137}\text{Ba}(\text{n},\text{p})^{137}\text{Cs}$, the theoretical calculation was given due to not enough information of the available measurements.

The evaluated errors depended on measuring errors and fitting errors. The evaluated recommended data are summarized in Table 5 and plotted in figures together with complied results without adjustment, which enclosed in appendix.

4. Brief introduction for some reactions

In this section, a brief explanation is given for the following reactions.

(1) $^{46}\text{Ti}(\text{n},\text{p})^{46}\text{Sc}$

Nine data sets were collected for evaluation. Ti element has five isotopic components, so the activities of ^{46}Sc may produced through the following reactions: $^{46}\text{Ti}(\text{n},\text{p})$, $^{47}\text{Ti}(\text{n},\text{np}+\text{pn}+\text{d})$ and $^{48}\text{Ti}(\text{n},\text{t})$, if the natural sample was used. Therefore two excitation functions for $^{46}\text{Ti}(\text{n},\text{p})^{46}\text{Sc}$ reaction were given in present evaluation. One is for using natural sample, another for isotopic sample shown in Figs. 2 and 3 respectively.

(2) $^{59}\text{Co}(\text{n},\text{p})^{59}\text{Fe}$

Thirteen complied data sets are shown in Fig. 10. In 7-12MeV energy range, present measured data and W.Mannhart's measurements are in good agreement with each other but higher than that of D.L.Smith. Since the carefully correction for the effect of low energy neutrons was made in the newly measurements.

(3) $^{58}\text{Ni}(\text{n},\text{p})^{58m+g}\text{Co}$

Seventeen data sets are shown in Fig.11. In 1-6MeV energy range, cross sections were measured using $^7\text{Li}-\text{p}$, $\text{T}-\text{p}$ and $\text{D}-\text{d}$ neutron sources. Among the three neutron sources, the effect of low energy neutrons for $\text{D}-\text{d}$ is the most serious. So the evaluation was mainly based on the measurements using $^7\text{Li}-\text{p}$ and $\text{T}-\text{p}$ neutron sources. Of course those measurements using $\text{D}-\text{d}$ neutron source were also adopted if the effect of low energy neutrons were deducted or avoided reasonably. In 6-13MeV energy range, our measured data are higher than early data, but in agreement with that in 1991. This may be due to the correction for the effect of low energy neutrons for early measurements was not sufficient. In above 15MeV energy range, present measurements are lower than all other measurements and in agreement with the evaluation of ENDF/B-6 and JENDL-3. As mentioned above, this is due to the effect of low energy neutrons in $\text{T}-\text{d}$ neutron source. In previous measurements the effect wasn't deducted. Present work shows that the effect of low energy neutron may be up to 31% in 18.3MeV. So the correction for the effect of low energy neutrons in present measurements was made by irradiating the sample in $\text{T}-\text{Ti}$ target and empty target,

which is free from T. It can be seen that the values are about 30~50% lower than previous measurements.

(4) $^{58}\text{Ni}(\text{n},\text{np+pn+d})^{57}\text{Co}$

Eight data sets were collected. Most of them were concentrated on 14MeV neutron energy region. In energies of 13~19MeV only two data sets were found. As Huang Jianzhou's measurements were wrong due to the erroneous efficiencies of NaI(Tl) detector, the A.Pavlik's measurements were adopted. Our measurements provide the first data in "gap region" near threshold.

(5) $^{64}\text{Zn}(\text{n},\text{p})^{64}\text{Cu}$

Eleven data sets can be seen in Fig.16. Besides us D.C.Santry measured the whole energy range, which are higher than all other measurements. In their measurement, NaI(Tl) detector was used. The subtraction of the interference reactions was not sufficient, which may be the reason for the discrepancies. In 6-13MeV energy range, D.L.Smith's measurements are lower than our data. In above 15MeV energy range, our measured data are lower than most of the other measurements. As we deducted the effect of low energy neutrons reasonably, we think that present measured data are rather accurate data in this energy range.

(6) $^{85}\text{Rb}(\text{n},2\text{n})^{84}\text{Rb}$

There was few measurements near threshold and a large discrepancies above 15MeV energy range. Therefore, we measured it in the two energy ranges. Among the available measurements, the values of R.J.Prestwood and H.A.Tewes are higher than others. Besides in the energies of 13~15MeV, M.Bormann's measurements is in agreement with present measurements. Considering most of the measurements being measured before 1980, the evaluation was mainly based on our present measured data.

(7) $^{176}\text{Hf}(\text{n},2\text{n})^{175}\text{Hf}$

Nine data sets were collected and plotted in Fig. 34, along with the evaluations of ENDF/B-6, JENDL-3, etc. Most of them were concentrated on 14MeV and in rather agreement with each other. In below 14MeV energy range, the deviation between our data, which were measured relative to $^{93}\text{Nb}(\text{n},2\text{n})^{92m}\text{Nb}$ reaction, and J.W.Meadows's one, which relative to $^{58}\text{Ni}(\text{n},\text{p})^{58}\text{Co}$ reaction, is about 200%. From Fig. 34 one can easy find that the deviation between JEF-2 and ENDF/B-6 is about 100%. At high energy, there was only our measurement at 18MeV. As the $^{177}\text{Hf}(\text{n},3\text{n})^{175}\text{Hf}$ reaction which threshold is 14.6MeV is open, the correction was made for the effect of interference reaction in the present measurement. Present evaluated data were based on measured data in low and high energy ranges by means of theoretical calculation.

(8) $^{181}\text{Ta}(\text{n},2\text{n})^{180m}\text{Ta}$

Seven data sets are plotted in Fig. 35. From threshold to 12MeV energy range there was no measured data. So we measured it to provide data in "gap region". In above 12MeV energy range, the available data can be divided into two groups

according to their values. The data of Lu Hanlin are higher than that of R.J.Prestwood and M.Bormann. This discrepancies were caused by using different decay scheme. So the available data were adjusted with Ryves's decay scheme before evaluation. Present evaluation was mainly based on measured data of T.B.Ryves, Y.Ikeda, Lu Hanlin and present measurement.

(9) $^{185}\text{Re}(n,2n)^{184\text{m}^+\text{g}}\text{Re}$

Six data sets were collected for evaluation, which are shown in Fig. 36. All measurements were concentrated on 14MeV and there was a large discrepancy. We measured the γ -ray self-absorbtion in Re sample. The correction for the γ -ray self-absorbtion in sample with 0.05mm thick is up to 20%. The correction for M.B.Blinov's measurements with 0.4mm thick sample was less than 10% and the correction in C.Konno's measurements with 2mm thick sample was not mentioned. Of course, most of γ rays of isomeric and ground states are mixed, and this may cause some deviations, but this is not the main reason for the discrepancies. Present evaluations were taken from theoretical calculations based on present and Wang Xiuyuan's measurements.

(10) $^{187}\text{Re}(n,2n)^{186\text{g}}\text{Re}$

Only four data sets were collected and concentrated on 14MeV. All measurements can be divided into two groups. One is before 1967, another is Fan Tieshuan's in 1992, which branching ratio of 137keV γ -ray was 8.5%. We re-evaluated the decay data of $^{186\text{g}}\text{Re}$ and recommended branching ratio of 137keV γ -ray is 8.83%. Present recommended datum at 14.8MeV was based on Fan Tieshuan's measurement corrected with new decay data. The evaluated excitation function was taken from the theoretical calculations.

5. Conclusion

The reliability of present work compared with previous published compilations^[16] are greatly improved. It mainly embodies in having been solved reasonably the effect of low energy neutrons in the measuring cross sections of 28 reactions.

In the energy range of 7-13MeV, the measured data are scarce and have a large discrepancy due to lacking of good monoenergetic neutron source. We have studied the neutron spectra at different experimental conditions by multiple foil activation technique, the effect of low energy neutrons on activation cross section measurement and their deducting method. Therefore, present measurement is more reliable than before. In the energy range of 17-19MeV, we have investigated the neutron spectrum for $T(d,n)^4\text{He}$ reaction by T-O-F method. The effect of low energy neutrons under our experimental conditions is minimum and accordingly deducted by irradiating a empty target, which is free from T. So our measurements are much lower than the collected data for low threshold reactions, and reasonable tendency of cross sections is obtained.

The excitation functions for 40 reactions measured by ourselves since 1989 were evaluated. As the evaluations are done on the basis of new measurements and

improvements of some evaluation means, the reliability of recommended data is much improved. Nevertheless, for some reactions such as of Ba isotopes, only the theoretical calculations were given at present.

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Table 4 Cross section data measured

$^{46}\text{Ti}(\text{n},\text{p})^{46}\text{Sc}$

E_{n} , MeV	σ , mb
6.00 (0.17)	152.1 (9.1)
7.07 (0.19)	208.1 (11.2)
8.37 (0.58)	248.9 (12.9)
9.37 (0.46)	249.1 (12.9)
10.40 (0.33)	273.4 (13.8)
11.40 (0.35)	293.7 (15.4)
14.80 (0.15)	290.0 (7.0)
19.1 (0.3)	297.0 (30.0)

$^{54}\text{Fe}(\text{n},\alpha)^{51}\text{Cr}$

E_{n} , MeV	σ , mb
6.00 (0.17)	12.4 (0.8)
7.07 (0.19)	18.1 (1.3)
8.37 (0.58)	37.1 (1.6)
9.37 (0.46)	44.1 (2.3)
10.40 (0.33)	60.3 (3.0)
11.40 (0.35)	63.9 (3.2)

$^{47}\text{Ti}(\text{n},\text{p})^{47}\text{Sc}$

E_{n} , MeV	σ , mb
6.00 (0.17)	76.6 (3.7)
7.07 (0.19)	87.6 (4.0)
8.37 (0.58)	106.2 (5.0)
9.37 (0.46)	114.1 (5.9)
10.40 (0.33)	125.7 (6.3)
11.40 (0.35)	120.8 (6.3)
14.00 (0.05)	206.0 (6.0)
14.80 (0.15)	291.0 (7.0)
17.3 (0.2)	898.0 (44.0)
17.9 (0.3)	919.0 (51.0)
19.1 (0.3)	1156.0 (83.0)

$^{56}\text{Fe}(\text{n},\text{p})^{56}\text{Mn}$

E_{n} , MeV	σ , mb
14.00 (0.05)	113.6 (2.8)
14.70 (0.15)	108.6 (2.7)
17.3 (0.2)	66.2 (2.6)
19.1 (0.3)	46.8 (3.3)

$^{59}\text{Co}(\text{n},\text{p})^{59}\text{Fe}$

E_{n} , MeV	σ , mb
6.00 (0.17)	19.1 (1.1)
7.07 (0.19)	22.1 (1.2)
8.37 (0.58)	30.6 (1.6)
9.37 (0.46)	35.7 (1.9)
10.40 (0.33)	49.2 (2.6)
11.40 (0.35)	53.4 (2.8)

$^{54}\text{Fe}(\text{n},\text{p})^{54}\text{Mn}$

E_{n} , MeV	σ , mb
6.00 (0.17)	500.0 (28.3)
7.07 (0.19)	537.2 (30.4)
8.37 (0.58)	502.9 (21.7)
9.37 (0.46)	530.2 (25.9)
10.40 (0.33)	530.5 (25.7)
11.40 (0.35)	506.5 (24.8)
14.00 (0.05)	345.0 (9.0)
14.70 (0.15)	289.0 (7.0)
17.3 (0.2)	151.0 (20.0)

$^{58}\text{Ni}(\text{n},\text{p})^{58m+g}\text{Co}$

E_{n} , MeV	σ , mb
4.00 (0.16)	352.4 (5.6)
4.9 (0.1)	481.1 (7.5)
6.00 (0.13)	581.1 (14.0)
7.00 (0.15)	628.6 (15.9)
14.00 (0.02)	356.8 (8.9)
17.99 (0.15)	101.0 (11.0)
19.02 (0.22)	89.8 (5.4)

$^{58}\text{Ni}(\text{n},\text{np+pn+d})^{57}\text{Co}$

E_{n}, MeV	σ, mb
9.37 (0.46)	0.37 (0.02)
9.5 (0.5)	2.8 (0.3)
9.9 (0.5)	7.8 (0.6)
10.40 (0.33)	42.1 (2.7)
11.40 (0.35)	175.0 (11.2)
12.81 (0.20)	388 (13)
13.55 (0.12)	516 (16)
14.0 (0.1)	585 (16)
14.62 (0.24)	673 (19)
14.85 (0.32)	688 (20)

$^{64}\text{Zn}(\text{n,p})^{64}\text{Cu}$

E_{n}, MeV	σ, mb
4.00 (0.16)	132.9 (3.8)
4.9 (0.1)	181.6 (6.3)
6.00 (0.13)	205.2 (7.9)
7.00 (0.15)	219.5 (8.4)
8.37 (0.58)	235 (12)
9.37 (0.46)	251 (14)
9.5 (0.5)	257 (13)
9.9 (0.5)	249 (13)
10.40 (0.33)	249 (13)
11.40 (0.35)	243 (12)
14.65 (0.20)	134 (4)
17.99 (0.15)	61 (8)
19.02 (0.02)	57 (5)

$^{60}\text{Ni}(\text{n,p})^{60\text{m+g}}\text{Co}$

E_{n}, MeV	σ, mb
6.00 (0.17)	28.0 (2.8)
7.07 (0.19)	76.5 (4.2)
8.37 (0.58)	89.1 (4.5)
9.37 (0.46)	105.5 (5.3)
10.40 (0.33)	126.0 (6.5)
11.40 (0.35)	161.8 (8.5)

$^{62}\text{Ni}(\text{n},\alpha)^{59}\text{Fe}$

E_{n}, MeV	σ, mb
8.37 (0.58)	4.85 (0.27)
9.37 (0.46)	7.13 (0.38)
10.40 (0.33)	9.71 (0.49)
11.4 (0.35)	15.48 (0.81)

$^{63}\text{Cu}(\text{n},\alpha)^{60}\text{Co}$

E_{n}, MeV	σ, mb
6.00 (0.17)	9.0 (0.8)
7.07 (0.19)	19.5 (1.9)
8.37 (0.58)	24.7 (1.7)
9.37 (0.46)	29.1 (2.1)
10.40 (0.33)	40.4 (2.0)
11.40 (0.35)	47.7 (2.5)

$^{71}\text{Ga}(\text{n},\gamma)^{72}\text{Ga}$

E_{n}, MeV	σ, mb
2.53E-08	4620 (90)
0.31 (0.02)	33.4 (1.5)
0.51 (0.03)	22.1 (1.1)
1.05 (0.03)	12.4 (0.7)
1.58 (0.04)	7.7 (0.4)

$^{85}\text{Rb}(\text{n},2\text{n})^{84\text{m+g}}\text{Rb}$

E_{n}, MeV	σ, mb
10.60 (0.27)	3.1 (1.4)
11.61 (0.30)	202.1 (9.3)

$^{93}\text{Nb}(\text{n},2\text{n})^{92\text{m}}\text{Nb}$

E_{n}, MeV	σ, mb
10.45 (0.34)	215.4 (10.3)
10.60 (0.27)	238.1 (11.4)
11.47 (0.36)	337.3 (16.2)
11.61 (0.30)	350.3 (16.8)

$^{92}\text{Mo}(\text{n},\text{p})^{92m}\text{Nb}$

E_n , MeV	σ , mb
5.03 (0.17)	42.6 (2.3)
6.00 (0.17)	69.1 (3.9)
6.57 (0.19)	73.7 (3.5)
7.07 (0.19)	82.8 (4.4)
8.37 (0.58)	85.8 (3.9)
9.37 (0.46)	95.0 (4.3)
10.40 (0.33)	104.7 (5.5)
11.40 (0.35)	118.0 (6.4)
14.00 (0.05)	70.3 (2.1)
14.70 (0.15)	61.0 (1.8)
14.83 (0.15)	56.4 (2.0)
17.3 (0.2)	36.5 (3.5)
19.09 (0.22)	29.8 (1.5)

$^{175}\text{Lu}(\text{n},2\text{n})^{174m+p}\text{Lu}$

E_n , MeV	σ , mb
10.5 (0.4)	1403 (70)
11.5 (0.4)	1610 (83)
13.5 (0.3)	1744 (122)
14.00 (0.05)	1833 (128)
14.44 (0.12)	1823 (79)
14.47 (0.12)	1870 (80)
14.60 (0.15)	1833 (128)
14.80 (0.15)	1766 (76)
15.0 (0.2)	1795 (125)

$^{140}\text{Ce}(\text{n},2\text{n})^{139}\text{Ce}$

E_n , MeV	σ , mb
10.60 (0.27)	505.8 (22.5)
11.61 (0.30)	898.6 (41.2)

$^{176}\text{Hf}(\text{n},2\text{n})^{175}\text{Hf}$

E_n , MeV	σ , mb
10.60 (0.27)	1648 (71)
11.61 (0.30)	1759.9 (80.6)
14.2 (0.2)	2081 (108)
14.7 (0.2)	2166 (112)
18.0 (0.3)	1743.2 (175.0)

$^{159}\text{Tb}(\text{n},\gamma)^{160}\text{Tb}$

E_n , MeV	σ , mb
0.57 (0.03)	298.8 (15.5)
1.10 (0.03)	179.0 (10.7)
1.60 (0.04)	120.6 (7.2)

$\text{Hf}(\text{n},\text{xn})^{175}\text{Hf}$

E_n , MeV	σ , mb
10.60 (0.27)	85.8 (3.7)
11.61 (0.30)	94.1 (4.2)
14.2 (0.2)	108.3 (5.6)
14.7 (0.2)	112.8 (5.8)
18.0 (0.3)	220.7 (13.0)

$^{169}\text{Tm}(\text{n},\gamma)^{170}\text{Tm}$

E_n , MeV	σ , mb
0.57 (0.03)	160.3 (10.1)
1.10 (0.03)	99.7 (6.9)
1.60 (0.04)	95.5 (6.7)

$^{180}\text{Hf}(\text{n},\gamma)^{181}\text{Hf}$

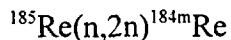
E_n , MeV	σ , mb
0.52(0.03)	36.3 (1.8)
1.10 (0.03)	45.3 (2.7)
1.60 (0.04)	39.8 (2.4)

$^{175}\text{Lu}(\text{n},2\text{n})^{174m}\text{Lu}$

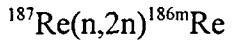
E_n , MeV	σ , mb
10.5 (0.4)	403 (28)
11.5 (0.4)	464 (25)
13.5 (0.3)	528 (36)
14.00 (0.05)	551 (38)
14.44 (0.12)	554 (28)
14.47 (0.12)	571 (28)
14.60 (0.15)	576 (39)
14.80 (0.15)	556 (28)
15.0 (0.2)	591 (40)

$^{181}\text{Ta}(\text{n},2\text{n})^{180m}\text{Ta}$

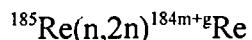
E_n , MeV	σ , mb
8.37 (0.58)	264.3 (10.6)
9.37 (0.46)	706.7 (33.3)
10.40 (0.33)	1008.9 (45.0)
11.40 (0.35)	1190.9 (56.0)



E_n , MeV	σ , mb
14.44 (0.12)	417 (21)
14.47 (0.12)	423 (21)



E_n , MeV	σ , mb
14.77 (0.12)	485 (116)

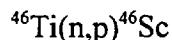


E_n , MeV	σ , mb
14.44 (0.12)	2303 (78)
14.47 (0.12)	2309 (78)

Table 5 Present recommended cross section data



E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
12.9	0.0	13.0	0.8 (0.2)	13.5	5.7 (0.1)
14.0	16.9 (0.3)	14.5	31.8 (0.6)	14.7	37.1 (0.7)
15.0	45.6 (0.9)	16.0	68.6 (3.4)	17.0	87.8 (4.4)
18.0	102.2 (10.2)	19.0	112.0 (11.2)	20.0	118.7 (11.9)



E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
2.0	0.0	2.5	0.005 (0.003)	3.0	0.7 (0.2)
4.0	24.6 (2.5)	5.0	75.0 (3.8)	6.0	143 (8)
7.0	197 (10)	8.0	231 (11)	9.0	252 (12)
10.0	266 (11)	11.0	276 (11)	12.0	280 (11)
13.0	277 (6)	14.0	266 (5)	14.5	257 (5)
14.7	254 (5)	15.0	249 (5)	16.0	231 (11)
17.0	212 (10)	18.0	193 (9)	20.0	155 (12)



E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
2.0	0.0	2.5	0.005 (0.003)	3.0	0.7 (0.2)
4.0	24.6 (2.5)	5.0	75.0 (3.8)	6.0	143 (8)
7.0	197 (10)	8.0	231 (11)	9.0	252 (12)
10.0	266 (11)	11.0	276 (11)	12.0	282 (11)
13.0	286 (6)	14.0	288 (6)	14.5	289 (6)
14.7	289 (6)	15.0	290 (6)	16.0	292 (14)
17.0	294 (15)	18.0	297 (16)	20.0	303 (25)

*: Total ^{46}Sc production in natural Titanium

$^{47}\text{Ti}(\text{n},\text{p})^{47}\text{Sc}$

E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb
0.4	0.0	0.5	0.002 (0.001)	1.0	0.4 (0.1)
2.0	12.4 (1.9)	3.0	32.8 (3.3)	4.0	50.5 (5.1)
5.0	67 (3)	6.0	82 (3)	7.0	95 (4)
8.0	107 (4)	9.0	117 (4)	10.0	127 (4)
11.0	135 (4)	12.0	140 (4)	13.0	143 (3)
14.0	141 (3)	14.5	136 (3)	14.7	133 (3)
15.0	128 (3)	16.0	107 (4)	17.0	85 (3)
18.0	65 (3)	19.0	50 (3)	20.0	40 (2)

$^{47}\text{Ti}(\text{n},\text{p})^{47}\text{Sc}^*$

E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb
0.4	0.0	0.5	0.002 (0.001)	1.0	0.4 (0.1)
2.0	12.4 (1.9)	3.0	32.8 (3.3)	4.0	50.5 (5.1)
5.0	67 (3)	6.0	82 (3)	7.0	95 (4)
8.0	107 (4)	9.0	117 (4)	10.0	127 (4)
11.0	135 (4)	12.0	143 (4)	13.0	157 (4)
14.0	198 (4)	14.5	244 (5)	14.7	269 (5)
15.0	312 (6)	16.0	467 (18)	17.0	671 (27)
18.0	926 (37)	19.0	1156 (56)	20.0	1389 (70)

*: Total ^{47}Sc production in natural Titanium

$^{48}\text{Ti}(\text{n},\text{p})^{48}\text{Sc}$

E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb
4.0	0.0	4.5	0.03(0.01)	5.0	0.09 (0.03)
6.0	1.6 (0.2)	7.0	6.2 (0.4)	8.0	13.0 (0.7)
9.0	20 (1)	10.0	28.3 (1.1)	11.0	38.5 (1.2)
12.0	48.3 (1.5)	13.0	56.5 (1.1)	14.0	61.8 (1.2)
14.5	62.6 (1.2)	14.7	62.7 (1.2)	15.0	62.0 (1.2)
16.0	57.1 (1.8)	17.0	51.2 (2.1)	18.0	45.4 (1.8)
19.0	40.2 (2.1)	20.0	35.5 (3.6)		

$^{54}\text{Fe}(\text{n},\text{p})^{54}\text{Mn}$

E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb
1.5	0.0	1.7	6.0 (1.2)	2.0	24.1 (2.4)
3.0	143.4 (11.5)	4.0	280.0 (14.0)	5.0	396.6 (19.8)
6.0	485.8 (24.3)	7.0	528.7 (26.4)	8.0	551.0 (27.6)
9.0	560.3 (22.4)	10.0	559.8 (22.4)	11.0	536.2 (16.1)
12.0	489.5 (14.7)	13.0	423.5 (8.5)	14.0	345.5 (6.9)
14.5	307.7 (3.1)	14.7	291.6 (2.9)	15.0	269.3 (5.4)
16.0	205.3 (8.2)	17.0	156.5 (7.9)	18.0	121.4 (9.7)
19.0	97.1 (9.7)	20.0	76.5 (11.5)		

$^{54}\text{Fe}(\text{n},\alpha)^{51}\text{Cr}$

E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb
3.0	0.0	3.5	0.08(0.02)	4.0	0.20 (0.04)
5.0	2.8 (0.3)	6.0	10.4 (0.9)	7.0	20.1 (1.1)
8.0	31.0 (1.6)	9.0	41.8 (1.3)	10.0	52.2 (1.5)
11.0	62.6 (1.3)	12.0	72.7 (1.5)	13.0	81.3 (1.2)
14.0	88.4 (1.3)	14.5	90.5 (0.9)	14.7	91.2 (0.9)
15.0	91.4 (1.3)	16.0	87.8 (1.8)	17.0	81.1 (2.4)
18.0	71.2 (2.5)	19.0	59.0 (2.4)	20.0	47.6 (3.8)

$^{56}\text{Fe}(\text{n},\text{p})^{56}\text{Mn}$

E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb
3.0	0.0	3.5	0.002(0.001)	4.5	0.25 (0.06)
5.0	1.06 (0.16)	6.0	12.3 (1.2)	7.0	28.1 (1.4)
8.0	44.7 (2.2)	9.0	60.7 (3.0)	10.0	76.0 (3.1)
11.0	91.1 (3.6)	12.0	104.9 (3.1)	13.0	115.7 (2.3)
14.0	114.6 (2.8)	14.5	110.1 (1.7)	14.7	107.5 (1.6)
15.0	103.2 (2.1)	16.0	85.2 (2.6)	17.0	70.3 (2.8)
18.0	57.7 (2.3)	19.0	48.1 (2.1)	20.0	42.5 (3.4)

$^{59}\text{Co}(\text{n},\text{p})^{59}\text{Fe}$

E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb
2.5	0.0	3.0	0.36(0.08)	4.0	3.3 (0.5)
5.0	8.6 (0.7)	6.0	15.0 (1.2)	7.0	21.8 (1.1)
8.0	28.6 (1.4)	9.0	36.1 (1.4)	10.0	43.9 (1.3)
11.0	51.2 (1.5)	12.0	56.0 (1.7)	13.0	56.4 (1.3)
14.0	52.5 (1.1)	14.5	49.7 (1.0)	14.7	48.5 (0.9)
15.0	46.8 (1.0)	16.0	41.1 (1.2)	17.0	35.4 (1.5)
18.0	29.7 (1.2)	19.0	23.9 (1.9)	20.0	17.8 (1.8)

$^{58}\text{Ni}(\text{n},\text{p})^{58m+g}\text{Co}$

E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb	E_{n} , MeV	σ , mb
0.5	0.0	0.7	0.06(0.01)	1.0	1.06 (0.06)
1.5	11.5 (0.6)	2.0	44.6 (2.7)	2.5	105.7 (6.3)
3.0	188.3 (9.4)	3.5	277.8 (13.9)	4.0	359.6 (18.0)
5.0	485.0 (24.3)	6.0	581.1 (29.1)	7.0	628.6 (25.2)
8.0	650.7 (26.0)	9.0	653.3 (26.1)	10.0	639.6 (25.6)
11.0	612.7 (24.5)	12.0	564.3 (19.8)	13.0	482.4 (16.9)
14.0	365.6 (9.1)	14.5	306.0 (7.7)	14.7	283.6 (7.1)
15.0	255.1 (6.4)	16.0	185.8 (11.1)	17.0	137.1 (8.3)
18.0	106.3 (8.5)	19.0	87.9 (8.8)	20.0	70.2 (7.0)

$^{58}\text{Ni}(\text{n},\text{np+pn+d})^{57}\text{Co}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
9.0	0.0	9.1	0.103 (0.010)	9.5	0.75 (0.08)
10.0	12.7 (0.8)	11.0	108.2 (3.8)	12.0	269.1 (9.4)
13.0	435.1 (15.2)	14.0	572.7 (14.3)	14.7	648.6 (16.2)
15.0	676.5 (37.2)	16.0	750.5 (37.5)	17.0	797.1 (39.9)
18.0	820.1 (41.0)	19.0	829.3 (41.5)	20.0	823.1 (81.3)

$^{60}\text{Ni}(\text{n},\text{p})^{60m+g}\text{Co}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
2.1	0.0	3.0	0.005 (0.003)	3.5	0.10 (0.03)
4.0	0.4 (0.1)	4.5	3.6 (0.4)	5.0	8.9 (0.5)
6.0	28 (1.4)	7.0	52 (2.1)	8.0	79 (3.2)
9.0	109 (4.4)	10.0	135 (5.4)	11.0	158 (6.3)
12.0	170 (4.3)	13.0	169 (4.2)	14.0	153 (3.8)
14.5	140 (2.8)	14.7	135 (2.7)	15.0	127 (3.2)
16.0	102 (6.1)	17.0	82 (6.4)	18.0	69 (6.9)
19.0	59 (5.9)	20.0	51 (5.1)		

$^{62}\text{Ni}(\text{n},\alpha)^{59}\text{Fe}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
4.0	0.0	5.0	0.01(0.003)	5.5	0.08 (0.02)
6.0	0.15 (0.02)	6.5	0.6 (0.06)	7.0	1.2 (0.1)
8.0	3.0 (0.2)	9.0	5.7 (0.3)	10.0	8.9 (0.4)
11.0	12.6 (0.5)	12.0	16.0 (0.4)	13.0	18.9 (0.5)
14.0	20.7 (0.5)	14.7	21.1 (0.4)	15.0	21.1 (0.5)
16.0	20.2 (0.5)	18.0	15.7 (1.3)	20.0	9.9 (1.0)

$^{63}\text{Cu}(\text{n},\alpha)^{60}\text{Co}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
2.0	0.0	2.5	0.006(0.003)	3.0	0.04 (0.01)
3.5	0.15 (0.02)	4.0	0.3 (0.03)	4.5	0.75 (0.08)
5.0	1.4 (0.1)	6.0	6.0 (0.3)	7.0	12.8 (0.6)
8.0	20.5 (1.0)	9.0	28.7 (1.4)	10.0	37.2 (1.9)
11.0	45.0 (1.8)	12.0	51.7 (2.1)	13.0	53.8 (1.6)
14.0	50.8 (1.3)	14.5	47.5 (1.1)	14.7	46.1 (1.1)
15.0	43.9 (1.3)	16.0	35.8 (1.8)	17.0	27.7 (1.4)
18.0	20.5 (2.1)	19.0	14.2 (1.4)	20.0	8.4 (0.9)

$^{64}\text{Zn}(\text{n},\text{p})^{64}\text{Cu}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
1.0	0.0	1.5	0.9(0.1)	2.0	6.7 (0.4)
2.5	36.5 (2.2)	3.0	72 (4)	3.5	108 (5)
4.0	137 (7)	5.0	179 (9)	6.0	207 (9)
7.0	224 (9)	8.0	237 (9)	9.0	246 (10)
10.0	252 (10)	11.0	255 (9)	12.0	249 (9)
13.0	220 (8)	14.0	166 (4)	14.5	142 (3)
14.7	134 (3)	15.0	122 (5)	16.0	93 (5)
17.0	74 (5)	18.0	56.1 (4.5)	19.0	51.9 (4.2)
20.0	46.2 (4.6)				

$^{85}\text{Rb}(\text{n},2\text{n})^{84\text{m}+\text{g}}\text{Rb}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
10.612	0.0	10.75	8.6 (0.5)	11.0	53.4 (3.2)
11.5	221 (9)	12.0	415 (17)	13.0	762 (17)
14.0	989 (22)	14.5	1074 (23)	14.7	1106 (24)
15.0	1149 (25)	16.0	1260 (44)	17.0	1315 (46)
18.0	1330 (200)	19.0	1338 (201)	20.0	1338 (200)

$^{93}\text{Nb}(\text{n},2\text{n})^{92\text{m}}\text{Nb}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
8.8	0.0	9.0	0.64 (0.02)	9.5	35.6 (1.2)
10.0	126 (5)	11.0	296 (10)	12.0	391 (14)
13.0	445 (9)	14.0	457.3 (9.1)	14.7	458.2 (9.2)
15.0	456.2 (9.1)	16.0	441 (13)	17.0	416 (12)
18.0	388 (19)	19.0	361 (18)	20.0	341 (17)

$^{92}\text{Mo}(\text{n},\text{p})^{92\text{m}}\text{Nb}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
2.0	0.0	2.5	0.69 (0.07)	3.0	5.1(0.5)
3.5	11.1 (1.1)	4.0	21.1 (2.1)	5.0	45.1 (4.5)
6.0	65.9 (3.3)	7.0	76.8 (3.8)	8.0	84.9 (4.3)
9.0	94.7 (4.7)	10.0	105.1 (5.3)	11.0	110.1 (5.5)
12.0	106.3 (5.3)	13.0	92.4 (3.0)	14.0	73.7 (2.2)
14.5	65.2 (1.9)	14.7	61.8 (1.6)	15.0	56.8 (2.8)
16.0	45.6 (2.3)	17.0	39.3 (2.0)	18.0	34.5 (1.7)
19.0	29.9 (1.8)	20.0	27.0 (1.6)		

$^{109}\text{Ag}(\text{n},2\text{n})^{108m}\text{Ag}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
9.381	0.0	9.5	2.24 (0.34)	10.0	87.5 (8.8)
10.5	192.8 (9.7)	11.0	301 (15)	12.0	486 (24)
13.0	615 (19)	14.0	700 (14)	14.7	737 (15)
15.0	749 (22)	16.0	773 (31)	17.0	777 (31)
18.0	749 (60)	19.0	664 (53)	20.0	545 (55)

$^{132}\text{Ba}(\text{n},2\text{n})^{131}\text{Ba}^*$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
9.893	0.0	10.0	10.5 (2.1)	10.5	256 (26)
11.0	501 (25)	12.0	995 (50)	13.0	1374 (41)
14.0	1599 (48)	14.5	1670 (50)	14.7	1694 (51)
15.0	1727 (52)	16.0	1806 (90)	17.0	1852 (93)
18.0	1862 (93)	19.0	1717 (172)	20.0	1366 (137)

*: Theoretical calculation.

$^{134}\text{Ba}(\text{n},2\text{n})^{133m}\text{Ba}^*$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
9.827	0.0	10.0	10.1 (2.0)	10.5	88.5 (13.3)
11.0	174 (17)	12.0	347 (35)	13.0	526 (26)
14.0	693 (21)	14.5	753 (23)	14.7	773 (23)
15.0	798 (40)	16.0	848 (43)	17.0	866 (69)
18.0	851 (68)	19.0	729 (73)	20.0	554 (55)

*: Theoretical calculation.

$^{134}\text{Ba}(\text{n},2\text{n})^{133}\text{Ba}^*$

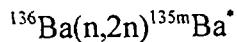
E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
9.539	0.0	10.0	41.2 (8.2)	10.5	210 (21)
11.0	414 (41)	12.0	846 (85)	13.0	1304 (65)
14.0	1652 (50)	14.5	1779 (53)	14.7	1816 (54)
15.0	1863 (93)	16.0	1953 (98)	17.0	1996 (160)
18.0	1940 (155)	19.0	1650 (165)	20.0	1247 (125)

*: Theoretical calculation.

$^{136}\text{Ba}(\text{n},\alpha)^{133m}\text{Xe}^*$

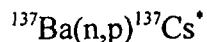
E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
6.0	0.0	8.0	0.002 (0.001)	9.0	0.005 (0.002)
10.0	0.017 (0.002)	11.0	0.049 (0.005)	12.0	0.121 (0.012)
13.0	0.264 (0.026)	14.0	0.496 (0.050)	14.7	0.712 (0.071)
15.0	0.816 (0.082)	16.0	1.20 (0.12)	17.0	1.59 (0.16)
18.0	1.95 (0.10)	19.0	2.21 (0.22)	20.0	2.37 (0.24)

*: Theoretical calculation.



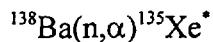
E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
9.443	0.0	9.5	1.98 (0.40)	10.0	128 (13)
11.0	404 (41)	12.0	641 (64)	13.0	812 (41)
14.0	916 (28)	14.5	951 (28)	14.7	964 (28)
15.0	981 (29)	16.0	1024 (51)	17.0	1035 (52)
18.0	917 (46)	19.0	709 (71)	20.0	523 (52)

*: Theoretical calculation.



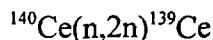
E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
5.0	0.0	6.0	0.052 (0.011)	7.0	0.183 (0.028)
8.0	0.45 (0.05)	9.0	0.89 (0.09)	10.0	1.53 (0.15)
11.0	2.44 (0.25)	12.0	3.65 (0.37)	13.0	5.21 (0.52)
14.0	7.1 (0.4)	14.5	8.2 (0.4)	14.7	8.6 (0.4)
15.0	9.2 (0.5)	16.0	11.4 (1.1)	17.0	13.3 (1.3)
18.0	14.9 (1.5)	19.0	16.0 (1.6)	20.0	16.8 (1.7)

*: Theoretical calculation.



E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
6.0	0.0	6.5	0.002 (0.001)	7.0	0.003 (0.001)
8.0	0.008 (0.002)	9.0	0.028 (0.006)	10.0	0.084 (0.008)
11.0	0.223 (0.022)	12.0	0.537 (0.054)	13.0	1.12 (0.06)
14.0	1.98 (0.06)	14.5	2.49 (0.07)	14.7	2.70 (0.08)
15.0	3.03 (0.09)	16.0	4.09 (0.21)	17.0	4.98 (0.25)
18.0	5.54 (0.28)	19.0	5.69 (0.57)	20.0	5.58 (0.56)

*: Theoretical calculation.



E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
9.2	0.0	9.5	0.35 (0.02)	10.0	197 (11)
11.0	783 (43)	12.0	1326 (73)	13.0	1616 (48)
14.0	1737 (52)	14.5	1770 (53)	14.7	1780 (53)
15.0	1794 (81)	16.0	1831 (82)	17.0	1849 (83)
18.0	1815 (82)	19.0	1633 (80)	20.0	1360 (67)

$^{151}\text{Eu}(n,2n)^{150g}\text{Eu}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
7.987	0.0	8.2	2.9 (0.7)	8.5	26.4 (2.7)
9.0	129.5 (6.5)	10.0	508 (20)	11.0	817 (33)
12.0	1008 (40)	13.0	1132 (34)	14.0	1210 (24)
14.5	1239 (25)	14.7	1250 (25)	15.0	1263 (26)
16.0	1267 (63)	17.0	1207 (96)	18.0	1100 (88)
19.0	912 (91)	20.0	695 (70)		

$^{153}\text{Eu}(n,2n)^{152g+m^2}\text{Eu}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
8.607	0.0	8.8	2.5 (0.5)	9.0	23.8 (3.6)
9.5	180 (18)	10.0	425 (42)	11.0	891 (88)
12.0	1207 (120)	13.0	1409 (70)	14.0	1534 (46)
14.5	1577 (46)	14.7	1593 (46)	15.0	1614 (48)
16.0	1653 (83)	17.0	1619 (130)	18.0	1535 (123)
19.0	1397 (140)	20.0	1223 (122)		

$^{159}\text{Tb}(n,2n)^{158}\text{Tb}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
8.185	0.0	8.5	41 (8)	9.0	216 (22)
9.5	526 (53)	10.0	908 (45)	11.0	1472 (74)
12.0	1755 (88)	13.0	1876 (38)	14.0	1928 (39)
14.5	1935 (39)	14.7	1941 (39)	15.0	1946 (39)
16.0	1927 (96)	17.0	1844 (92)	18.0	1608 (81)
19.0	1324 (132)	20.0	1052 (105)		

$^{175}\text{Lu}(n,2n)^{174m+g}\text{Lu}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
7.711	0.0	8.0	61.5 (3.1)	8.5	312 (16)
9.0	637 (22)	10.0	1227 (43)	11.0	1583 (55)
12.0	1744 (61)	13.0	1811 (63)	14.0	1838 (55)
14.5	1835 (55)	14.7	1829 (55)	15.0	1813 (54)
16.0	1683 (76)	17.0	1420 (64)	18.0	1070 (48)
19.0	753 (34)	20.0	575 (26)		

$\text{Hf}(n, xn)^{175}\text{Hf}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
8.212	0.0	8.3	0.6 (0.2)	8.5	2.7 (0.4)
9.0	21.0 (2.1)	10.0	65.6 (6.6)	11.0	88.2 (4.4)
12.0	98.0 (4.9)	13.0	104.5 (2.1)	14.0	108.3 (2.2)
14.5	109.4 (2.2)	14.7	109.8 (2.2)	15.0	110.9 (2.2)
16.0	123.3 (6.2)	17.0	164.8 (8.3)	18.0	223.7 (11.2)
19.0	274.6 (27.5)	20.0	309.8 (31.0)		

$\text{^{176}Hf}(n, 2n)^{175}\text{Hf}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
8.212	0.0	8.5	70.0 (3.5)	9.0	322 (16)
9.5	742 (37)	10.0	1151 (58)	11.0	1705 (85)
12.0	1971 (99)	13.0	2075 (104)	14.0	2107 (53)
14.7	2108 (53)	15.0	2105 (53)	16.0	2075 (166)
17.0	1990 (159)	18.0	1787 (143)	19.0	1417 (113)
20.0	1024 (82)				

$\text{^{181}Ta}(n, 2n)^{180\text{m}}\text{Ta}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
7.676	0.0	7.8	38.0 (7.6)	8.0	110 (11)
8.5	323 (16)	9.0	528 (26)	10.0	882 (44)
11.0	1138 (57)	12.0	1281 (64)	13.0	1325 (27)
14.0	1314 (26)	14.5	1290 (26)	14.7	1272 (25)
15.0	1245 (25)	16.0	1101 (33)	17.0	888 (27)
18.0	646 (19)	19.0	439 (26)	20.0	287 (18)

$\text{^{185}Re}(n, 2n)^{184\text{m+g}}\text{Re}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
7.711	0.0	8.0	11.1 (1.1)	8.5	223 (22)
9.0	708 (71)	10.0	1572 (157)	11.0	1995 (200)
12.0	2182 (218)	13.0	2267 (90)	14.0	2298 (92)
14.5	2312 (92)	14.7	2317 (93)	15.0	2318 (93)
16.0	2261 (226)	17.0	2013 (201)	18.0	1589 (159)
19.0	1171 (117)	20.0	852 (85)		

$^{185}\text{Re}(n,2n)^{184m}\text{Re}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
7.719	0.0	8.0	0.56 (0.06)	8.5	26.8 (2.7)
9.0	85.1 (8.5)	10.0	210.2 (21.0)	11.0	295.8 (29.6)
12.0	354.2 (35.4)	13.0	393.0 (11.8)	14.0	415.5 (12.5)
14.5	425.0 (12.7)	14.7	428.0 (12.8)	15.0	431.3 (12.9)
16.0	425.2 (42.5)	17.0	389.3 (38.9)	18.0	338.1 (33.8)
19.0	284.3 (28.4)	20.0	233.4 (23.4)		

$^{187}\text{Re}(n,2n)^{186m}\text{Re}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
7.548	0.0	7.7	2.14 (0.21)	8.0	13.7 (1.4)
8.5	66.8 (6.7)	9.0	151.1 (15.1)	10.0	307.0 (30.7)
11.0	396.2 (39.6)	12.0	446.3 (44.6)	13.0	473.8 (47.4)
14.0	491.7 (49.2)	14.5	498.1 (49.8)	14.7	499.2 (49.9)
15.0	498.6 (49.9)	16.0	463.5 (46.4)	17.0	380.6 (38.1)
18.0	287.8 (28.8)	19.0	211.9 (21.2)	20.0	158.6 (15.9)

$^{187}\text{Re}(n,2n)^{186g}\text{Re}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
7.399	0.0	7.7	23.6 (2.4)	8.0	136 (14)
8.5	506 (51)	9.0	922 (92)	10.0	1466 (147)
11.0	1712 (171)	12.0	1818 (182)	13.0	1852 (74)
14.0	1857 (74)	14.5	1858 (74)	14.7	1852 (74)
15.0	1837 (74)	16.0	1672 (167)	17.0	1343 (134)
18.0	997 (100)	19.0	723 (72)	20.0	534 (53)

$^{182}\text{W}(n,n'\alpha)^{178m^2}\text{Hf}$

E_n , MeV	σ , mb	E_n , MeV	σ , mb	E_n , MeV	σ , mb
12.5	0.0	13.5	0.0012 (0.0007)	14.0	0.0045 (0.0003)
14.5	0.0121 (0.0061)	14.8	0.0165 (0.0083)	15.0	0.0261 (0.0131)
16.0	0.0595 (0.0298)	17.0	0.2129 (0.1277)	18.0	0.4941 (0.2965)
19.0	1.3592 (0.8154)	20.0	2.7742 (1.6645)		

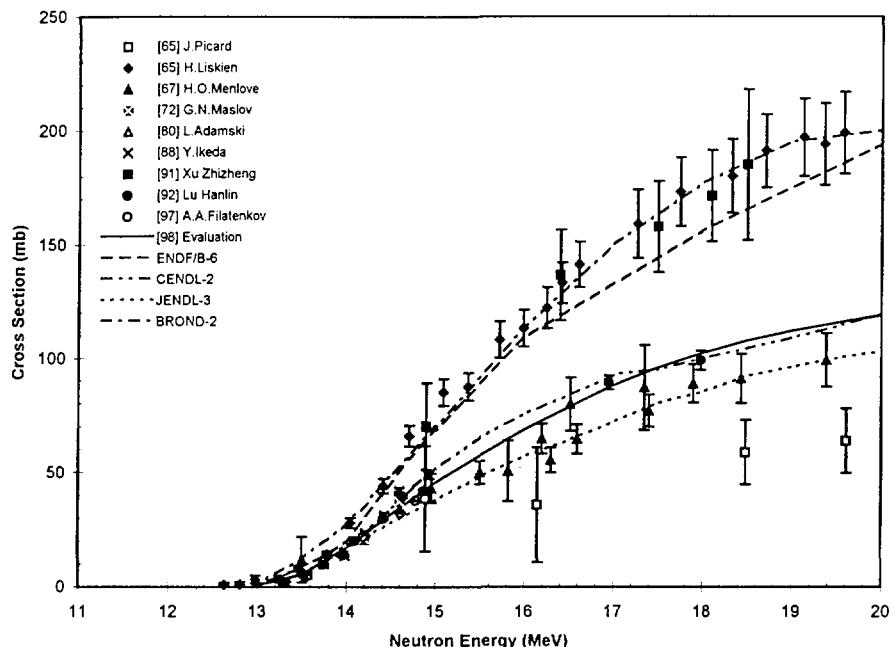


Fig.1 Cross Section for $^{23}\text{Na}(n,2n)\text{Na}^{22}$ Reaction

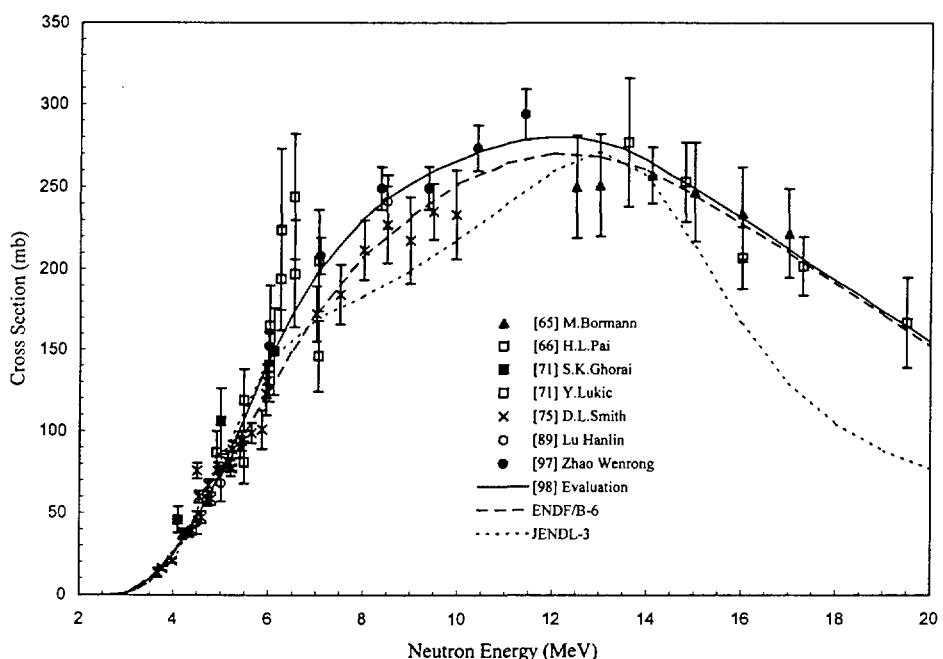


Fig. 2 Cross Section for $^{46}\text{Ti}(n,p)\text{Sc}^{46}$ Reaction

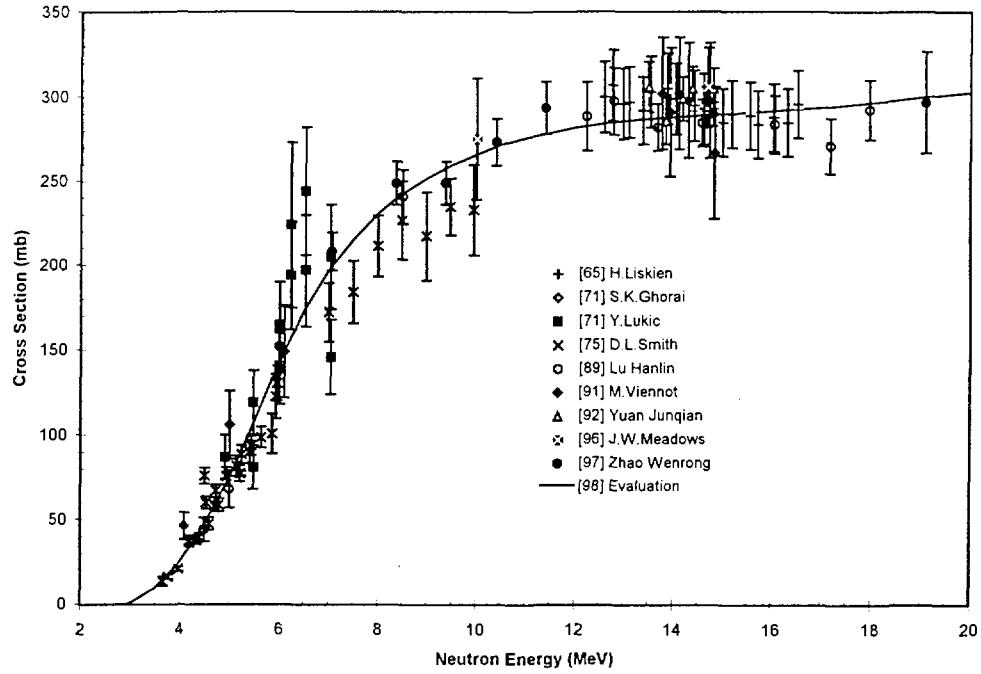


Fig. 3 Cross Section for $^{46}\text{Ti}(n,p)\text{Sc}^{46}$ Reaction
 *: Total ^{46}Sc production in natural Titanium

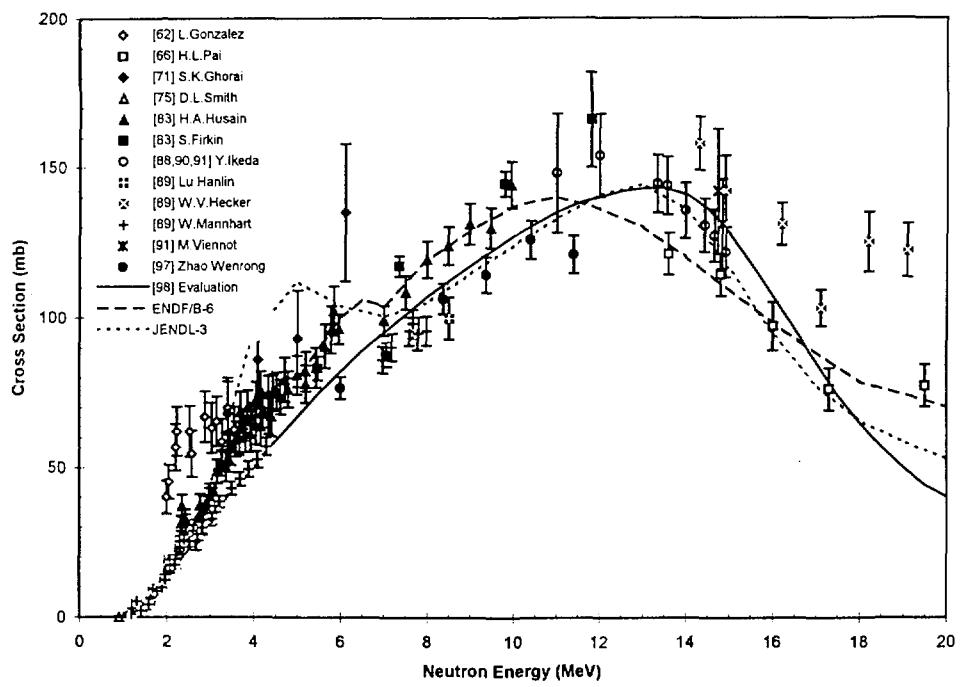


Fig. 4 Cross Section for $^{47}\text{Ti}(n,p)\text{Sc}^{47}$ Reaction

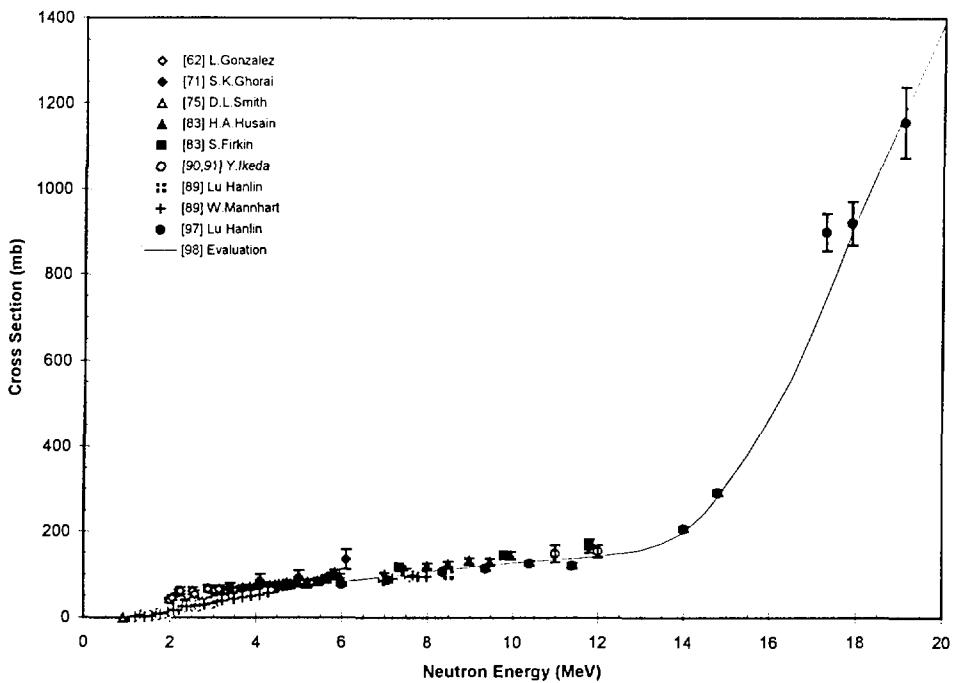


Fig. 5 Cross Section for $^{47}\text{Ti}(n,p)\text{Sc}^{47}$ Reaction
*: Total ^{47}Sc production in natural Titanium

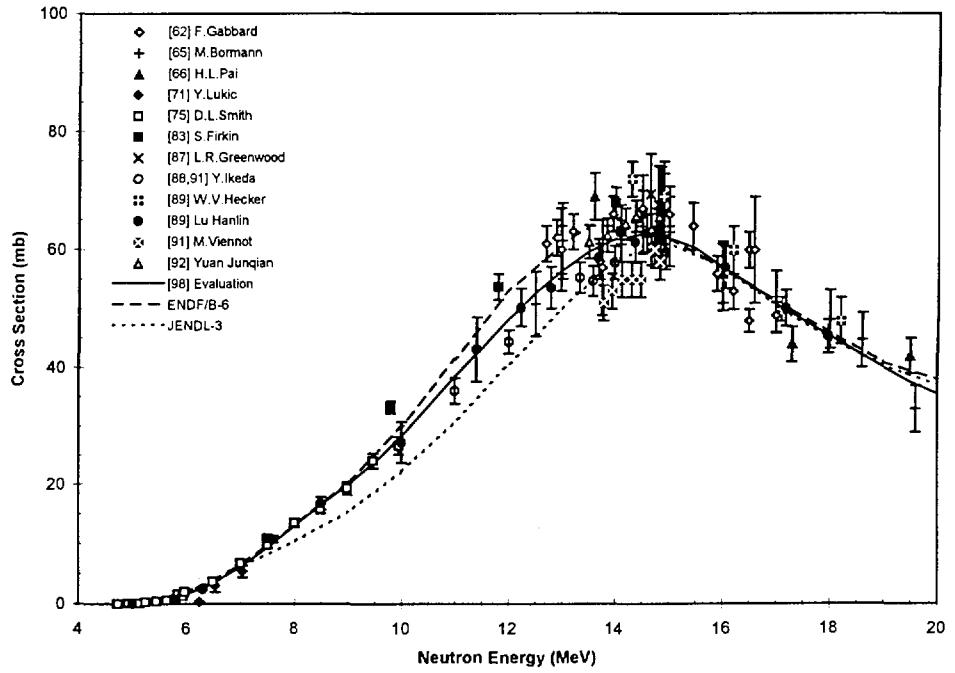


Fig. 6 Cross Section for $^{48}\text{Ti}(n,p)\text{Sc}^{48}$ Reaction

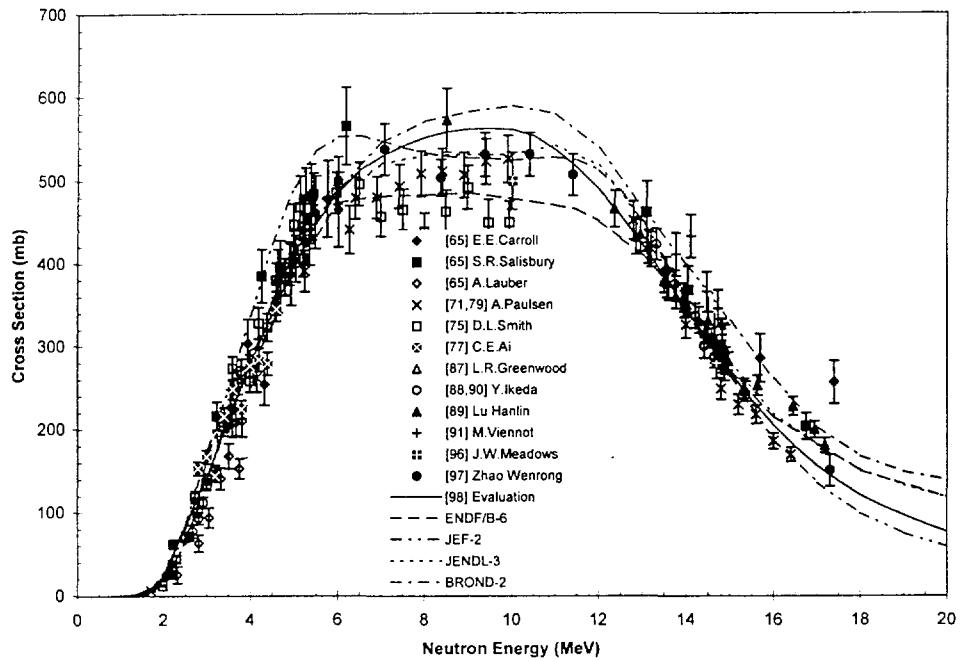


Fig. 7 Cross Section for $^{54}\text{Fe}(\text{n},\text{p})\text{Mn}^{54}$ Reaction

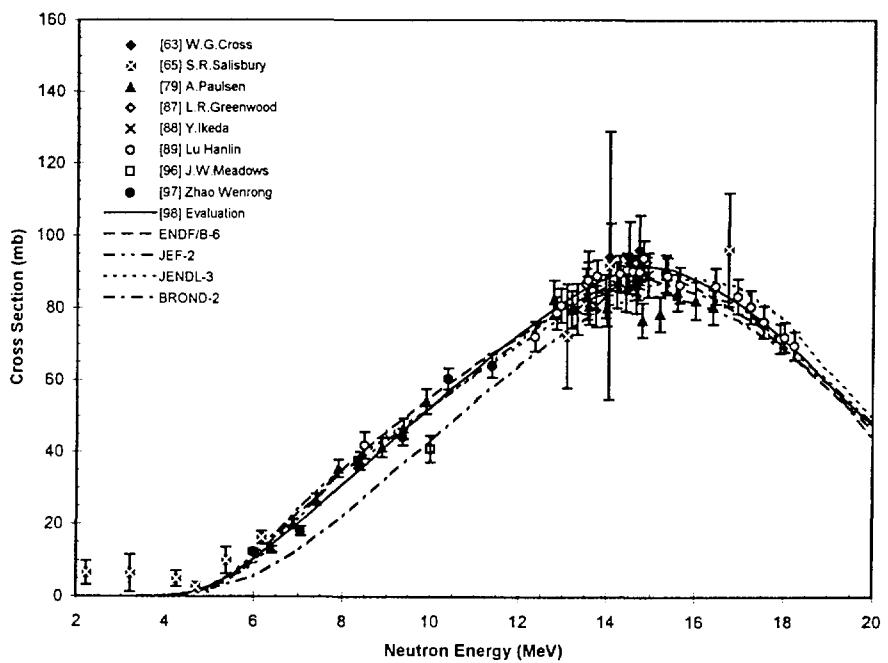


Fig. 8 Cross Section for $^{54}\text{Fe}(\text{n},\text{\alpha})\text{Cr}^{51}$ Reaction

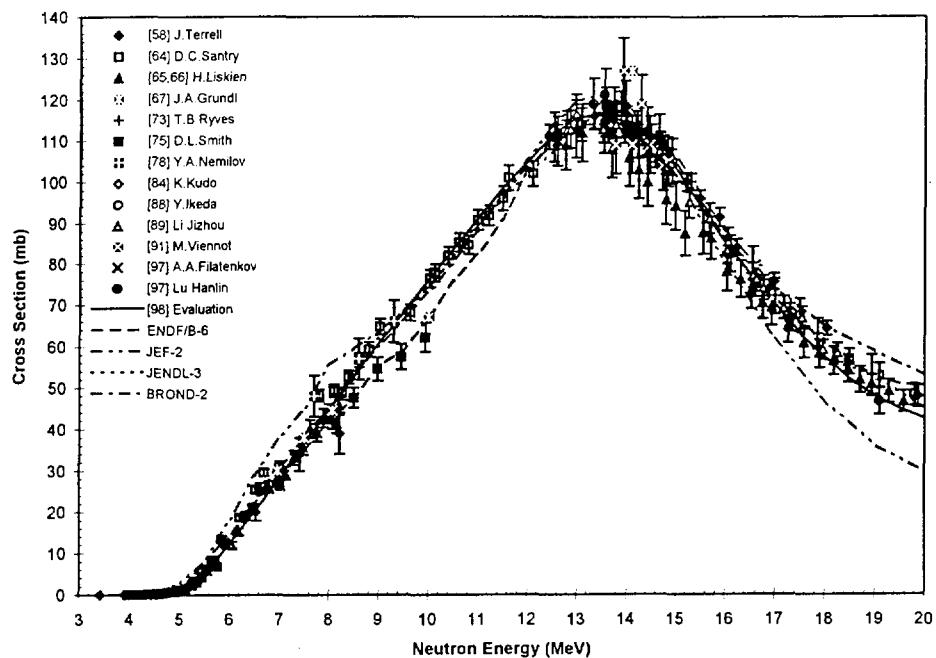


Fig. 9 Cross Section for $^{56}\text{Fe}(\text{n},\text{p})\text{Mn}^{56}$ Reaction

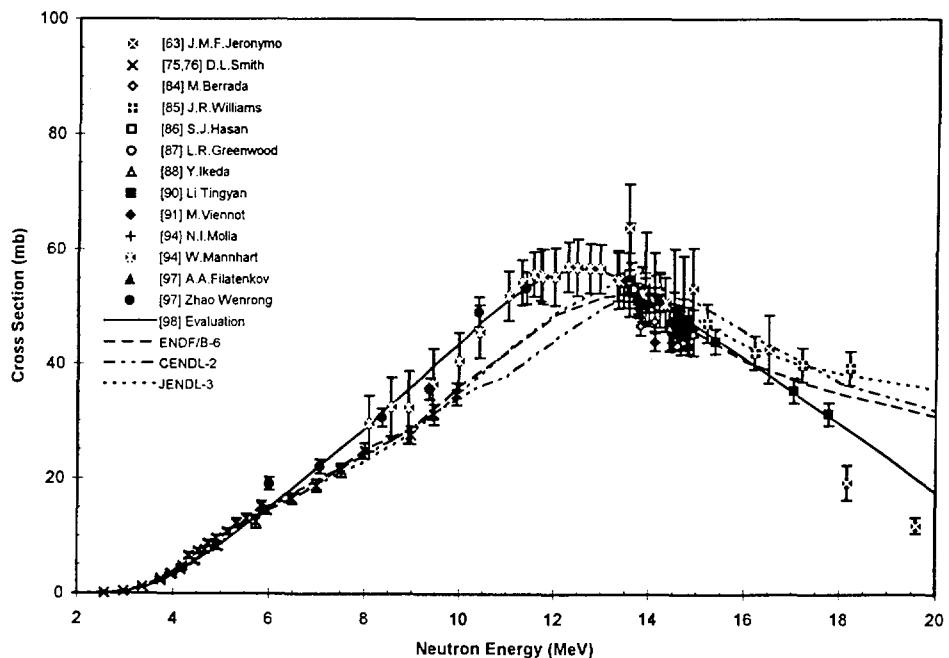


Fig. 10 Cross Section for $^{59}\text{Co}(\text{n},\text{p})\text{Fe}^{59}$ Reaction

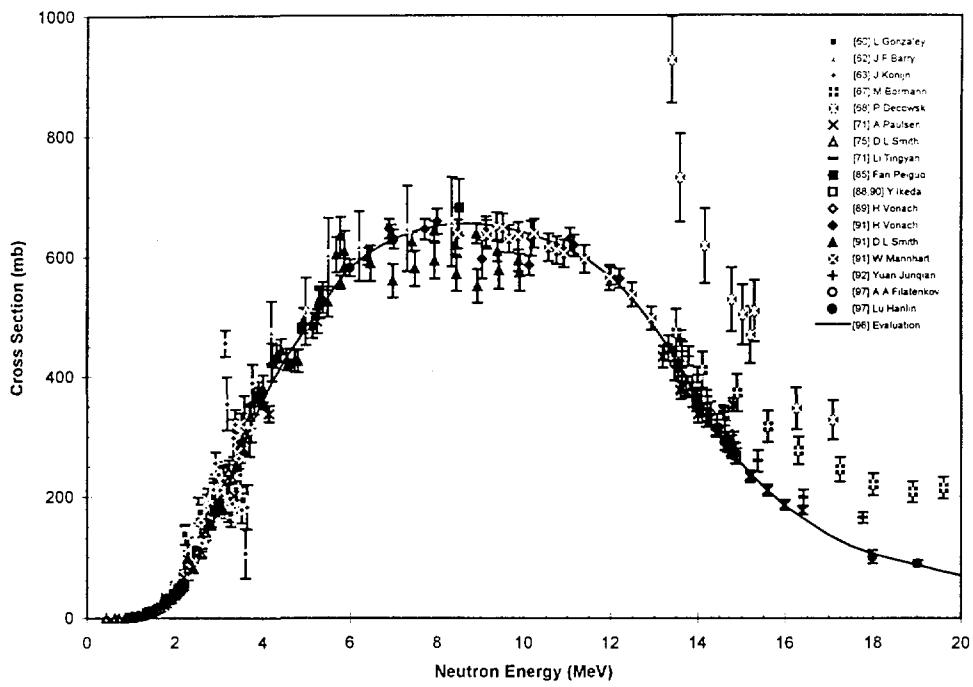


Fig. 11 Cross Section for $^{58}\text{Ni}(n,p)\text{Co}^{58m+g}$ Reaction

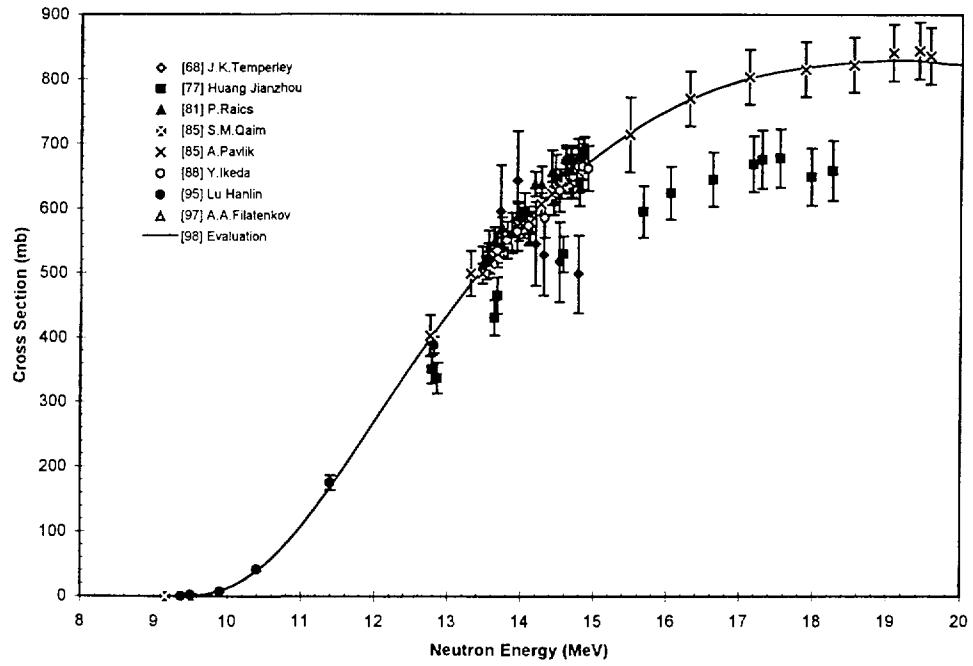


Fig. 12 Cross Section for $^{58}\text{Ni}(n,np+pn+d)\text{Co}^{57}$ Reaction

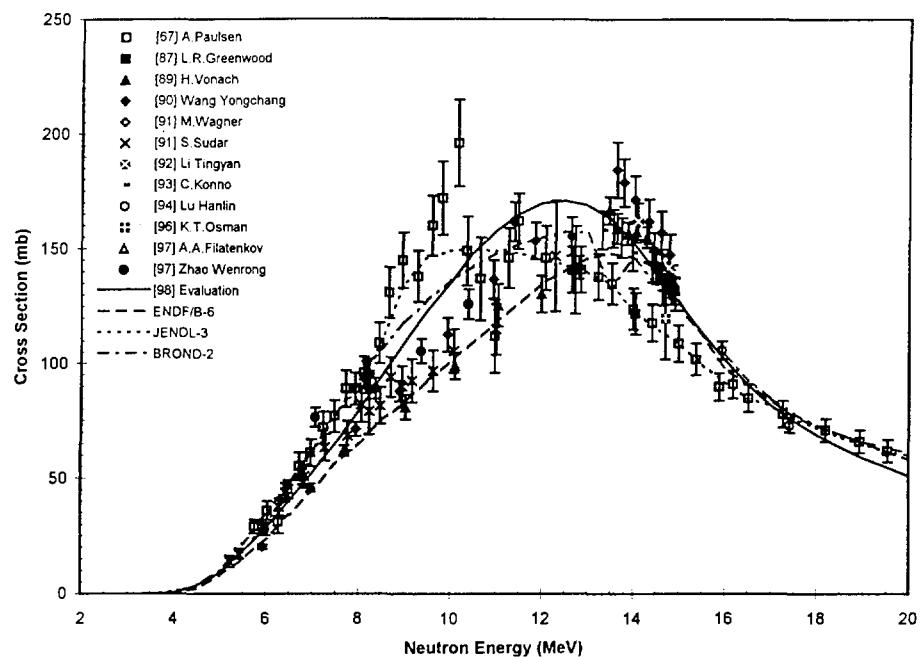


Fig. 13 Cross Section for $^{60}\text{Ni}(\text{n},\text{p})\text{Co}^{60\text{m}+\text{g}}$ Reaction

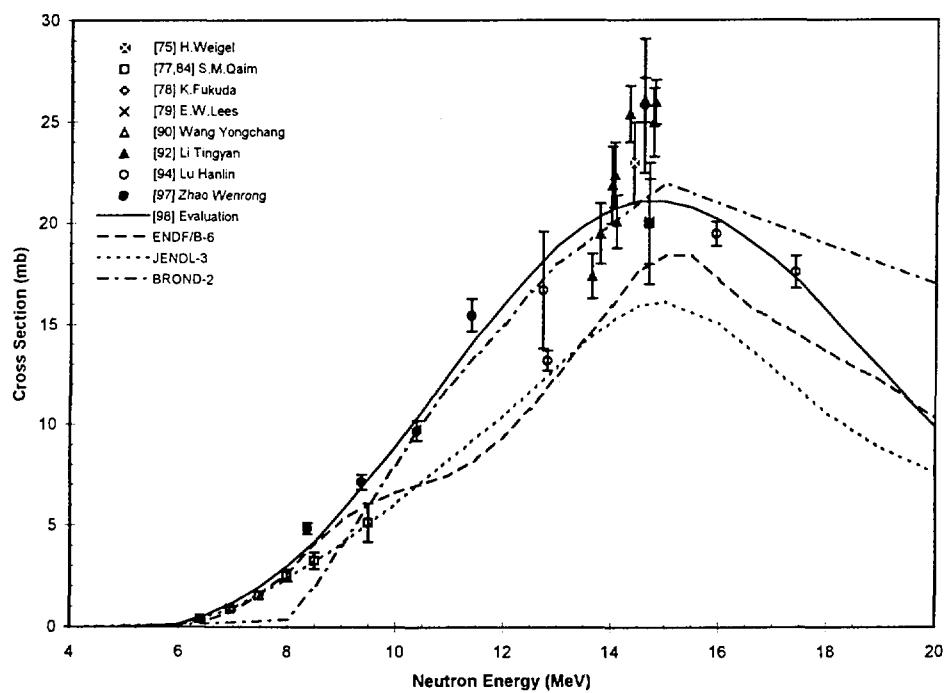


Fig. 14 Cross Section for $^{62}\text{Ni}(\text{n},\alpha)\text{Fe}^{59}$ Reaction

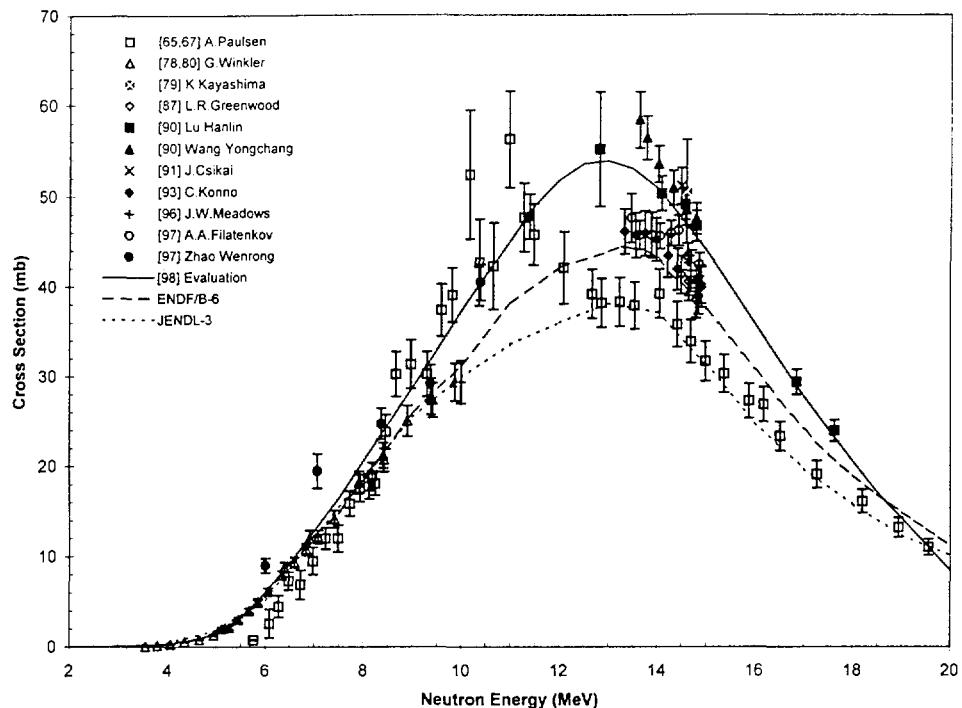


Fig. 15 Cross Section for $^{63}\text{Cu}(n,\alpha)\text{Co}^{60}$ Reaction

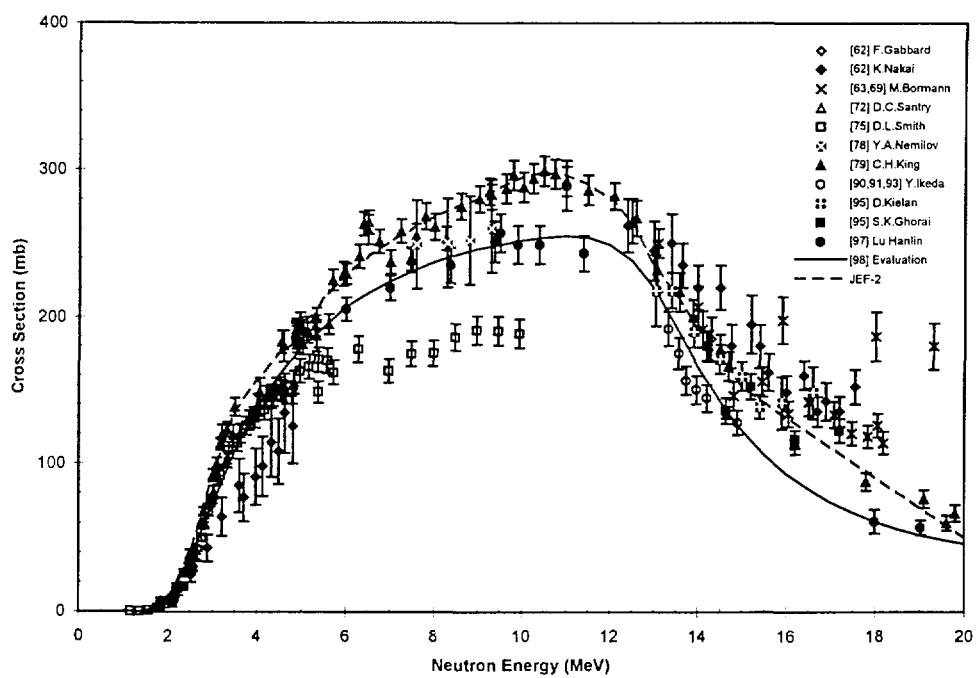


Fig. 16 Cross Section for $^{64}\text{Zn}(n,p)\text{Cu}^{64}$ Reaction

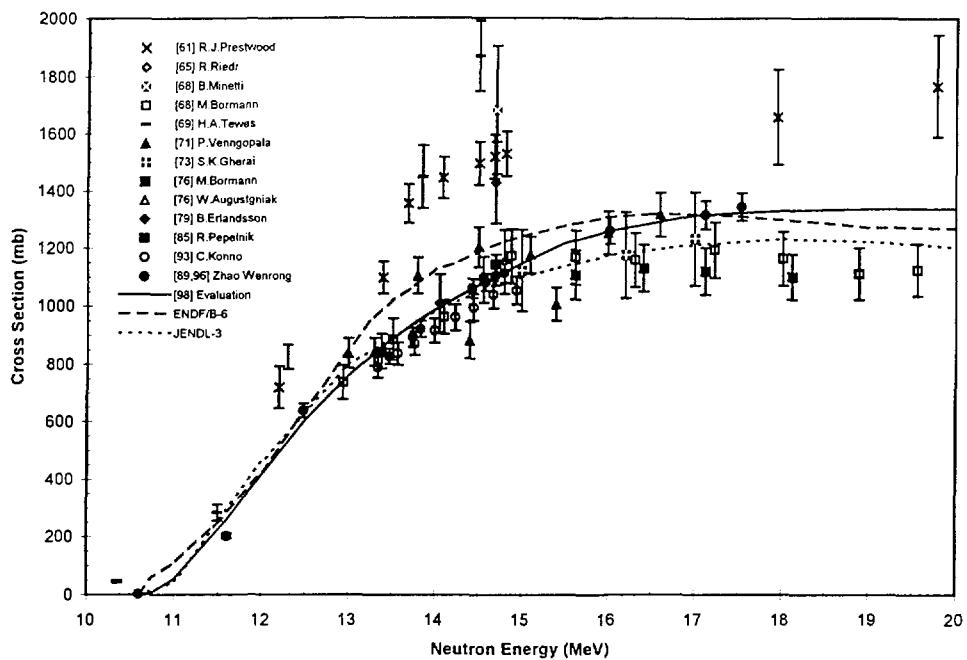


Fig. 17 Cross Section for $^{85}\text{Rb}(n,2n)\text{Rb}^{84\text{m}+g}$ Reaction

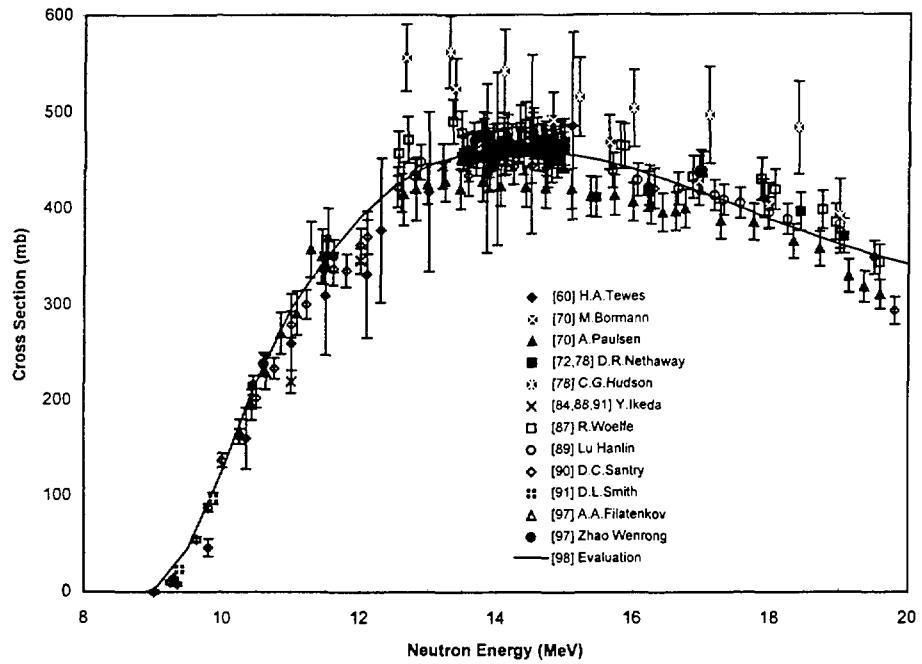


Fig. 18 Cross Section for $^{93}\text{Nb}(n,2n)\text{Nb}^{92\text{m}}$ Reaction

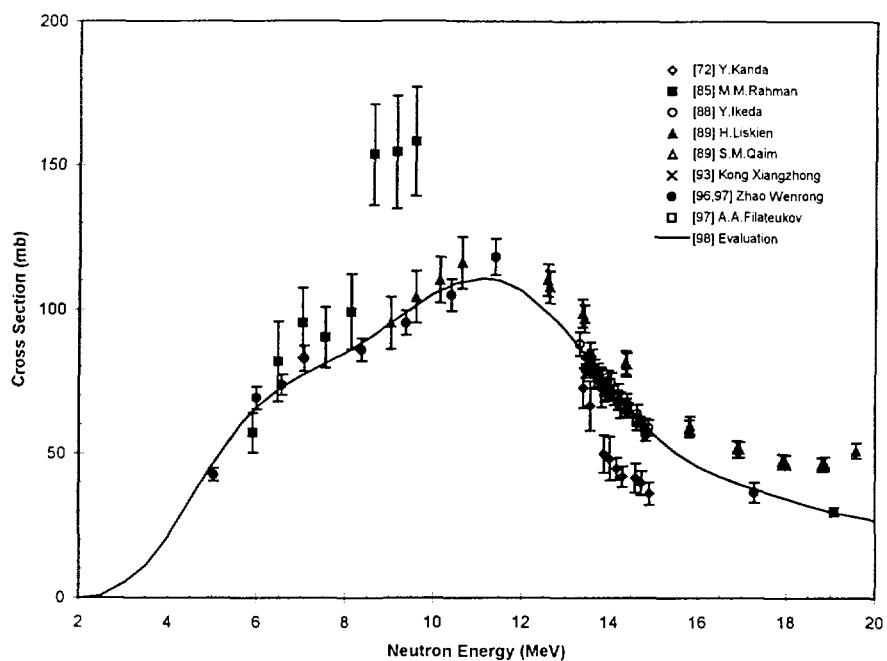


Fig. 19 Cross Section for $^{92}\text{Mo}(n,p)^{92}\text{Nb}$ Reaction

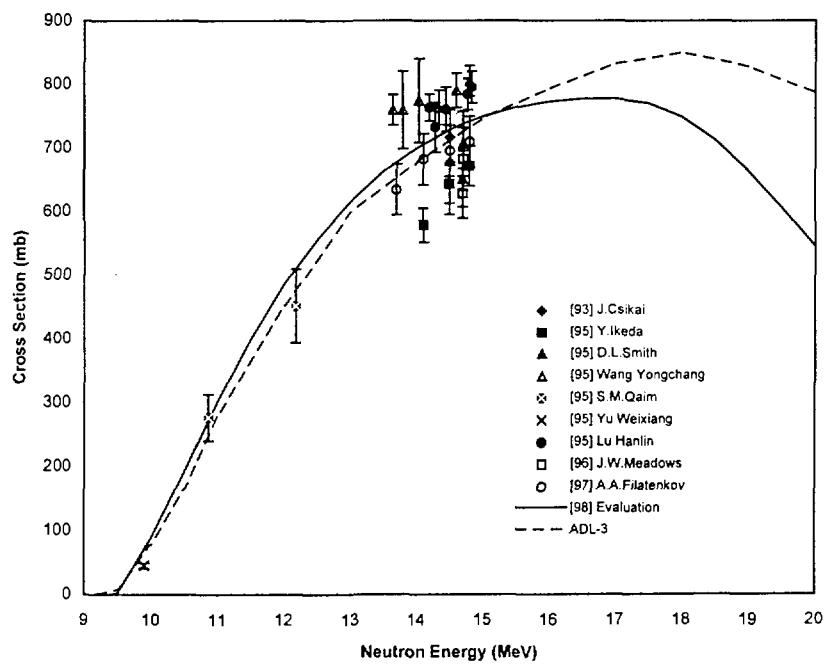


Fig. 20 Cross Section for $^{109}\text{Ag}(n,2n)^{108}\text{Ag}$ Reaction

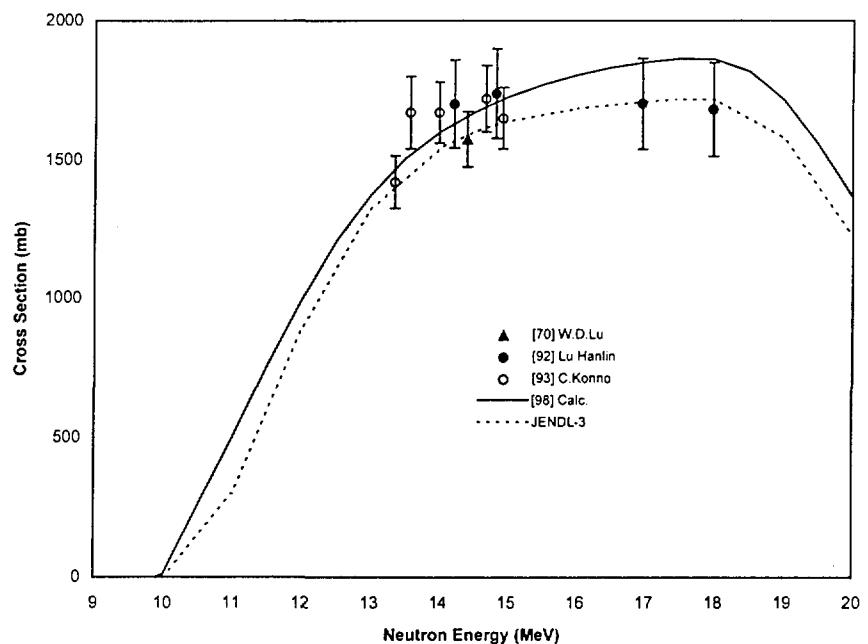


Fig. 21 Cross Section for $^{132}\text{Ba}(n,2n)^{131}\text{Ba}$ Reaction

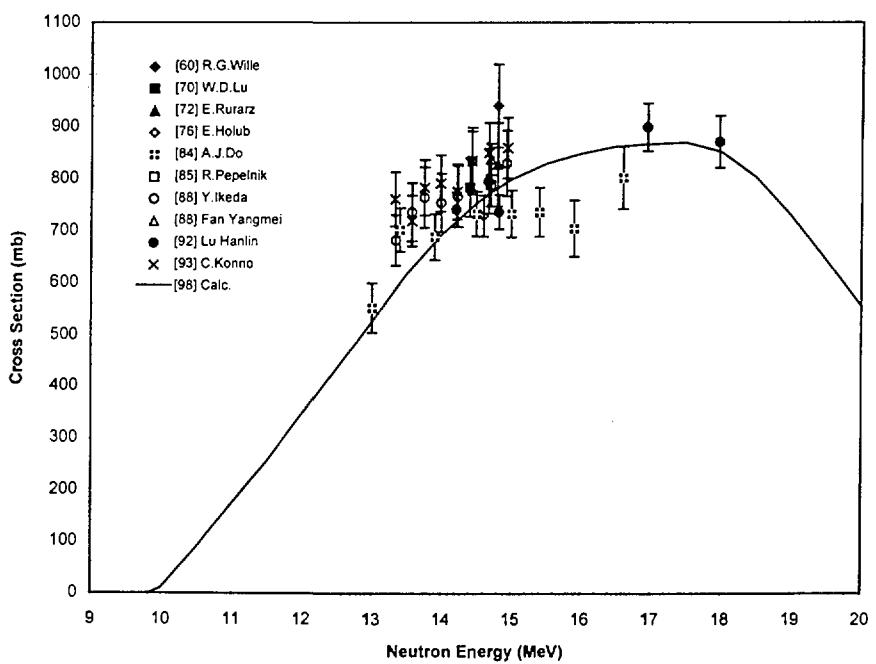


Fig. 22 Cross Section for $^{134}\text{Ba}(n,2n)^{133\text{m}}\text{Ba}$ Reaction

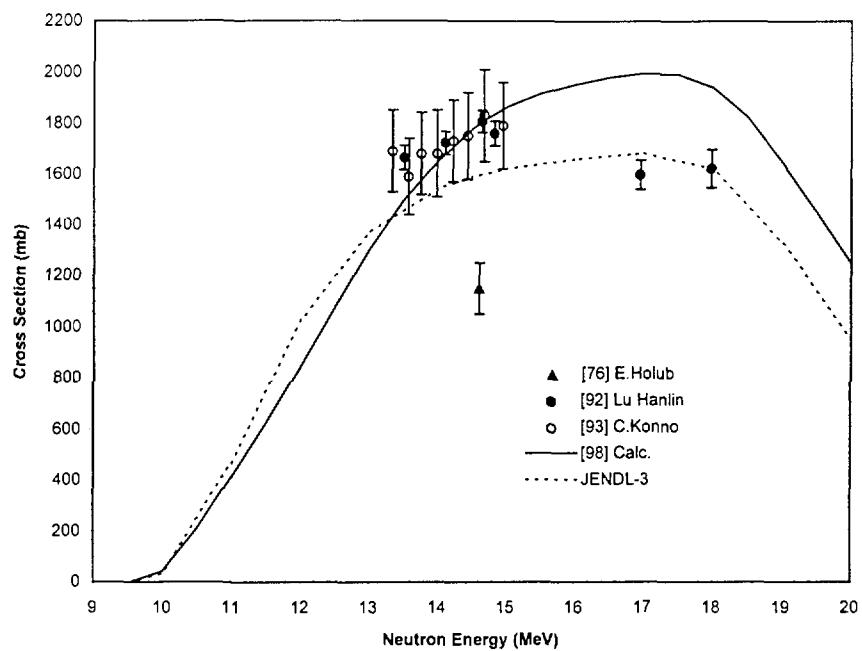


Fig. 23 Cross Section for $^{134}\text{Ba}(n,2n)^{133}$ Reaction

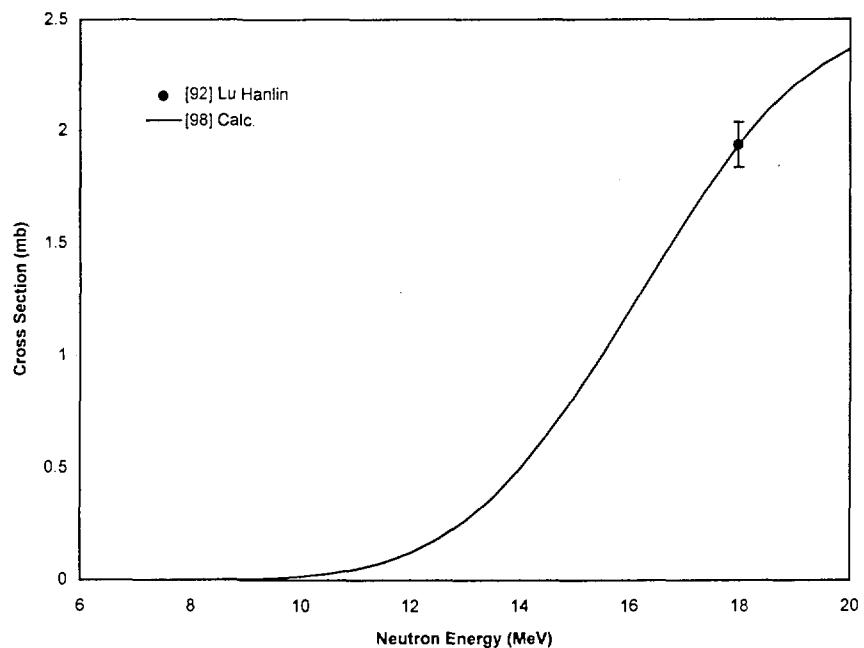


Fig. 24 Cross Section for $^{136}\text{Ba}(n,\alpha)^{133\text{m}}$ Reaction

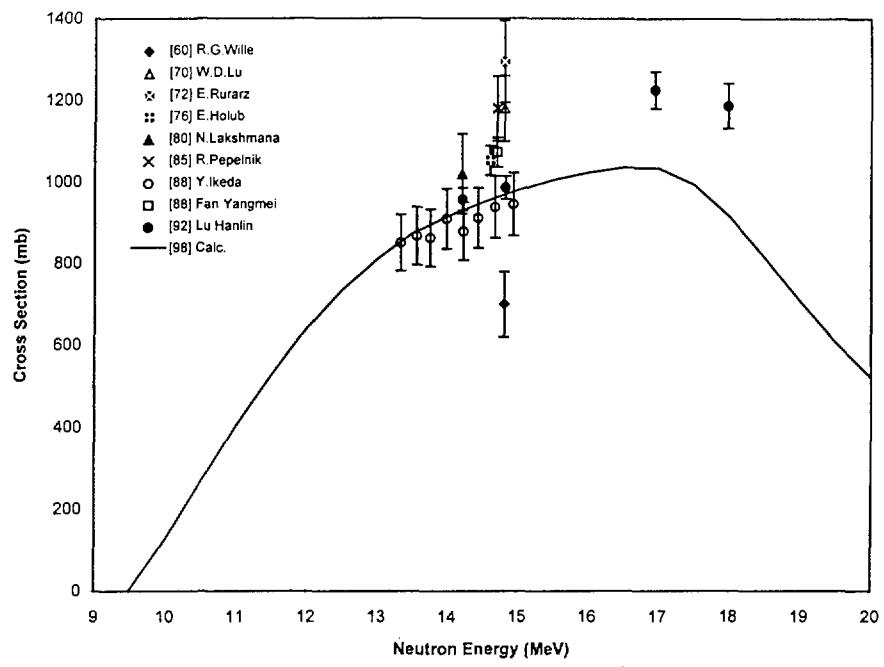


Fig.25 Cross Section for $^{136}\text{Ba}(n,2n)^{135\text{m}}$ Reaction

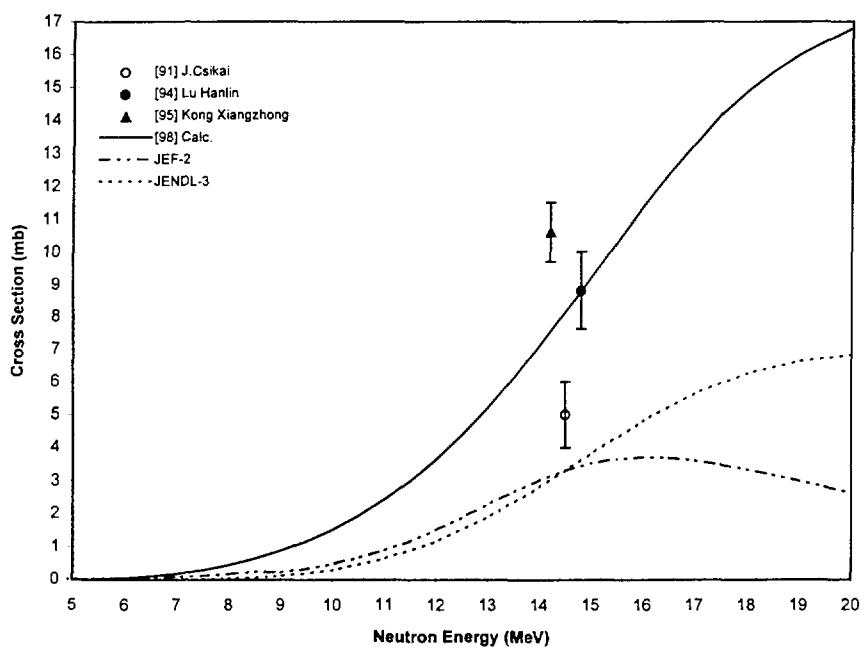


Fig.26 Cross Section for $^{137}\text{Ba}(n,p)^{137}\text{Cs}$ Reaction

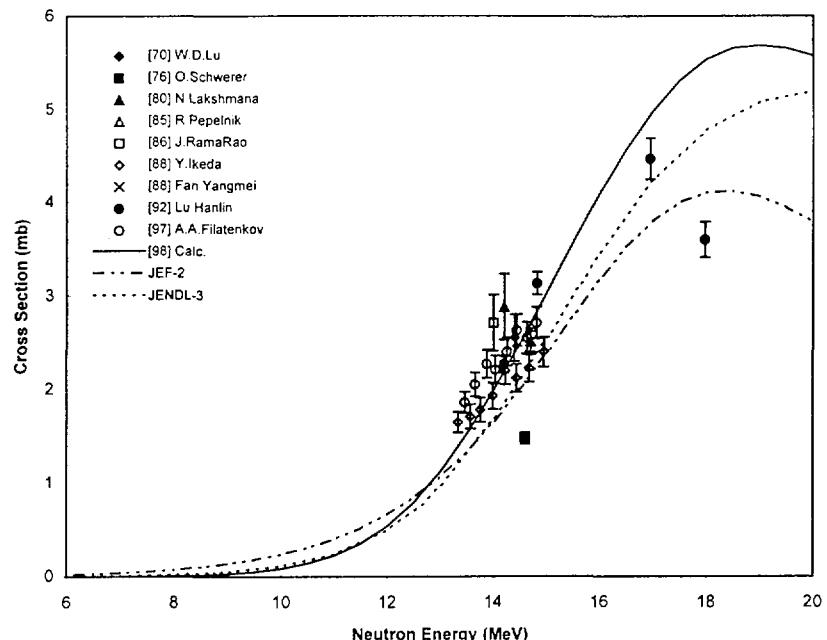


Fig.27 Cross Section for $^{138}\text{Ba}(n, \alpha)^{135}\text{Xe}$ Reaction

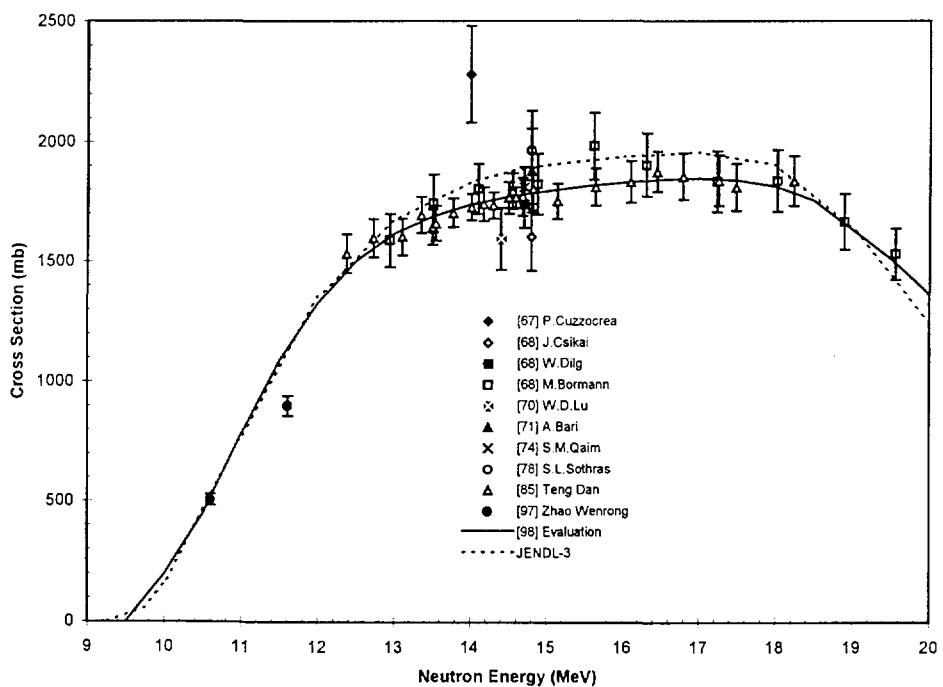


Fig. 28 Cross Section for $^{140}\text{Ce}(n, 2n)^{139}\text{Ce}$ Reaction

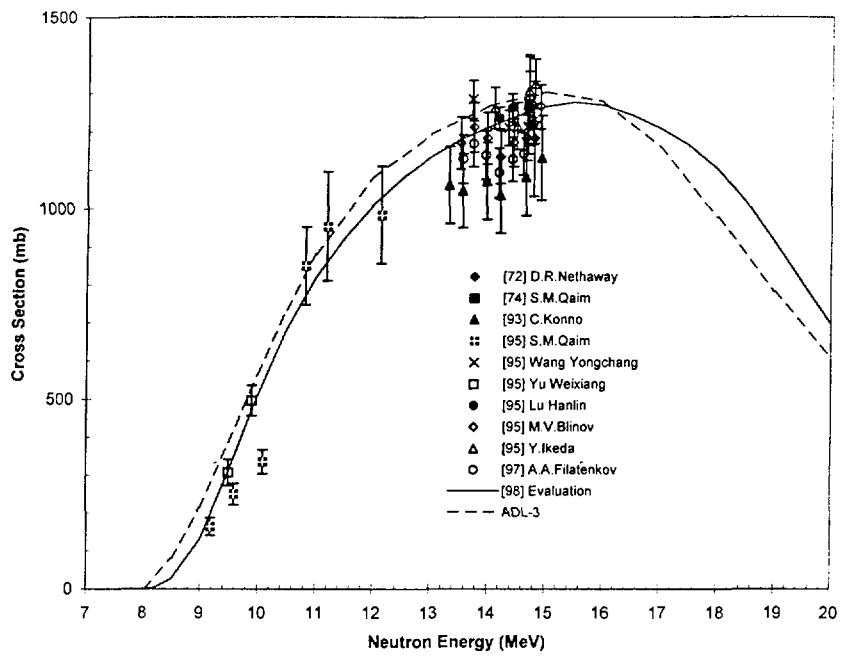


Fig. 29 Cross Section for $^{151}\text{Eu}(n,2n)^{150}\text{g}$ Reaction

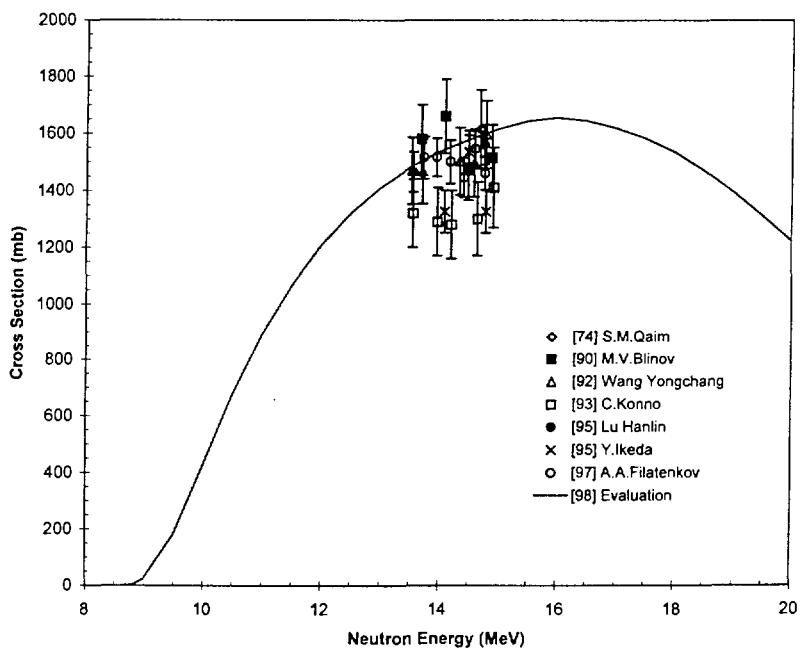


Fig. 30 Cross Section for $^{153}\text{Eu}(n,2n)^{152\text{g}+\text{m}2}$ Reaction

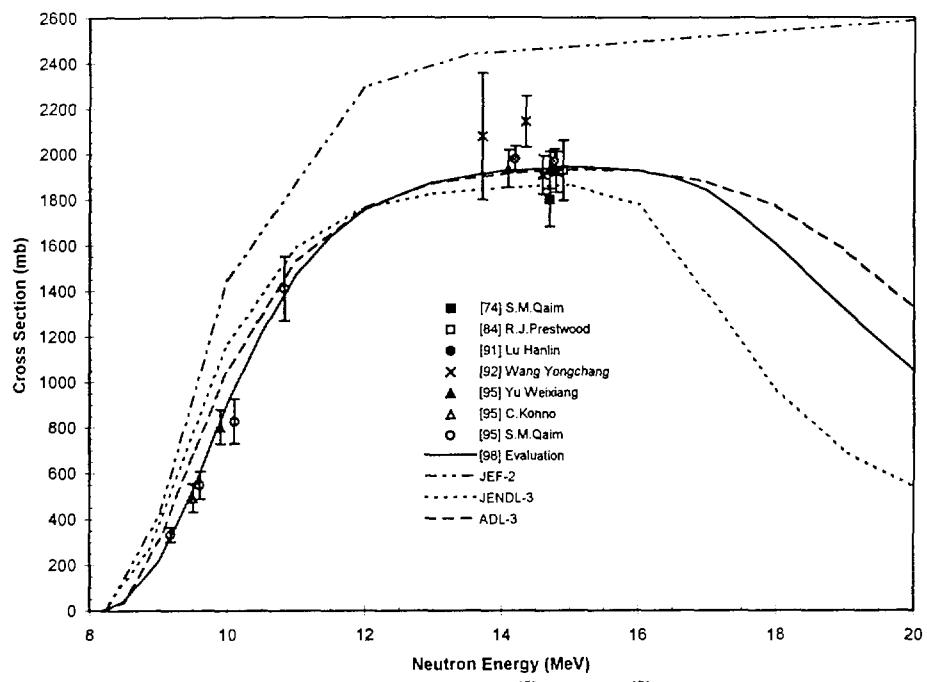


Fig. 31 Cross Section for $^{159}\text{Tb}(n,2n)^{158}\text{Tb}$ Reaction

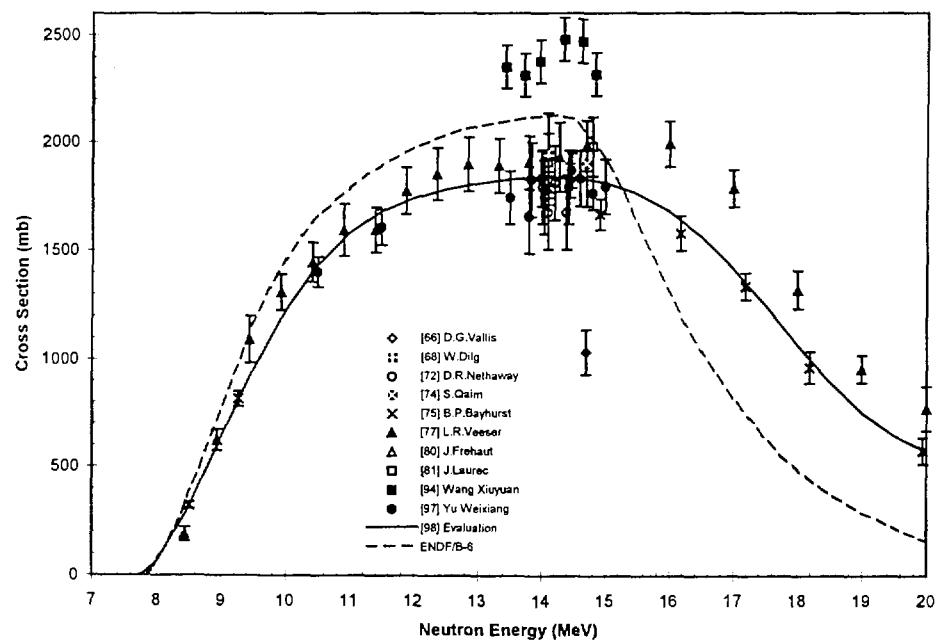


Fig. 32 Cross Section for $^{175}\text{Lu}(n,2n)^{174\text{m}+g}\text{Lu}$ Reaction

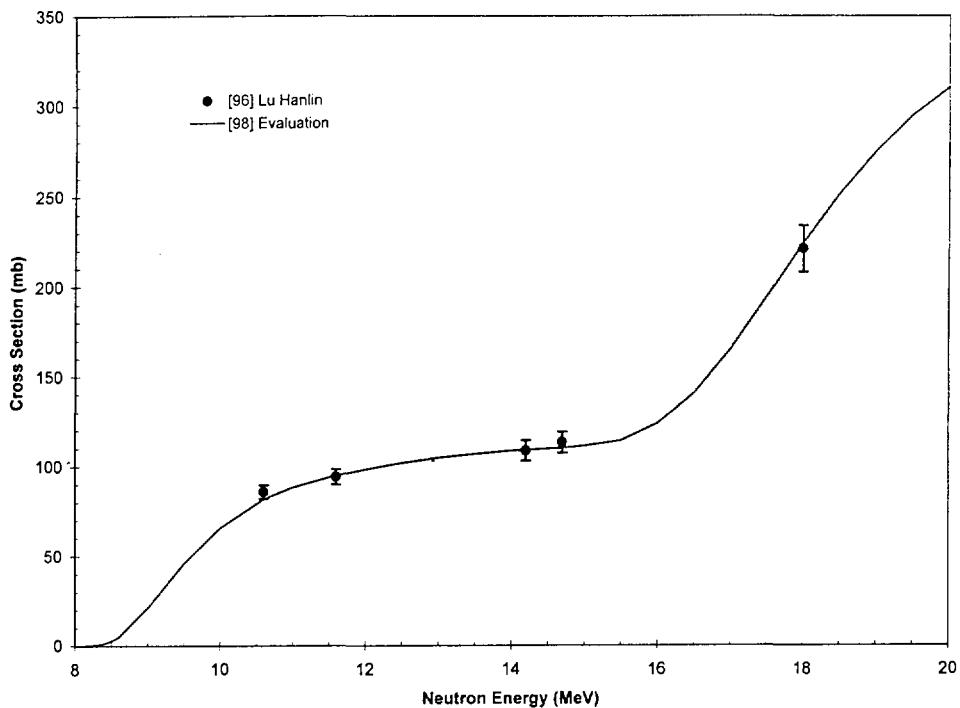


Fig. 33 Cross Section for $\text{Hf}(n, xn)^{175}\text{Hf}$ Reaction

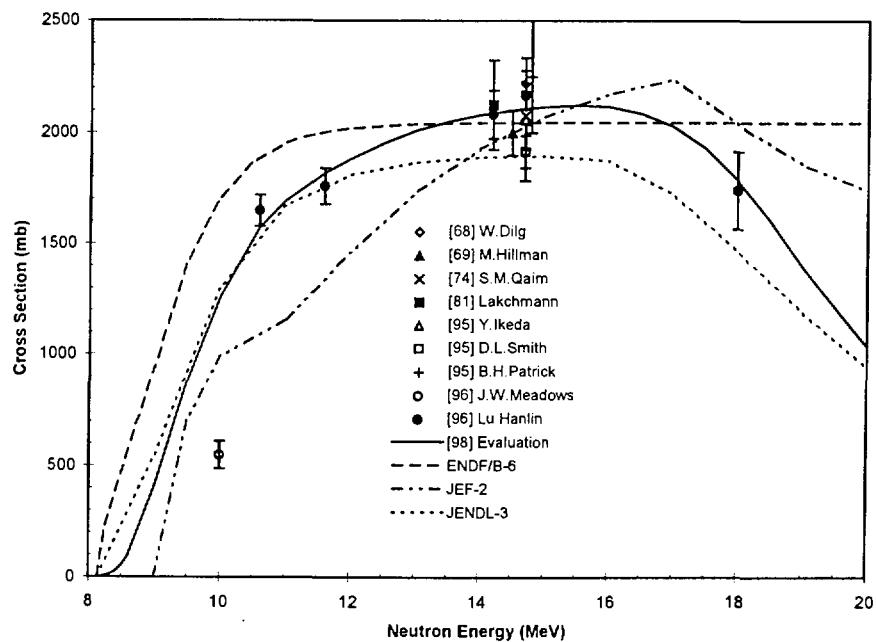


Fig. 34 Cross Section for $^{176}\text{Hf}(n, 2n)^{175}\text{Hf}$ Reaction

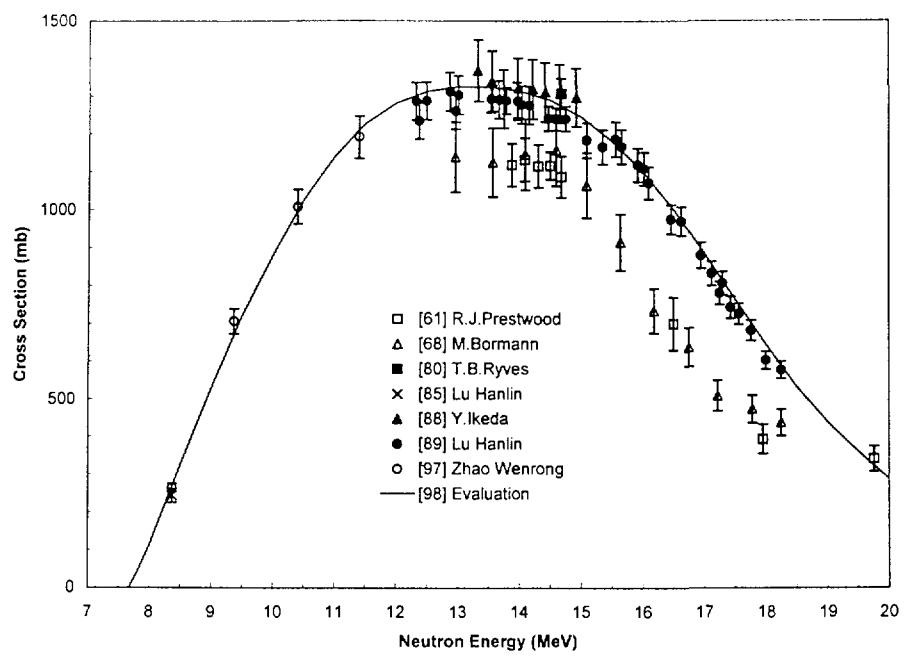


Fig. 35 Cross Section for $^{181}\text{Ta}(n,2n)^{180\text{m}}$ Reaction

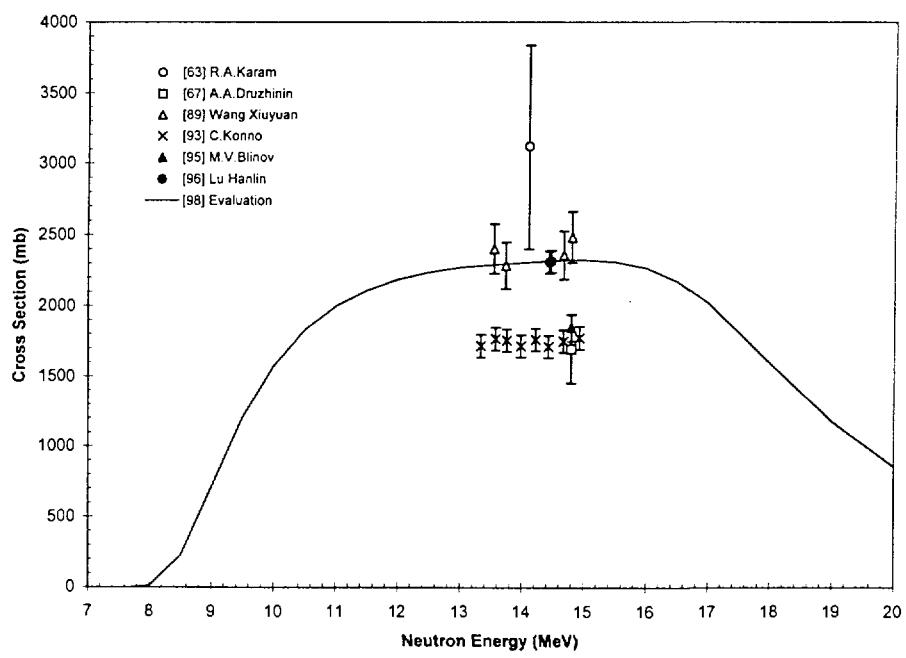


Fig. 36 Cross Section for $^{185}\text{Re}(n,2n)^{184\text{m}^*0}$ Reaction

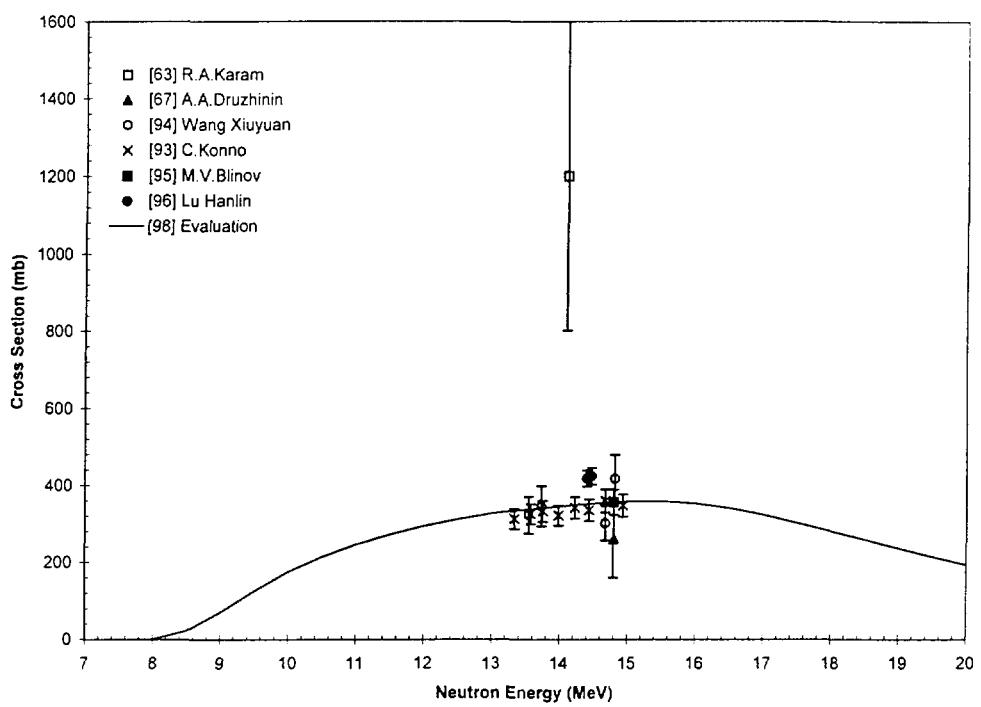


Fig. 37 Cross Section for $^{185}\text{Re}(n,2n)^{184\text{m}}\text{Re}$ Reaction

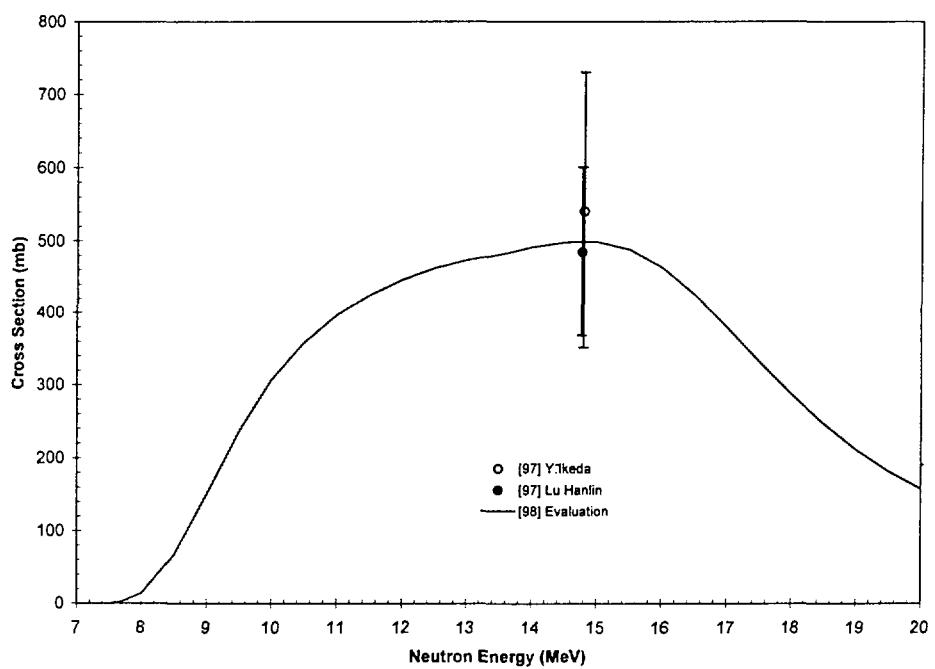


Fig. 38 Cross Section for $^{187}\text{Re}(n,2n)^{186\text{m}}\text{Re}$ Reaction

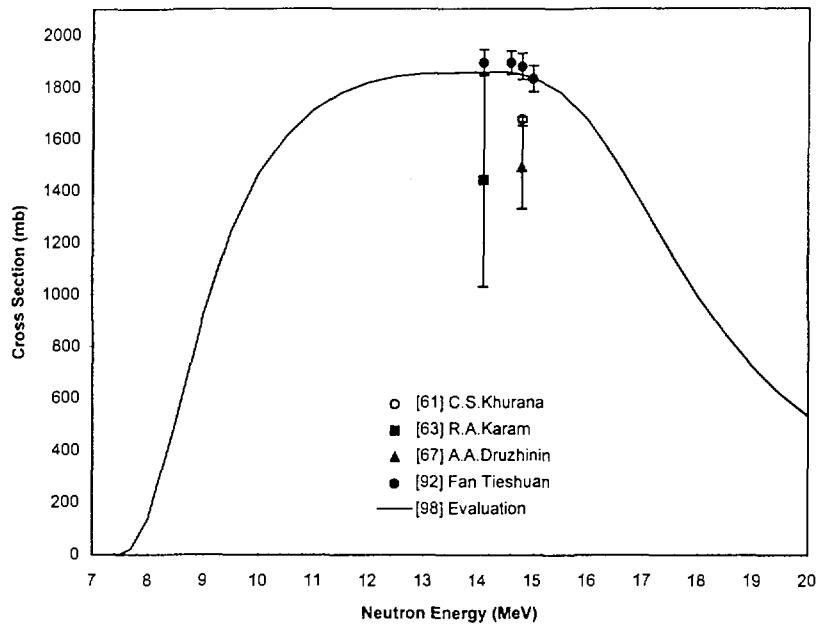


Fig. 39 Cross Section for $^{187}\text{Re}(n,2n)^{186}\text{g}$ Reaction

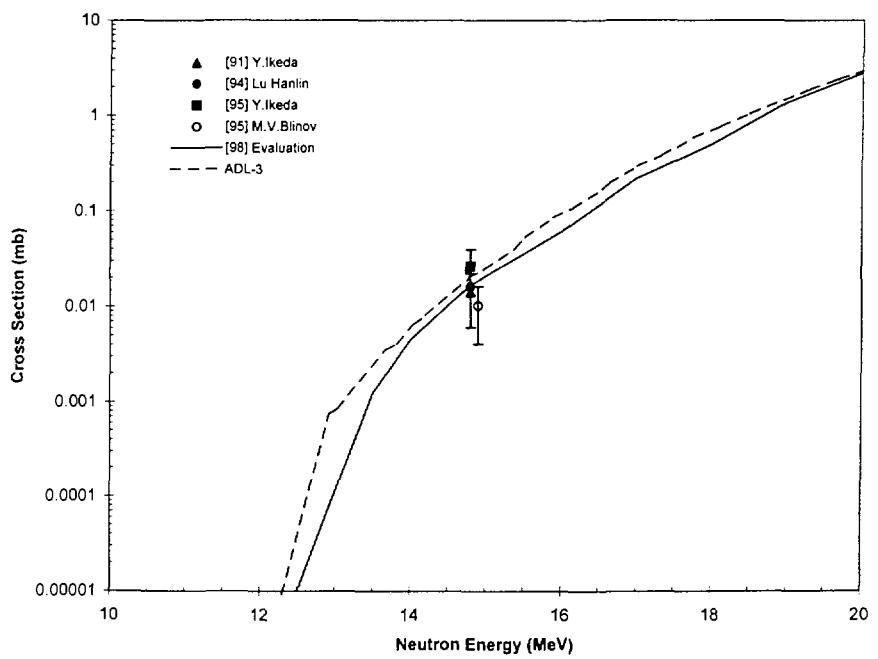


Fig. 40 Cross Section for $^{182}\text{W}(n,n'\alpha)^{178\text{m}2}$ Reaction

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail: services@iaeand.iaea.or.at
fax: (43-1)26007
cable: INATOM VIENNA
telex: 1-12645 atom a
telephone: (43-1)2600-21710

online: TELNET or FTP: iaeand.iaea.or.at
username: IAEANDS for interactive Nuclear Data Information System
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