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March 2001

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Consistent Evaluations of (n,2n) and (n,np) Reaction Excitation Functions for some Even-Even Isotopes Using Empirical Systematics

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An approach for consistent evaluation of (n,2n) and (n,np) reaction excitation functions for some even-even isotopes with the (n,np) reaction thresholds lower than (n,2n) reaction ones is described. For determination of cross sections in the maximum of the (n,2n) and (n,np) reaction excitation functions some empirical systematics developed by Manokhin were used together with trends in dependence of gaps between the (n,2n) and (n,np) thresholds on atomic mass number A. The shapes of the (n,2n) and (n,np) reaction excitation functions were calculated using the normalized functions from the Manokhin's systematics. Excitation functions of (n,2n) and (n,np) reactions were evaluated for several nuclei by using the systematics and it was found that the approach used for the present study gives reasonable results.

Keywords: (n,2n) Reaction, (n,np) Reaction, Cross Section, Excitation Function, Empirical Systematics, Even-Even Nuclei, Evaluation

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経験的系統式を用いた偶々核同位体の(n,2n)及び(n,np)反応励起関数の矛盾ない評価

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(n,np)反応断面積のしきいエネルギーが(n,2n)反応断面積のしきいエネルギーよりも低い偶々核について、(n,2n)反応と(n,np)反応の両者の断面積の励起関数を矛盾なく評価するアプローチについて論じた。(n,2n)及び(n,np)反応断面積の励起関数の最大値の決定においては、Manokhin の系統式を用いるとともに、(n,2n)及び(n,np)反応のしきいエネルギーの差の質量数依存性も考慮した。(n,2n)及び(n,np)反応の励起関数の計算には、Manokhin の系統式によって与えられる規格化された励起関数を用いた。いくつかの核種に対する(n,2n)及び(n,np)反応断面積の評価を行い、本研究における手法が妥当であることを明らかにした。

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1. Introduction

Although many studies to establish empirical systematics of threshold reaction cross sections have been carried out, most of the systematics were developed at the energy from 14 to 15 MeV. Manokhin developed empirical systematics to represent excitation function of (n,2n) and (n,np) reaction cross sections from threshold energy to 20 MeV [1)] based on experimental data. These systematics can be used for an evaluation and a selection of more reliable excitation functions among those which have no experimental data and are calculated on the base of theoretical models.

In this paper an approach for consistent evaluation of (n,2n) and (n,np) reaction excitation functions for some even-even isotopes with the (n,np) reaction thresholds lower than (n,2n) reaction ones is described. For determination of cross sections in the maximum of the (n,2n) and (n,np) reaction excitation functions some empirical systematics from the work [1)] were used together with trends in dependence of gaps between the (n,2n) and (n,np) thresholds on atomic mass number A. The shapes of the (n,2n) and (n,np) reaction excitation functions were calculated using the normalized functions from the work [1)].

2. Interrelation of (n,2n) and (n,np) reactions

First of all an interrelation between absolute values of the (n,2n) and (n,np) reaction cross sections at the maximum of their excitation functions should be analyzed. This interrelation depends on an interrelation of the thresholds of these reactions and the values of gaps between them.

When $E_{th}(n,2n) < E_{th}(n,np)$ (where $E_{th}(n,2n)$, $E_{th}(n,np)$ are thresholds of the (n,2n) and (n,np) reactions, respectively), the (n,2n) reaction dominates and its absolute maximum value can be calculated according to the work [1), 2)] from the relation:

$$65.4 \times A^{2/3}\ [\text{mb}]. \qquad (1)$$

When $E_{th}(n,2n) > E_{th}(n,np) + Q_C$, (where Q_C is Coulomb barrier), the (n,np) reaction dominates and the maximum (n,2n) reaction cross section depends on the gap between their thresholds $[E_{th}(n,2n) - E_{th}(n,np) + Q_C)]$: the more this gap the more the maximum (n,np) reaction cross section and less the maximum (n,2n) reaction cross section.

The available experimental data show that the maximum (n,2n) cross sections as a function of mass number A decrease with the increasing of $(E_{th}(n,2n) - E_{th}(n,np))$. Having in mind the conclusion of the work[1)] that the sum of these two reactions near (n,3n) reaction threshold can be evaluated by the values $65.4 \times A^{2/3}$ [mb], we can assume that the maximum (n,np) reaction cross sections as a function of A increase against the value $(E_{th}(n,2n) - E_{th}(n,np))$.

To use this trend for the evaluation of maximum cross sections, some assumptions should be made concerning parameter which is the same for isotopes to be compared. The neutron excess value (N-Z) should be used as such parameter. In Fig.1 the dependence of the gaps between the thresholds of (n,2n) and (n,np) against A is shown for some isotopes. The values for isotopes with the same (N-Z) are linked by lines. From study of correlation between the dependencies shown in Fig.1 and dependencies of the maximum (n,2n) cross sections, some additional information concerning the maximum values of the (n,2n) and (n,np) reaction cross sections can be obtained.

3. Evaluation of (n,np) excitation functions for isotopes with (N-Z)=2

There are three isotopes with neutron excess (N-Z)=2 which have large gaps (E_{th}(n2n) - E_{th}(nnp)): ^{46}Ti, ^{50}Cr and ^{54}Fe. The dependence of these gaps on atomic mass number is almost linear as shown in Fig.1 and Table 1. For ^{46}Ti and ^{54}Fe there are experimental data which give possibility to evaluate more or less reliably the maximum (n,2n) cross sections. In Figs. 2-3 the curves evaluated on the basis of systematics from the work [1] are given. The maximum (n,2n) cross sections for ^{46}Ti and ^{56}Fe are equal to ~230 mb and ~100 mb, respectively. It is seen that the (n,2n) cross section dependence for these two isotopes on atomic mass number is inversely proportional to dependence of the gaps.

Having in mind almost linear dependence of the gaps, we can assume that (n,2n) cross sections will decrease also linear with the increasing of (E_{th}(n,2n) - E_{th}(n,np)). As a result we can draw line through the evaluated (n,2n) cross sections for ^{46}Ti and ^{54}Fe and determine the maximum (n,2n) cross section for ^{50}Cr by the value of ~155 mb and calculate the (n,2n) excitation function (Fig. 4) using the normalized (n,2n) excitation function [1] shown in Table 2. This calculated excitation function contradicts to the available evaluated curves based on Borman's data [3] however agrees with the trend in the cross sections that resulted from the recent data by Ikeda et al. [4] in the energy region of 14-15 MeV.

Using the (n,2n) cross sections given above, the maximum (n,np) cross section were calculated by subtracting the (n,2n) cross sections from the sum of the (n,2n) and (n,np) reactions predicted by relation (1). For calculation of the (n,np) excitation function shapes, the normalized function [1] shown in Table 2 was used. The results of calculations for three isotopes are given in Table 1 and in Figs. 5-7. One can see that the ^{50}Cr (n,np) excitation function agrees very well with the experimental data of Fessler et al. [5] A sum of the (n,np) and (n,p) reaction cross sections near 14.8 MeV (about 765 mb) satisfactory agrees with the (n,xp) reaction cross section of Grimes et al. (830±100 mb) [6] within experimental uncertainty. For ^{46}Ti and ^{54}Fe we have quite reliable experimental data near 15 MeV for (n,p) reactions (215 mb and 275 mb, respectively). Adding these values to the (n,np) cross sections values at the same energy, one can obtain the sums (630 mb and 820 mb, respectively) that close to the experimental data by Grimes et al. [6] for (n,xp) reactions ((669±90) mb for ^{46}Ti and and (900±110) mb for ^{54}Fe).

The gap of (E_{th} (n,2n) - E_{th} (n,np)) for ^{58}Ni is not more than for ^{54}Fe as one can expect from almost linear dependence for the gaps of ^{46}Ti, ^{50}Cr and ^{54}Fe. This may be connected with magic atomic mass number and magic Z of ^{58}Ni. However the gap of (E_{th} (n,2n) - E_{th} (n,np)) for ^{58}Ni close to the gap of (E_{th}(n,2n) - E_{th}(n,np)) for ^{54}Fe, one can assume that the (n,2n) reaction cross section for ^{58}Ni is comparable with the (n,2n) cross section for ^{54}Fe. The Fig. 8 gives the maximum (n,2n) cross section about 75-80 mb, that is close to 100 mb for the maximum (n,2n) cross section for ^{54}Fe.

The (n,np) cross section for ^{58}Ni is measured quite well (Fig. 9) and equal to ~880 mb near maximum of excitation function. A sum of experimental maximum cross sections of the (n,np) and (n,2n) reactions is equal to ~960 mb and the calculated sum from the relation (1) is equal to 975 mb. The difference is within uncertainty of experimental data (about 5%, i.e. ~40-45 mb). This supports an assumption that the sum of the maximum (n,2n) and (n,np) reaction cross sections are approximately equal to the cross section calculated from the relation (1) if $E_{th}(n,2n) > E_{th}(n,np)$.

4. Evaluation of (n,np) excitation functions for isotopes with (N-Z)=6

There are three suitable isotopes with N-Z=6 for evaluation of (n,np) reaction cross sections on the basis of known (n,2n) reaction cross sections using the approach described above: ^{70}Ge, ^{74}Se and ^{78}Kr. For two isotopes (^{70}Ge and ^{74}Se) there are excitation functions evaluated on the basis of available experimental data and systematics of the work [1]. The maximum cross sections of the (n,2n) reaction from these evaluations are 860 mb for ^{70}Ge and 690 mb for ^{74}Se (Table 3 and Figs. 10-11).

Having in mind the dependence for the gap (E_{th} (n,2n) - E_{th} (n,np)) on A (Fig.1), we can extrapolate the maximum (n,2n) cross sections for ^{70}Ge and ^{74}Se to the maximum (n,2n) cross section of 580 mb for ^{78}Kr (Fig.12 and Table 3).

Applying the approach used above, the (n,np) reaction maximum cross section (see Table 3) and (n,np) excitation functions can be evaluated for isotopes for ^{70}Ge, ^{70}Se and ^{78}Kr (Figs. 13-15).

5. Evaluation of (n,np) excitation functions for isotopes with (N-Z)=8

The results of (n,np) excitation functions are given below for the isotopes with neutron excess (N-Z)=8, for which the experimental data allows to evaluate the maximum (n,2n) reaction cross sections. These cross sections correlate inversely proportional with the ($E_{th}(n,2n)$ - $E_{th}(n,np)$) (see Fig. 1). The numerical results and plots are presented in Table 4 and in Figs. 16-21.

6. Evaluation of (n,np) excitation functions for isotopes with (N-Z)=0

In this case we have linear dependence of the gap ($E_{th}(n,2n)$ - $E_{th}(n,np)$) on A (Fig. 22). Though experimental data for the (n,2n) reaction cross sections are absent for the most isotopes, there are experimental data for $^{14}N(n,2n)$ as shown in Fig. 23. Maximum cross section of this reaction is about 11 mb. Having in mind the dependence in Fig. 22, we can assume that for other isotopes the maximum (n,2n) reaction cross sections would be less than that for $^{14}N(n,2n)$. Because of small (n,2n) reaction cross sections we can accept that the cross section predicted by relation (1) is mainly due to the (n,np) reactions. As a result we can evaluate the (n,np) reactions as it is shown in Figs. 24-31.

The numerical results of calculations by relation (1) and assumed maximum (n,np) reaction cross sections (with taking into account that the (n,2n) reaction cross section is not more 10 mb) are presented in Table 5. In Figs. 24-31 for comparison some theoretical curves are given. In several cases we can see satisfactory agreement. However for ^{14}N and ^{16}O there are great disagreement. Two conclusions are possible: the approach does not work for small A or theoretical curves are not reliable.

7. Conclusion

On the basis of analysis made above, we can enough reliably assume that the maximum (n,2n) cross sections correlate and depend on the gap (E_{th} (n,2n) - E_{th} (n,np)) inversely proportionally and the maximum (n,np) reaction cross section is proportional to the gap (E_{th}(n,2n) - E_{th}(n,np)), if $E_{th}(n,2n) > E_{th}(n,np) + Q_C$.

This assumption can be used for interpolation and extrapolation of maximum (n,2n) cross sections for isotopes with unknown cross sections using the available experimental data for isotopes with the same (N-Z). The maximum value of (n,np) reaction excitation functions can be evaluated by subtracting the maximum (n,2n) cross section from the sum of these two reactions.

On the basis of so determined maximum cross sections we have possibility to calculate excitation function curves using the normalised functions from the work [1)].

The approach used for evaluation of the (n,np) reaction excitation functions gives reasonable results for even-even isotopes if $E_{th}(n2n) > E_{th}(nnp)+Q_C$. Further investigation is needed for situation when $E_{th}(n2n) \approx E_{th}(nnp)+Q_C$.

References

1) Manokhin, V. N.: "Some Criteria for Selection of Evaluated Threshold Reaction Excitation Functions", INDC(CCP)-397 (1997).

2) Manokhin, V. N. and Blokhin, A. I.: "Empirical Dependence of Parameters of Neutron Threshold Reaction Excitation Functions on A, Z, (N-Z)", Proc.Int.Conf. on Nuclear Data for Science and Technology, Trieste, Italy, pp. 871 – 873 (1997).

3) Borman, M.: "Neutron Shell Effects in the (n,2n) Cross-Sections at 14 MeV", Nucl. Phys., 65, 257 (1965).

4) Ikeda, Y., Konno, C., Oishi, K., Nakamura, T., Miyade, H., Kawade, K., Yamamoto, H. and Katoh, T.: "Activation Cross Section Measurements for Fusion Reactor Structural Materials at Neutron Energy from 13.3 to 15.0 MeV Using FNS Facility", JAERI 1312 (1988).

5) Fessler, A. and Qaim, S. M.: "Excitation Functions at $^{50}Cr(n,np+pn+d)^{49}V$, $^{58}Ni(n,\alpha)^{55}Fe$, $^{58}Ni(n,\alpha p+p\alpha)^{54}Mn$ and $^{62}Ni(n,\alpha)^{59}Fe$ Reactions", Radiochim. Acta, 84, 1 (1999).

6) Grimes, S.M., Haight, R.C., Alvar, K.R., Barschall, H.H., Borchers, R.R.: "Charged-particle Emission in Reactions of 15 MeV Neutrons with Isotopes of Chromium, Iron, Nickel, and Copper", Phys. Rev. C19, 2127 (1979).

Table 1 (n,2n) and (n,np) cross sections for isotopes with (N-Z) = 2

Isotope	N-Z	E_{th}(n,2n) - E_{th}(n,np), MeV	(n,2n) cross section, mb	Sum of (n,2n) and (n,np) cross sections, mb	Calculated (n,np) cross section, mb
^{46}Ti	2	2.91	230	840	610
^{50}Cr	2	3.50	155*	885	730
^{54}Fe	2	4.61	100	930	830
^{58}Ni	2	4.12	80	975	895

Note: * The value is determined by interpolation.

Table 2 Normalized excitation functions of (n,2n) and (n,np) reactions. Symbols in the table denote the following quantities. ΔE: $E-E_{th}$, E_{th}: threshold energy, ΔE_{max}: $E_{max} - E$, E: neutron energy, E_{max}: neutron energy at the maximum of excitation function, σ : cross section, σ_{max}: maximum cross section value.

$\Delta E / \Delta E_{max}$	σ / σ_{max}	
	(n,2n) reaction	(n,np) reaction
0.05	0.03	0.04
0.10	0.09	0.14
0.15	0.18	0.26
0.20	0.30	0.40
0.25	0.42	0.53
0.30	0.53	0.64
0.35	0.60	0.73
0.40	0.68	0.79
0.45	0.75	0.84
0.50	0.81	0.88
0.55	0.85	0.90
0.60	0.88	0.92
0.65	0.91	0.94
0.70	0.93	0.955
0.75	0.95	0.965
0.80	0.97	0.975
0.85	0.98	0.980
0.90	0.99	0.990

Table 3 (n,2n) and (n,np) cross sections for isotopes with (N-Z) = 6

Isotope	N-Z	E_{th}(n,2n) - E_{th}(n,np), MeV	(n,2n) cross section, mb	Sum of (n,2n) and (n,np) cross sections, mb	Calculated (n,np) cross section, mb
^{70}Ge	6	3.05	860	1110	250
^{74}Se	6	3.57	690	1155	465
^{78}Kr	6	3.89	580*	1190	610

Note: * The value is determined by extrapolation.

Table 4 (n,2n) and (n,np) cross sections for isotopes with (N-Z) = 8

Isotope	N-Z	E_{th}(n,2n) - E_{th}(n,np), MeV	(n,2n) cross section, mb	Sum of (n,2n) and (n,np) cross sections, mb	Calculated (n,np) cross sections, mb
^{84}Sr	8	3.10	950	1250	300
^{92}Mo	8	5.27	450	1330	900
^{96}Ru	8	3.39	800	1370	570

Table 5 (n,2n) and (n,np) cross sections for isotopes with (N-Z) = 0

Isotope	N-Z	E_{th} (n,2n) - E_{th} (n,np), MeV	(n,2n) cross section, mb	Sum of (n,2n) and (n,np) cross sections, mb	Assumed maximum (n,np) cross sections, mb
^{14}N	0	3.28	11	380	370
^{16}O	0	3.66	<10	415	405
^{20}Ne	0	4.22	<10	482	472
^{24}Mg	0	5.04	<10	544	535
^{28}Si	0	5.80	<10	604	595
^{32}S	0	6.37	<10	659	650
^{36}Ar	0	6.94	<10	708	700
^{40}Ca	0	7.50	<10	764	755

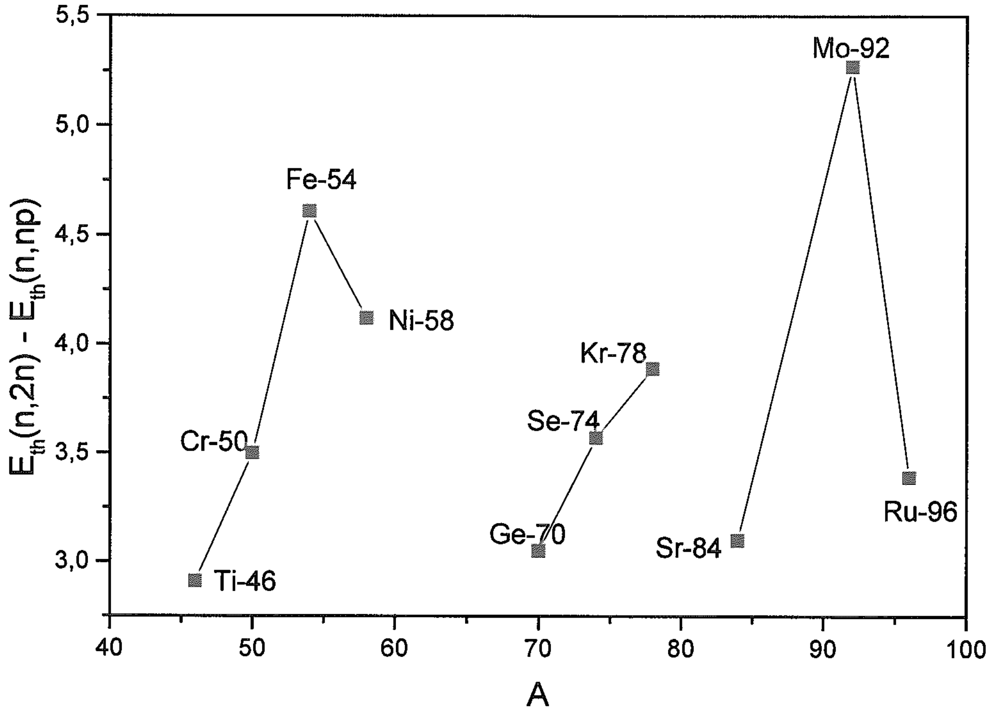

Fig.1 Dependence of (E_{th} (n,2n) - E_{th} (n,np)) on atomic mass number A

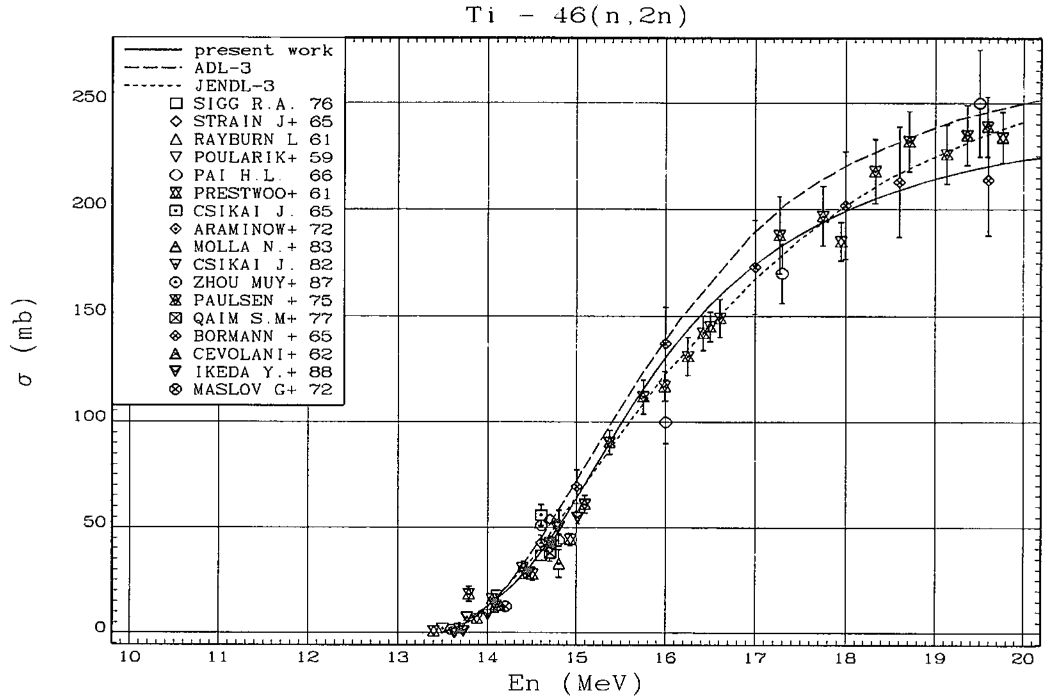

Fig. 2 ^{46}Ti(n,2n) reaction cross section

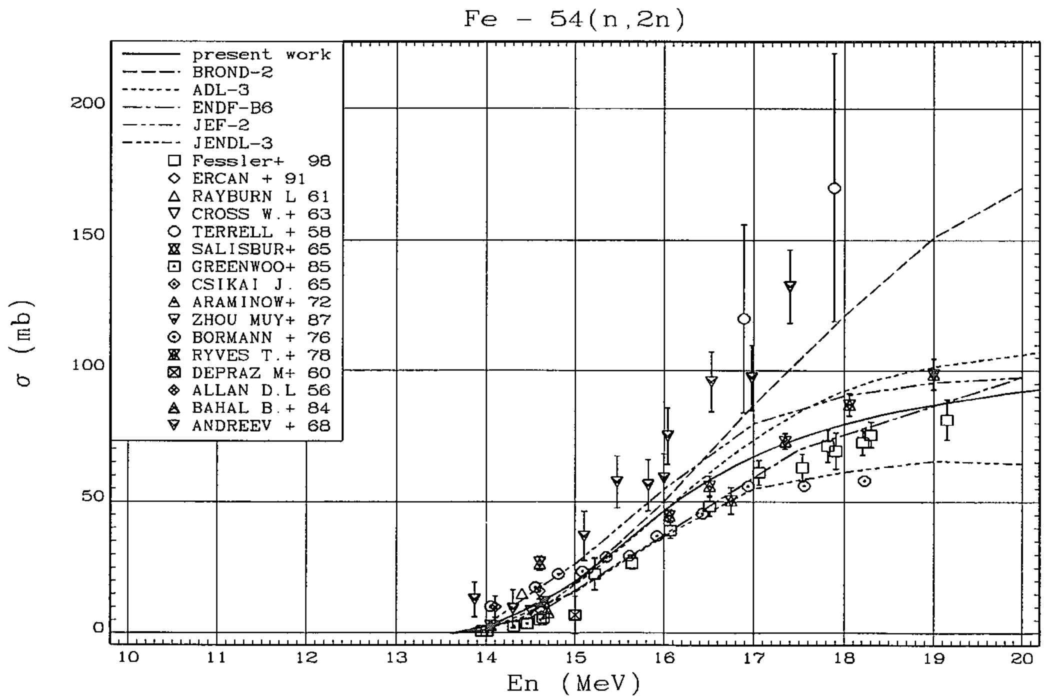

Fig. 3 ^{54}Fe(n,2n) reaction cross section

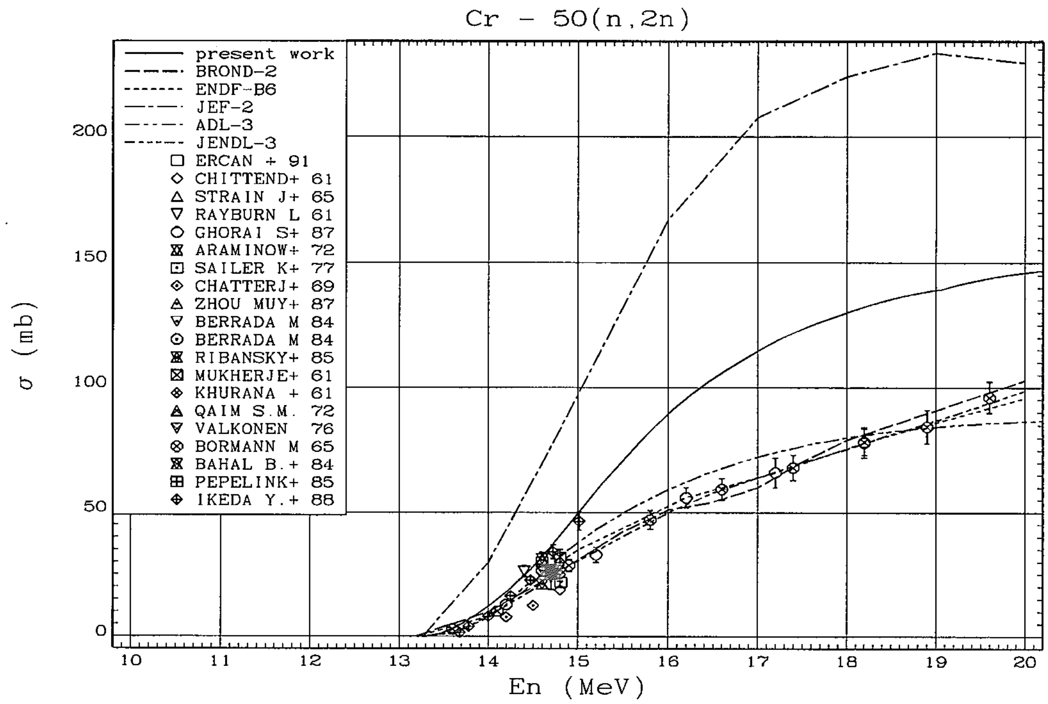

Fig. 4 ^{50}Cr(n,2n) reaction cross section

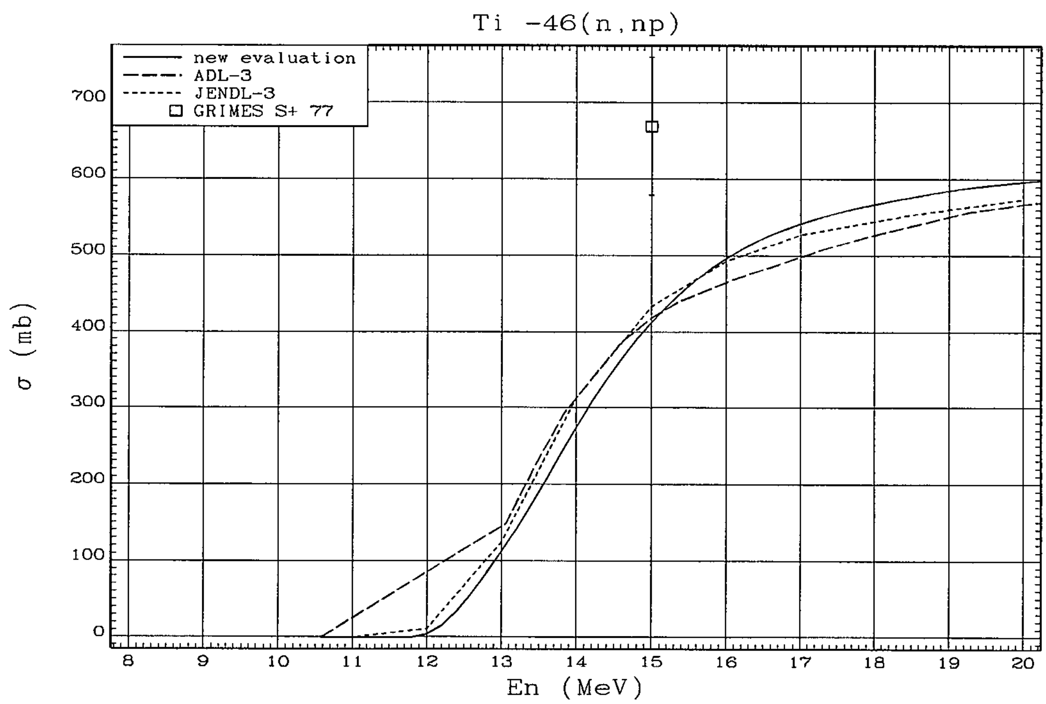

Fig. 5 ^{46}Ti(n,np) reaction cross section

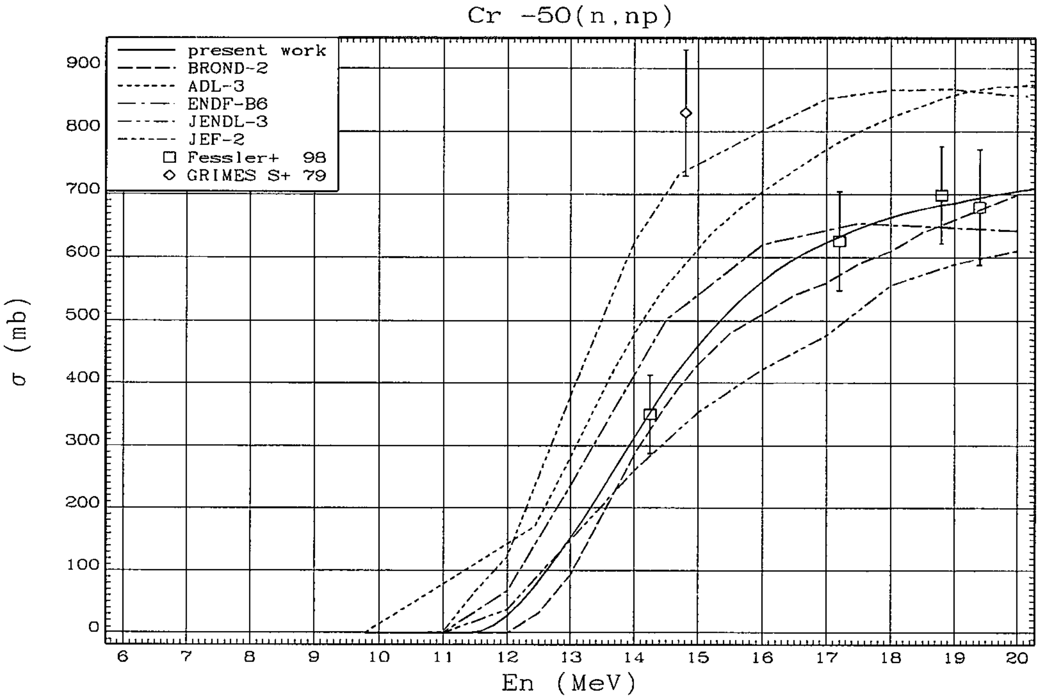

Fig. 6 ^{50}Cr(n,np) reaction cross section

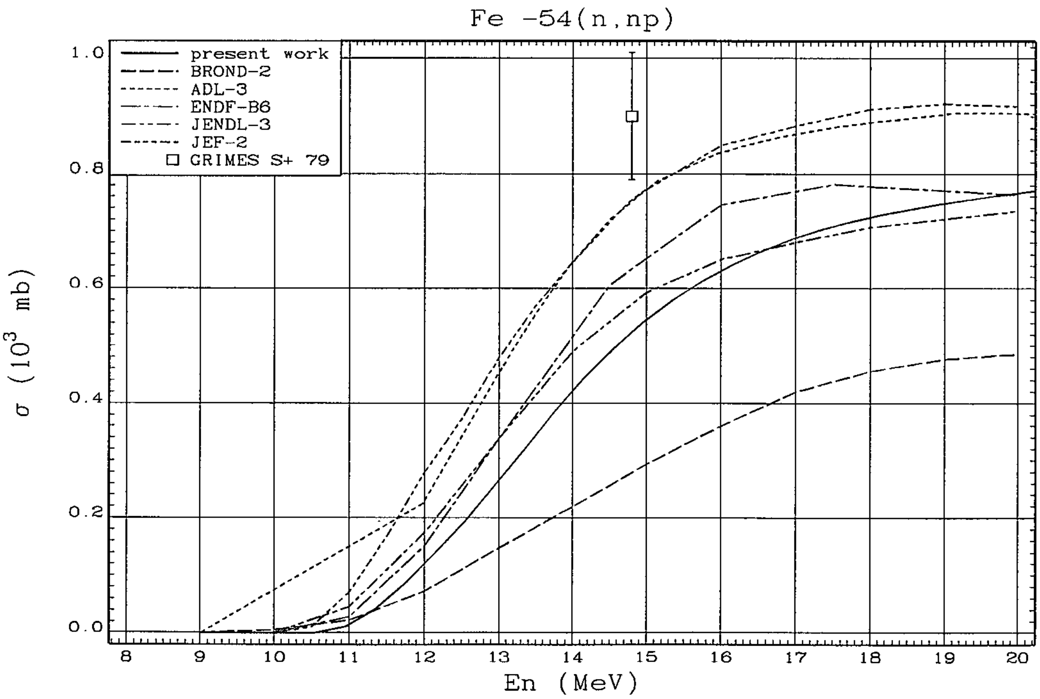

Fig. 7 ^{54}Fe(n,np) reaction cross section

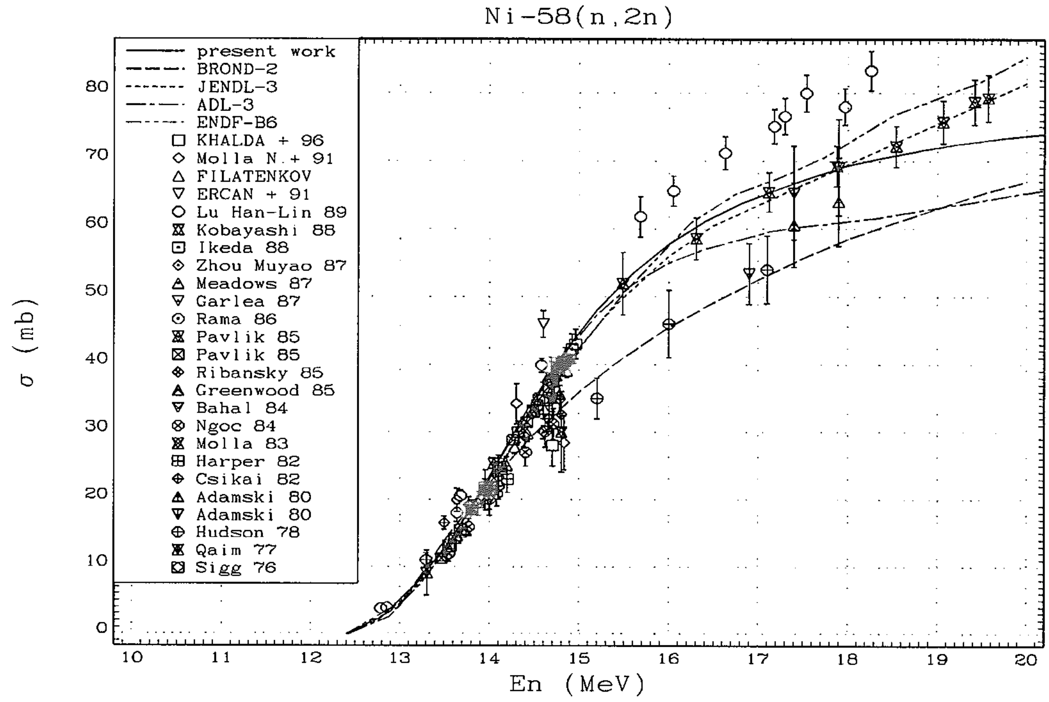

Fig. 8 ^{58}Ni(n,2n) reaction cross section

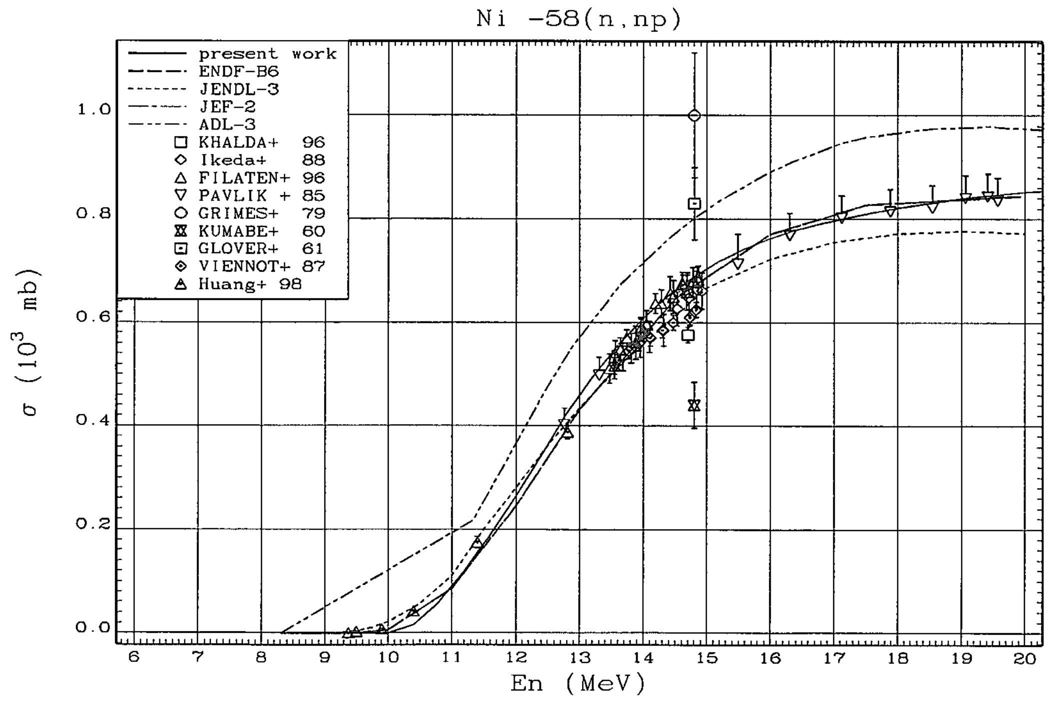

Fig. 9 ^{58}Ni(n,np) reaction cross section

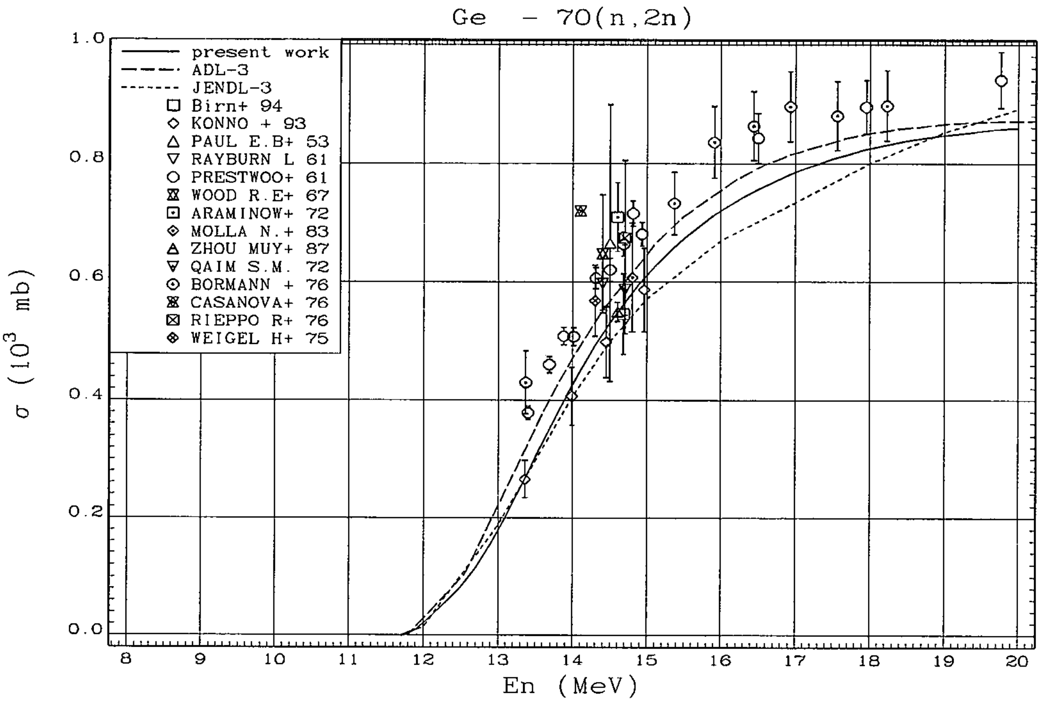

Fig. 10 ^{70}Ge(n,2n) reaction cross section

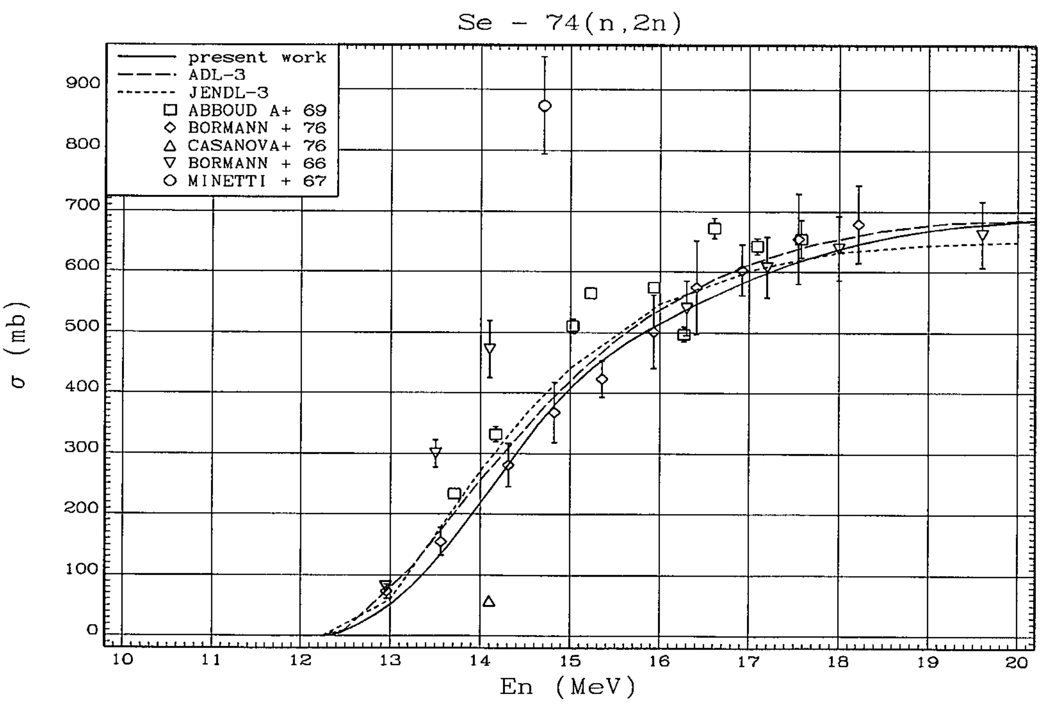

Fig. 11 ^{74}Se(n,2n) reaction cross section

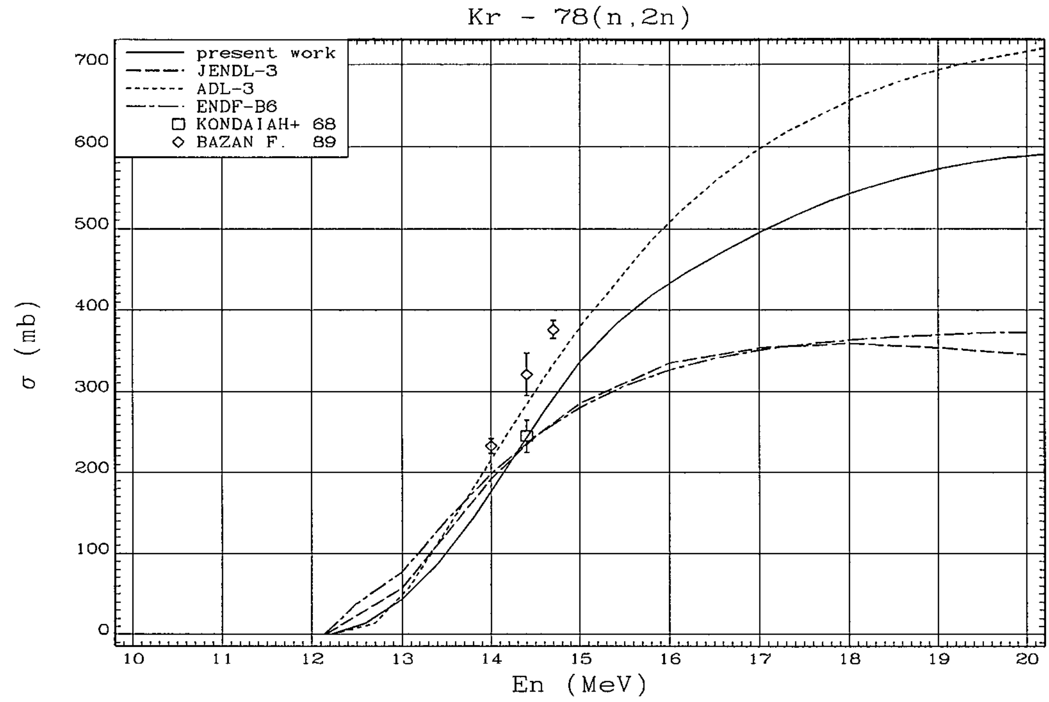

Fig. 12 ^{78}Kr(n,2n) reaction cross section

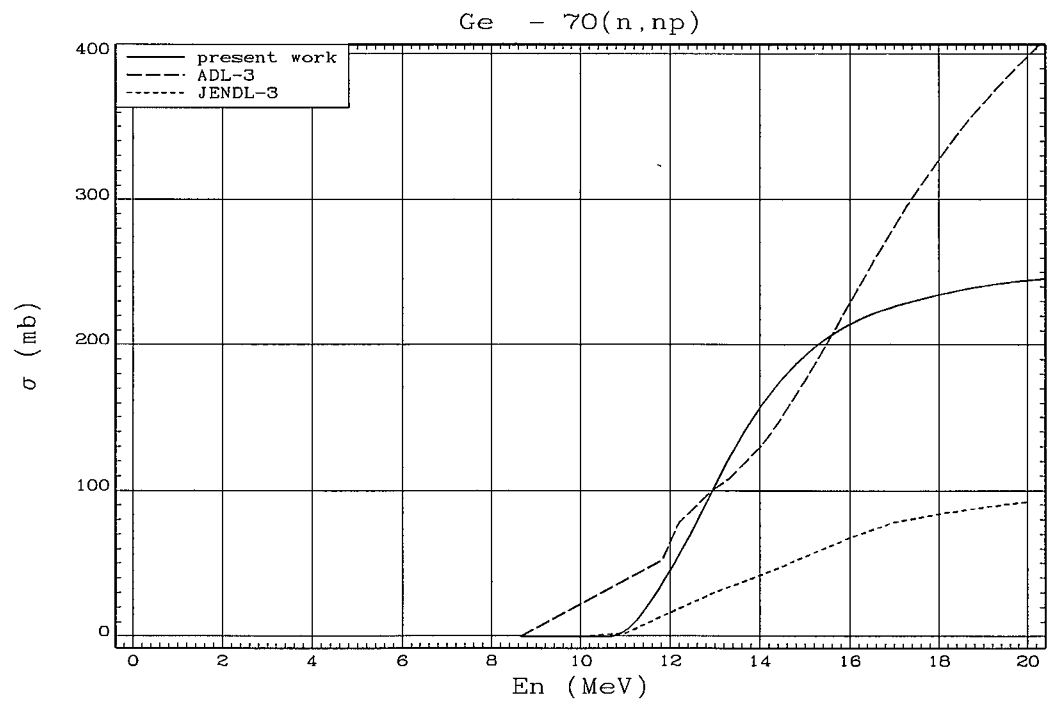

Fig. 13 ^{70}Ge(n,np) reaction cross section

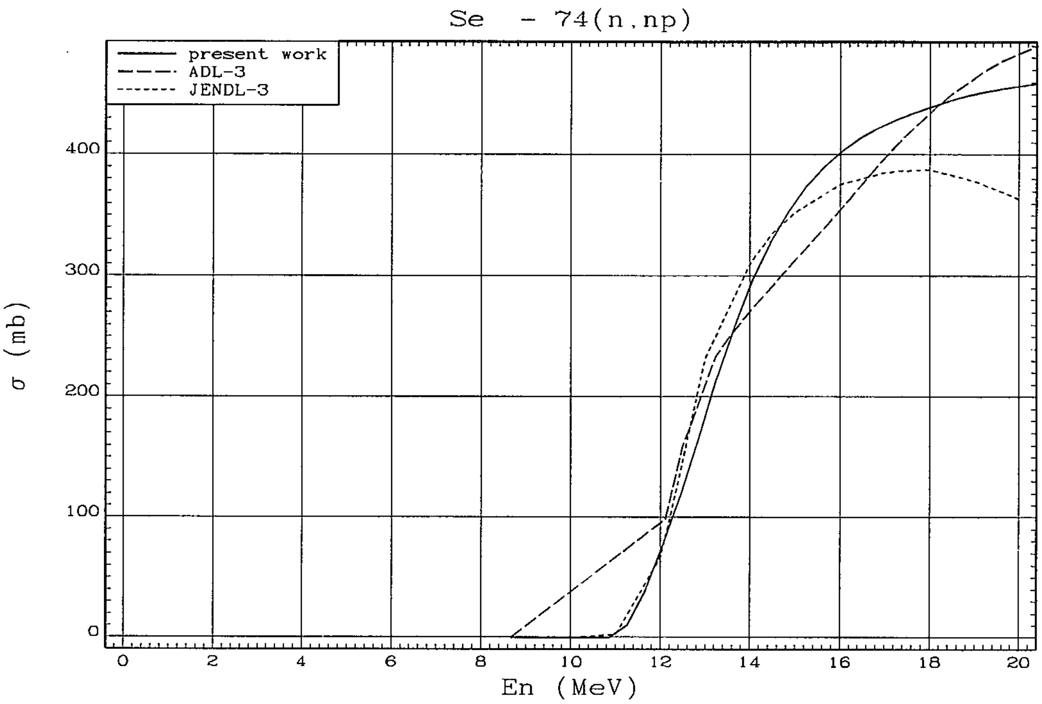

Fig. 14 ^{74}Se(n,np) reaction cross section

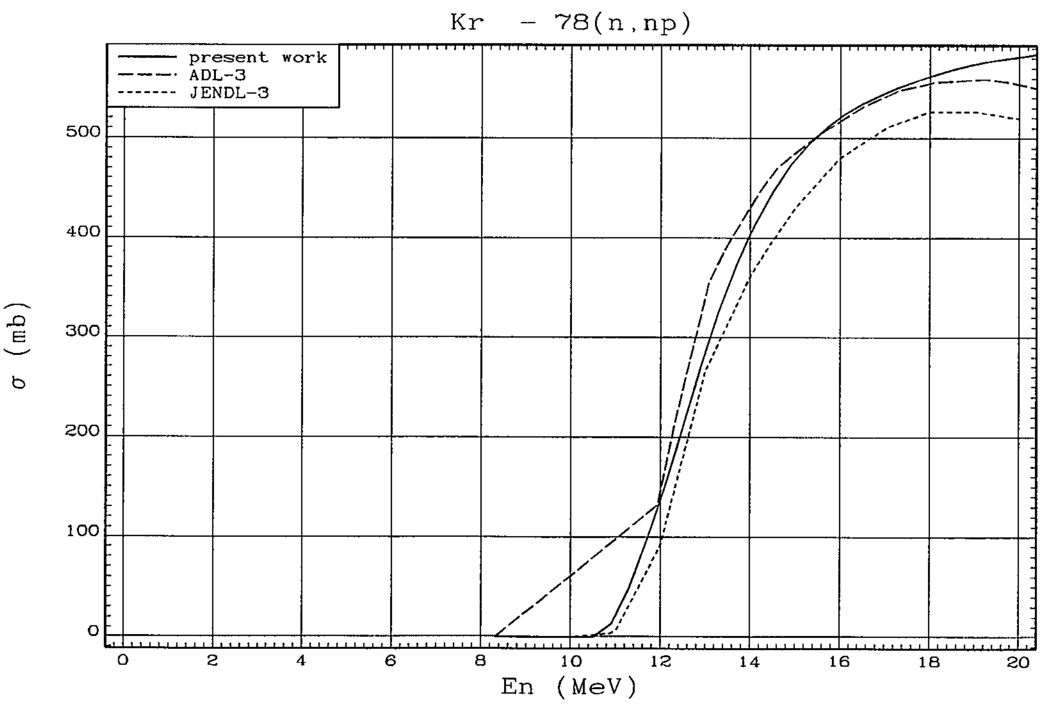

Fig. 15 ^{78}Kr(n,np) reaction cross section

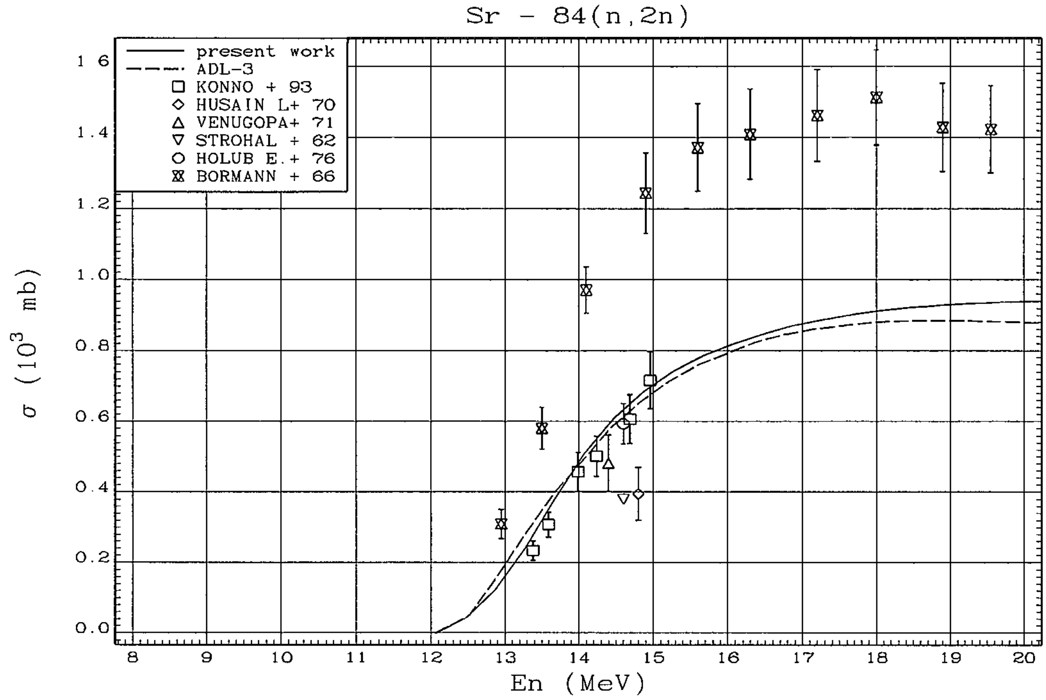

Fig. 16 ^{84}Sr(n,2n) reaction cross section

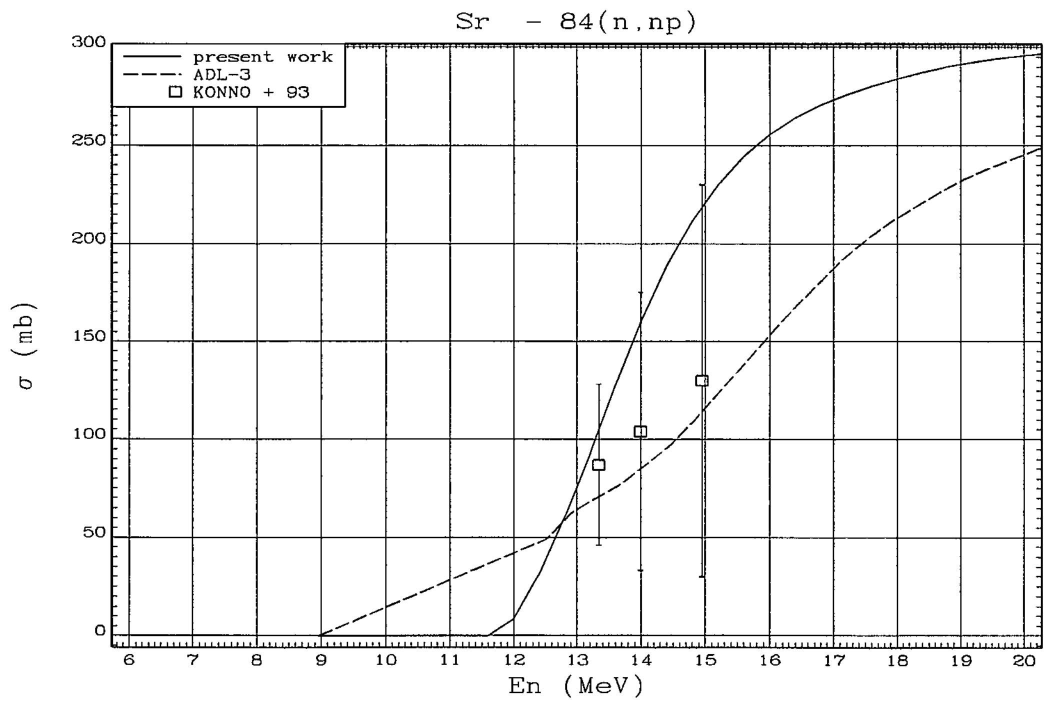

Fig. 17 ^{84}Sr(n,np) reaction cross section

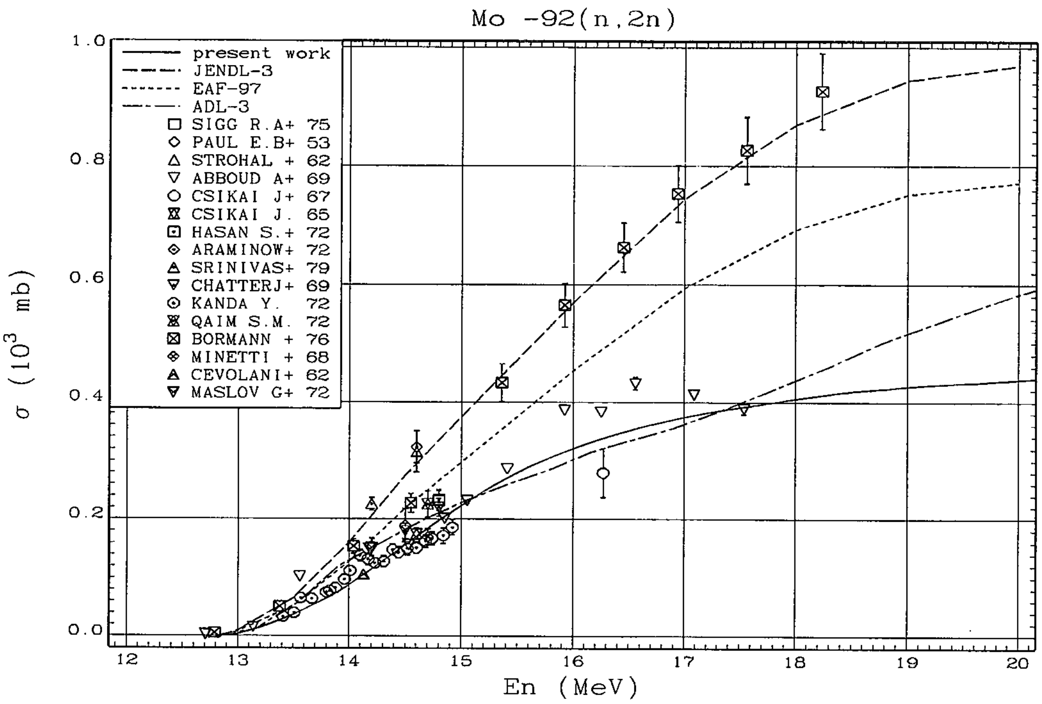

Fig. 18 ^{92}Mo(n,2n) reaction cross section

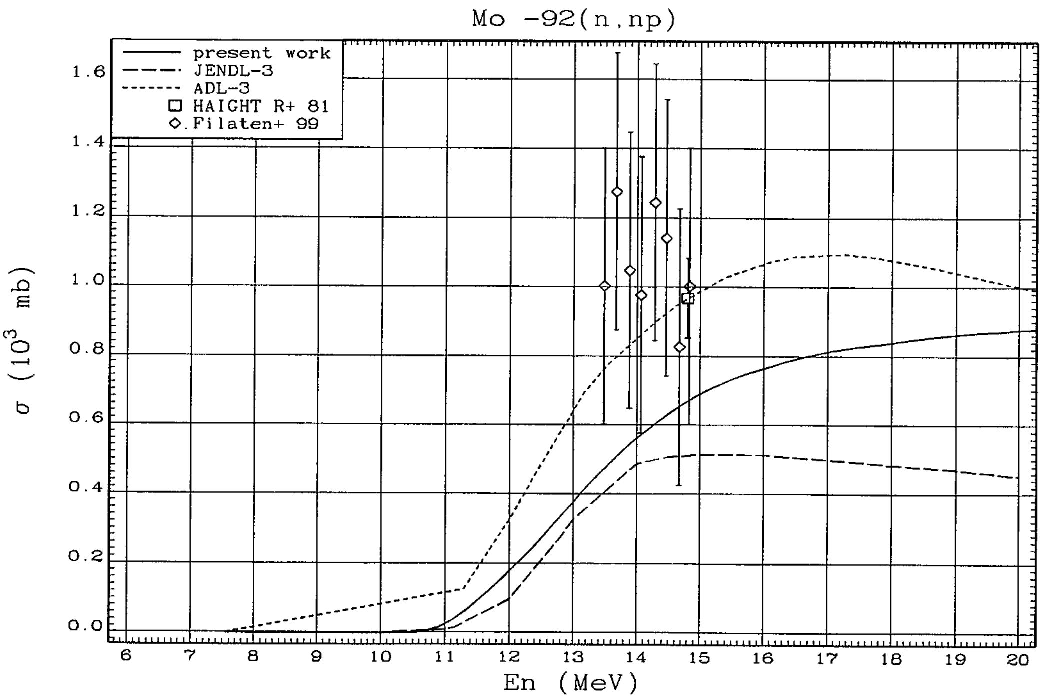

Fig. 19 ^{92}Mo(n,np) reaction cross section

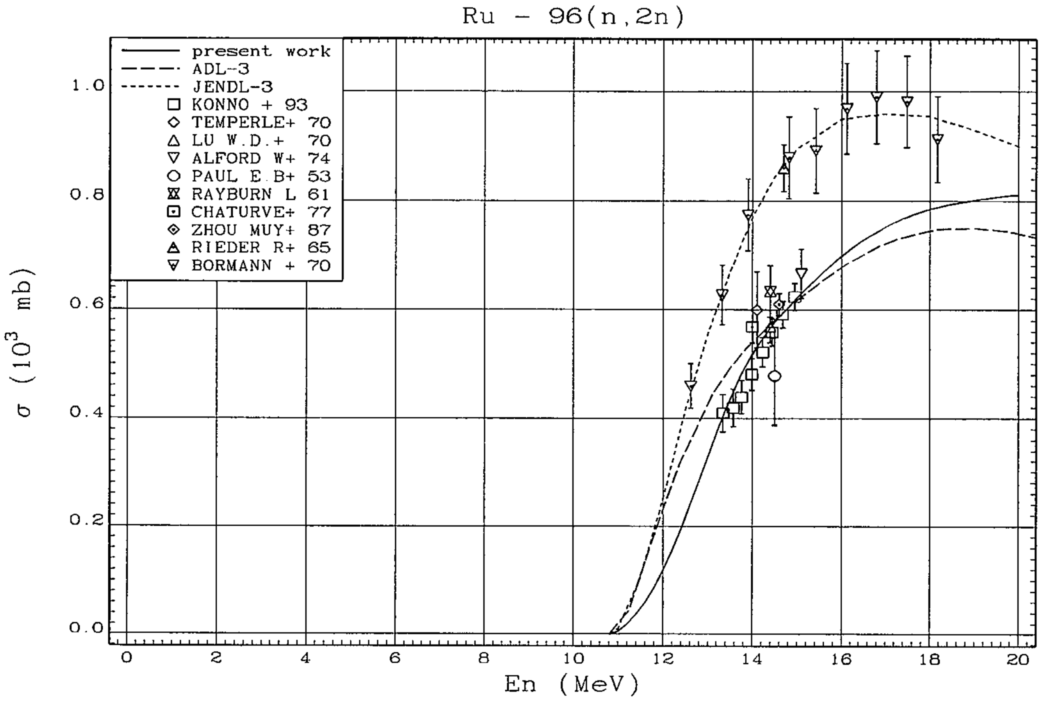

Fig. 20 ^{96}Ru(n,2n) reaction cross section

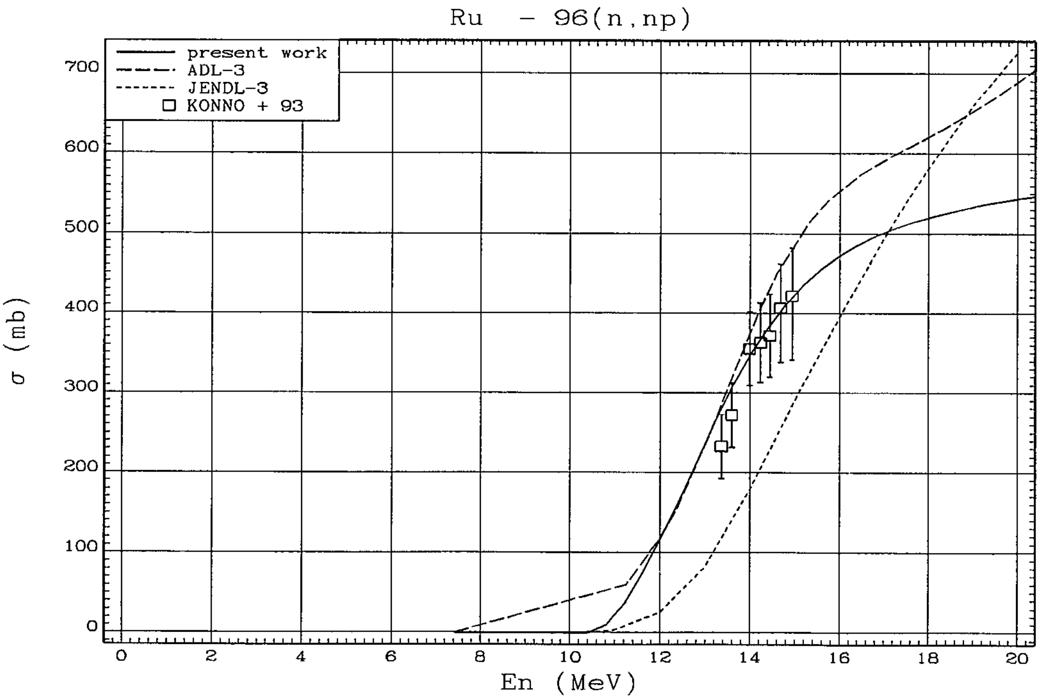

Fig. 21 ^{96}Ru(n,np) reaction cross section

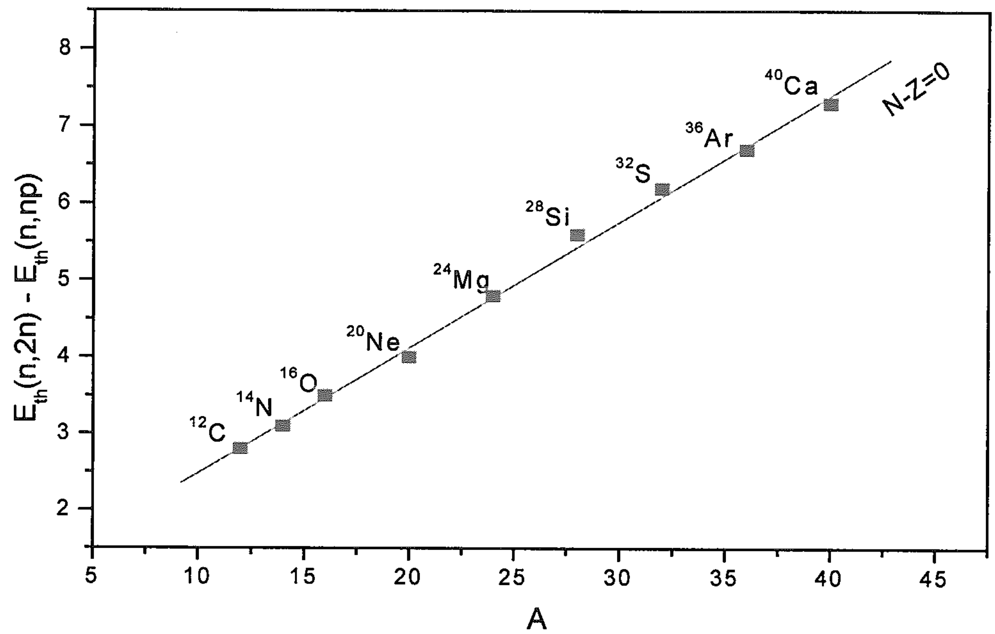

Fig.22 Dependence of (E_{th} (n,2n) - E_{th} (n,np)) on atomic mass number A

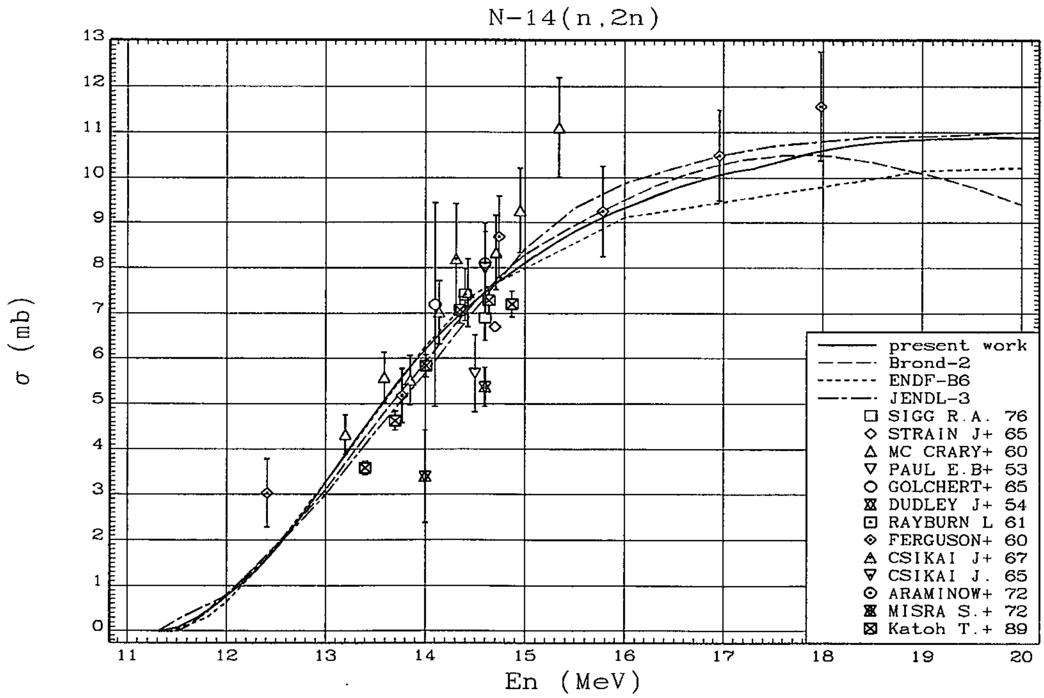

Fig. 23 ^{14}N(n,2n) reaction cross section

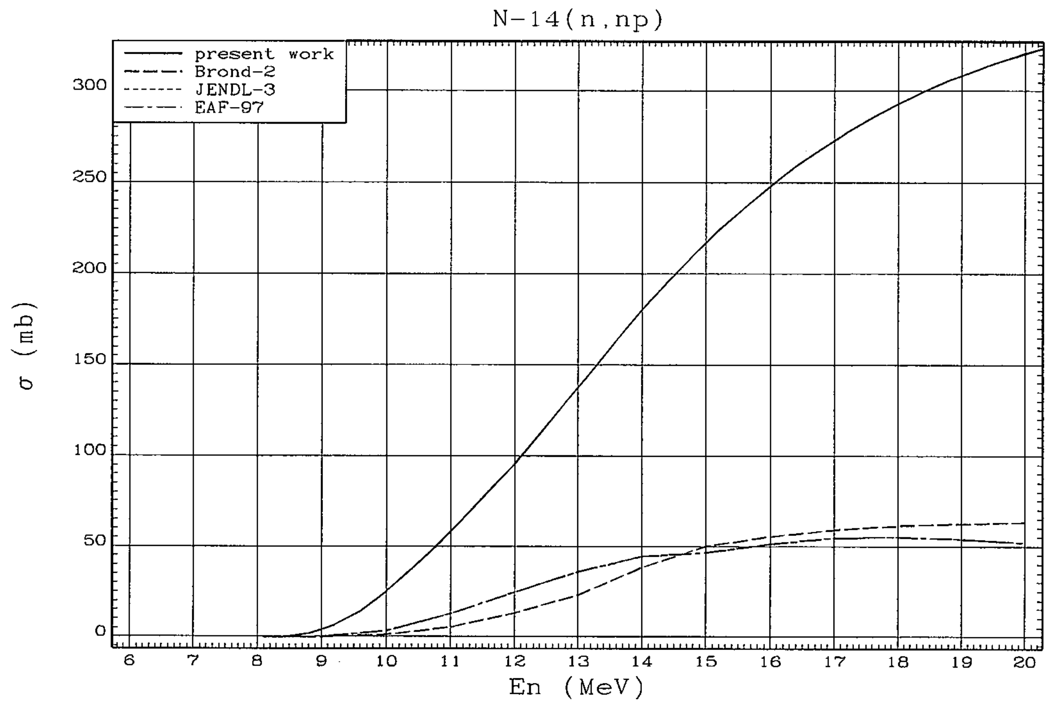

Fig. 24 ^{14}N(n,np) reaction cross section

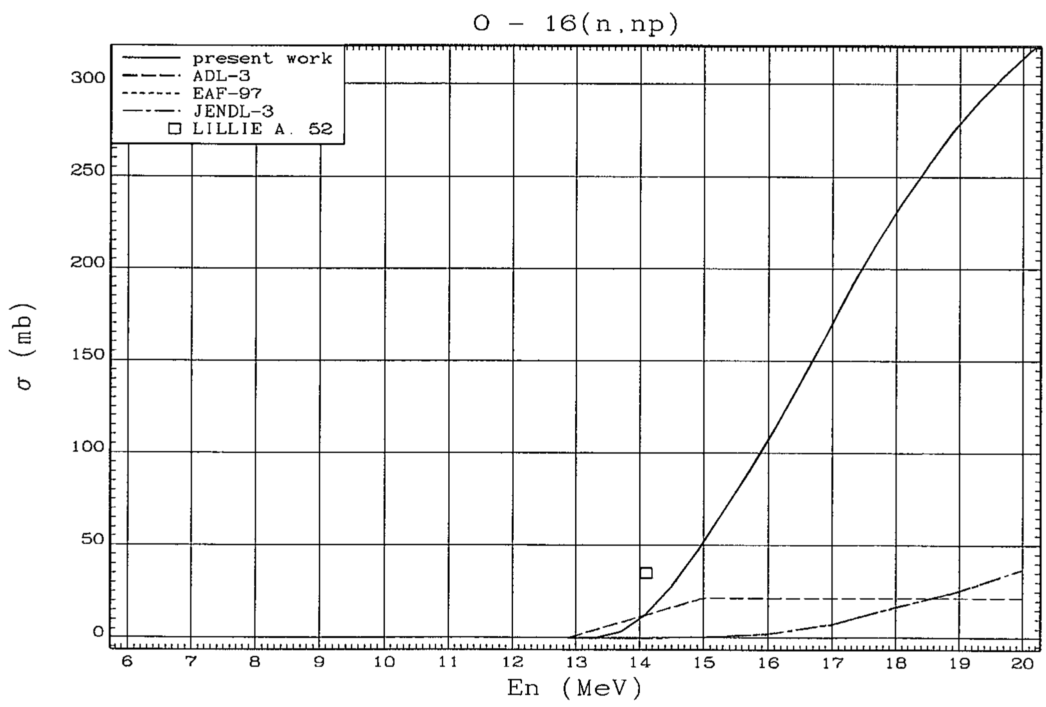

Fig. 25 ^{16}O(n,np) reaction cross section

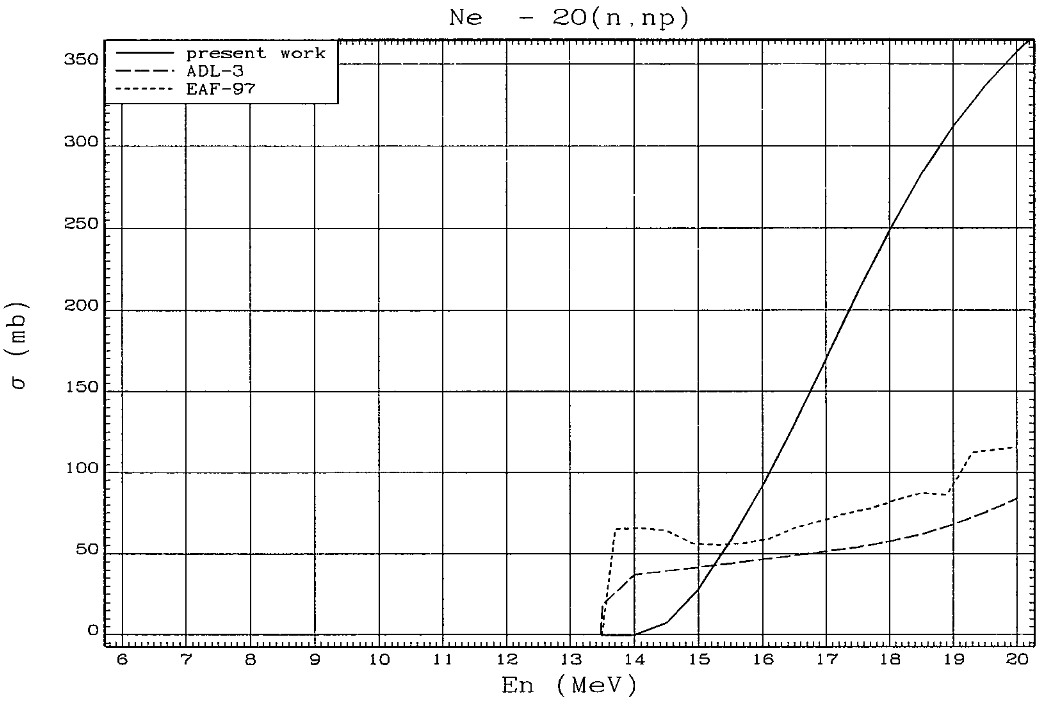

Fig. 26 ^{20}Ne(n,np) reaction cross section

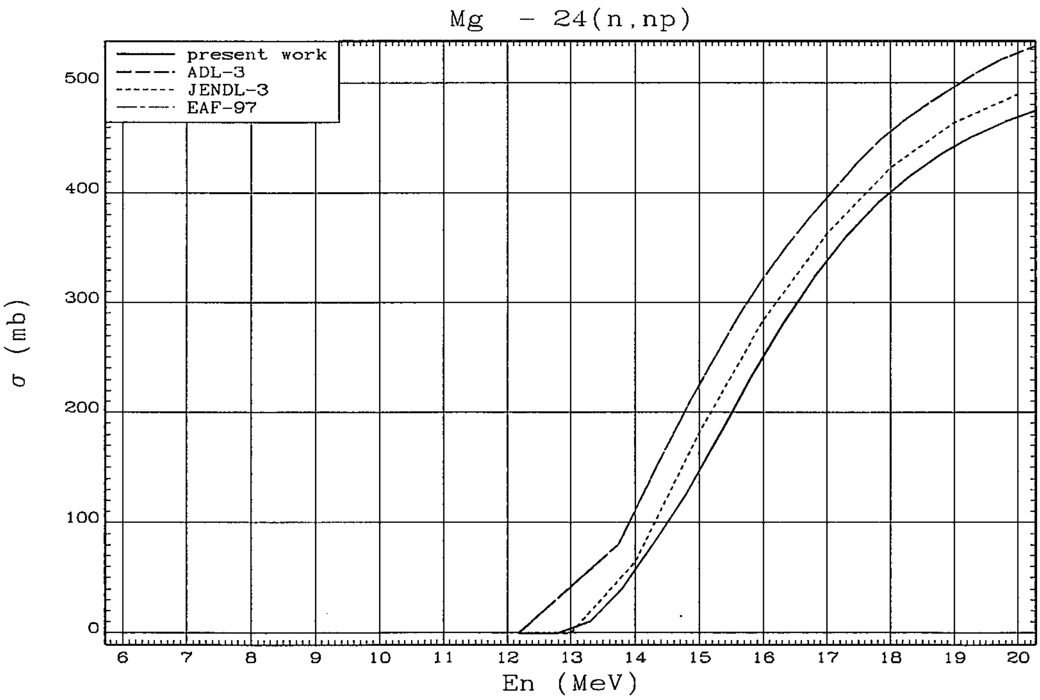

Fig. 27 ^{24}Mg(n,np) reaction cross section

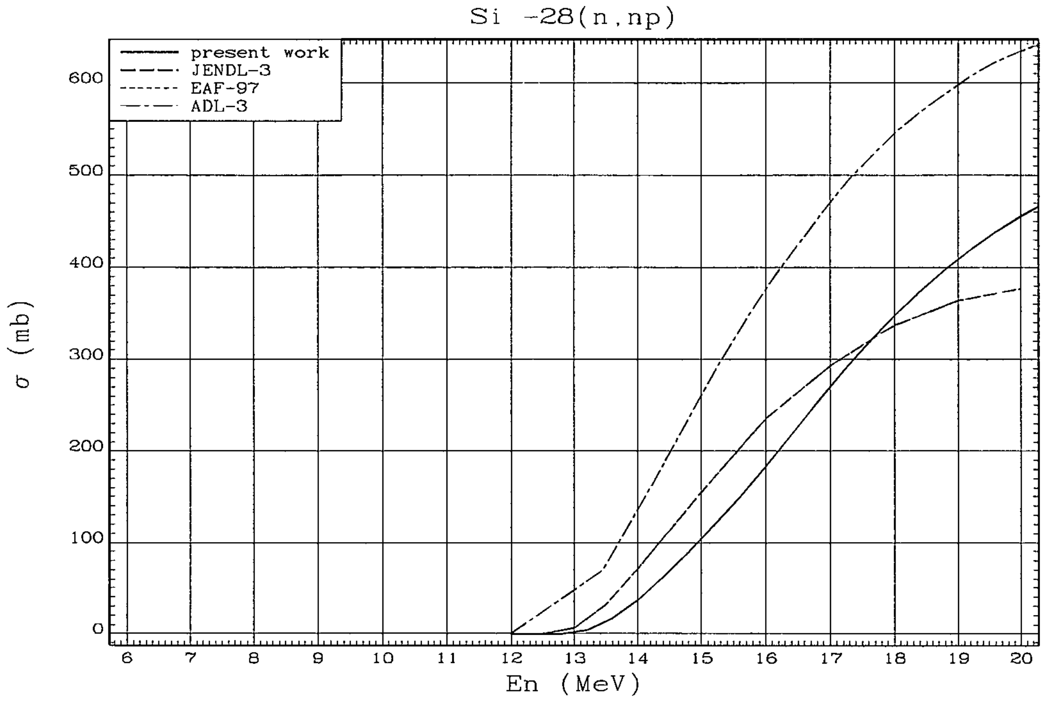

Fig. 28 ^{28}Si(n,np) reaction cross section

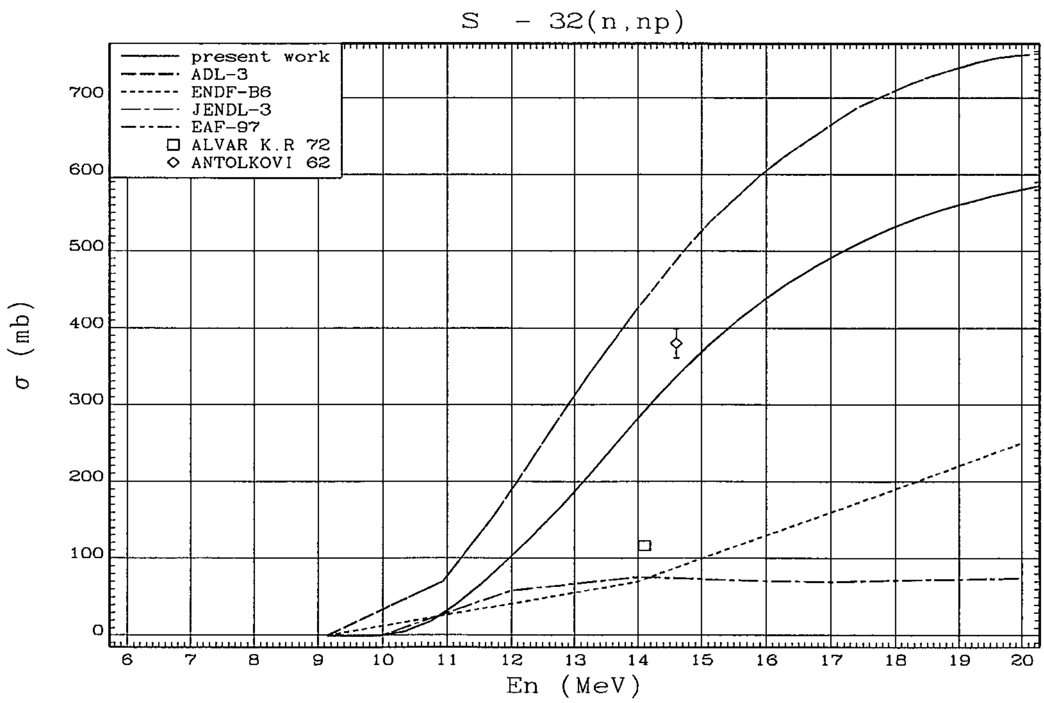

Fig. 29 ^{32}S(n,np) reaction cross section

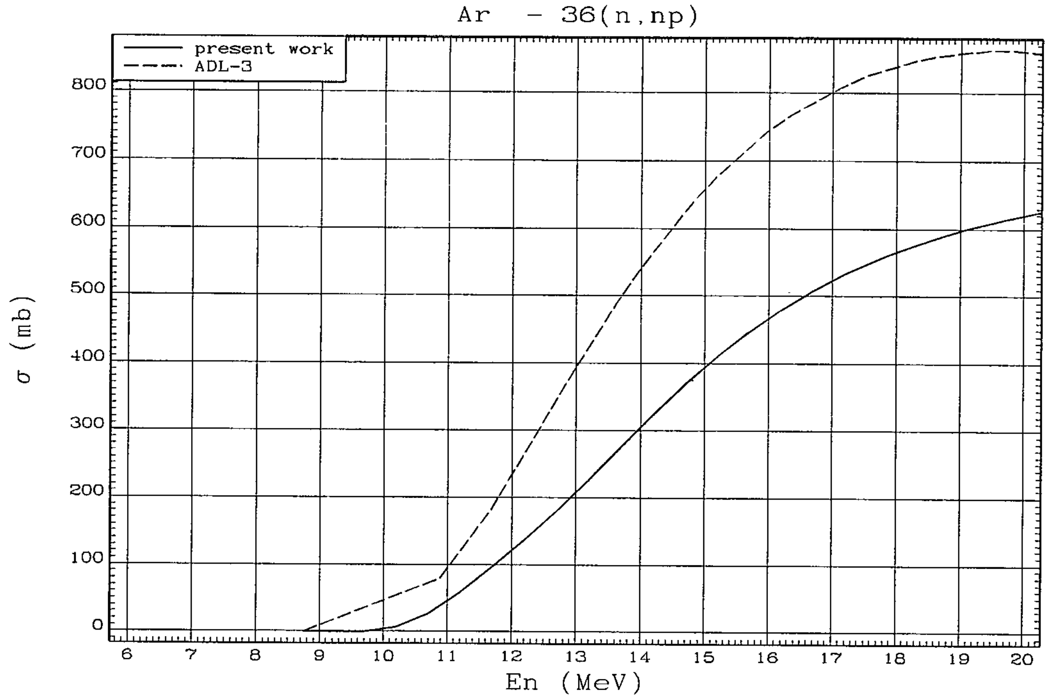

Fig. 30 ^{36}Ar(n,np) reaction cross section

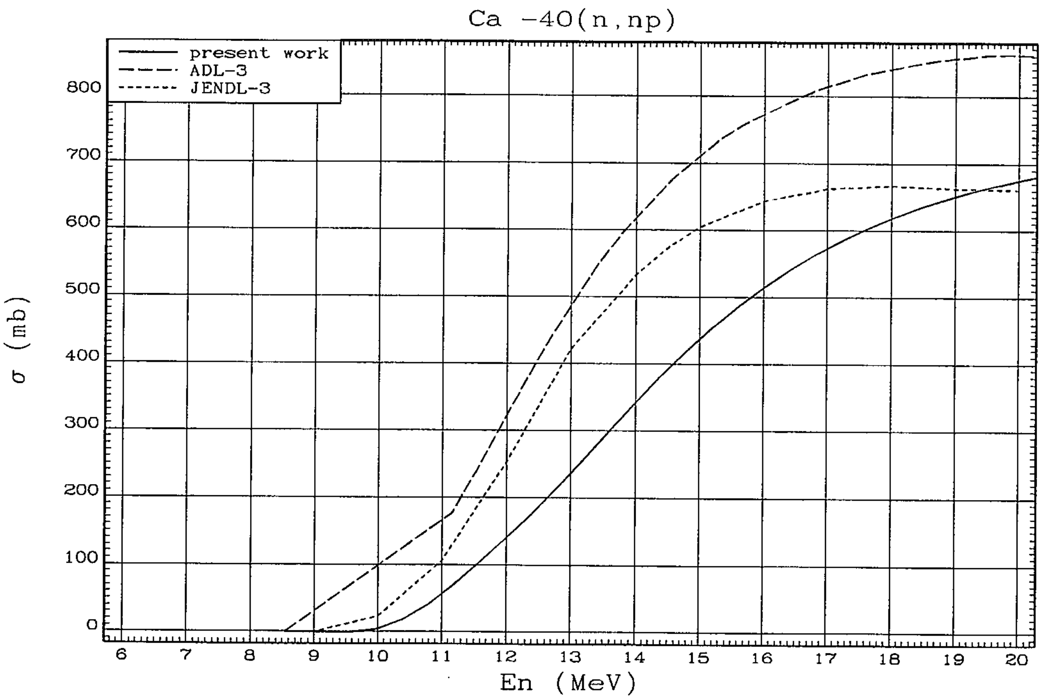

Fig. 31 ^{40}Ca(n,np) reaction cross section

国際単位系(SI)と換算表

表1　SI基本単位および補助単位

量	名　称	記　号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表3　固有の名称をもつSI組立単位

量	名　称	記号	他のSI単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	$m \cdot kg/s^2$
圧力，応力	パスカル	Pa	N/m^2
エネルギー，仕事，熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位，電圧，起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	V·s
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	cd·sr
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量当量	シーベルト	Sv	J/kg

表2　SIと併用される単位

名　称	記　号
分，時，日	min, h, d
度，分，秒	°, ′, ″
リットル	l, L
トン	t
電子ボルト	eV
原子質量単位	u

$1\ eV = 1.60218 \times 10^{-19}\ J$

$1\ u = 1.66054 \times 10^{-27}\ kg$

表4　SIと共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

$1\ Å = 0.1\ nm = 10^{-10}\ m$

$1\ b = 100\ fm^2 = 10^{-28}\ m^2$

$1\ bar = 0.1\ MPa = 10^5\ Pa$

$1\ Gal = 1\ cm/s^2 = 10^{-2}\ m/s^2$

$1\ Ci = 3.7 \times 10^{10}\ Bq$

$1\ R = 2.58 \times 10^{-4}\ C/kg$

$1\ rad = 1\ cGy = 10^{-2}\ Gy$

$1\ rem = 1\ cSv = 10^{-2}\ Sv$

表5　SI接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

(注)

1. 表1－5は「国際単位系」第5版，国際度量衡局 1985年刊行による。ただし，1 eV および1 uの値はCODATAの1986年推奨値によった。
2. 表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。
3. barは，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。
4. EC閣僚理事会指令ではbar，barnおよび「血圧の単位」mmHgを表2のカテゴリーに入れている。

換　算　表

力	N(=10^5dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘度　$1\ Pa \cdot s (N \cdot s/m^2) = 10\ P$(ポアズ)$(g/(cm \cdot s))$

動粘度　$1\ m^2/s = 10^4 St$(ストークス)(cm^2/s)

圧力	MPa(=10 bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J(=10^7erg)	kgf·m	kW·h	cal(計量法)	Btu	ft・lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal = 4.18605 J (計量法)

　= 4.184 J　(熱化学)

　= 4.1855 J　(15 ℃)

　= 4.1868 J (国際蒸気表)

仕事率　1 PS (仏馬力)

　= 75 kgf·m/s

　= 735.499 W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

(86年12月26日現在)