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COMPILATION AND EVALUATION OF (N,T) CROSS-SECTIONS AROUND 14 MEV

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Abstract

Experimental (n,t) cross-section data around 14 MeV were reviewed and evaluated, partly using theoretical fits. Recommended values are given for 37 nuclides. For those nuclides where no experimental data exist, empirical formulae are referred to; their accuracy is analysed.

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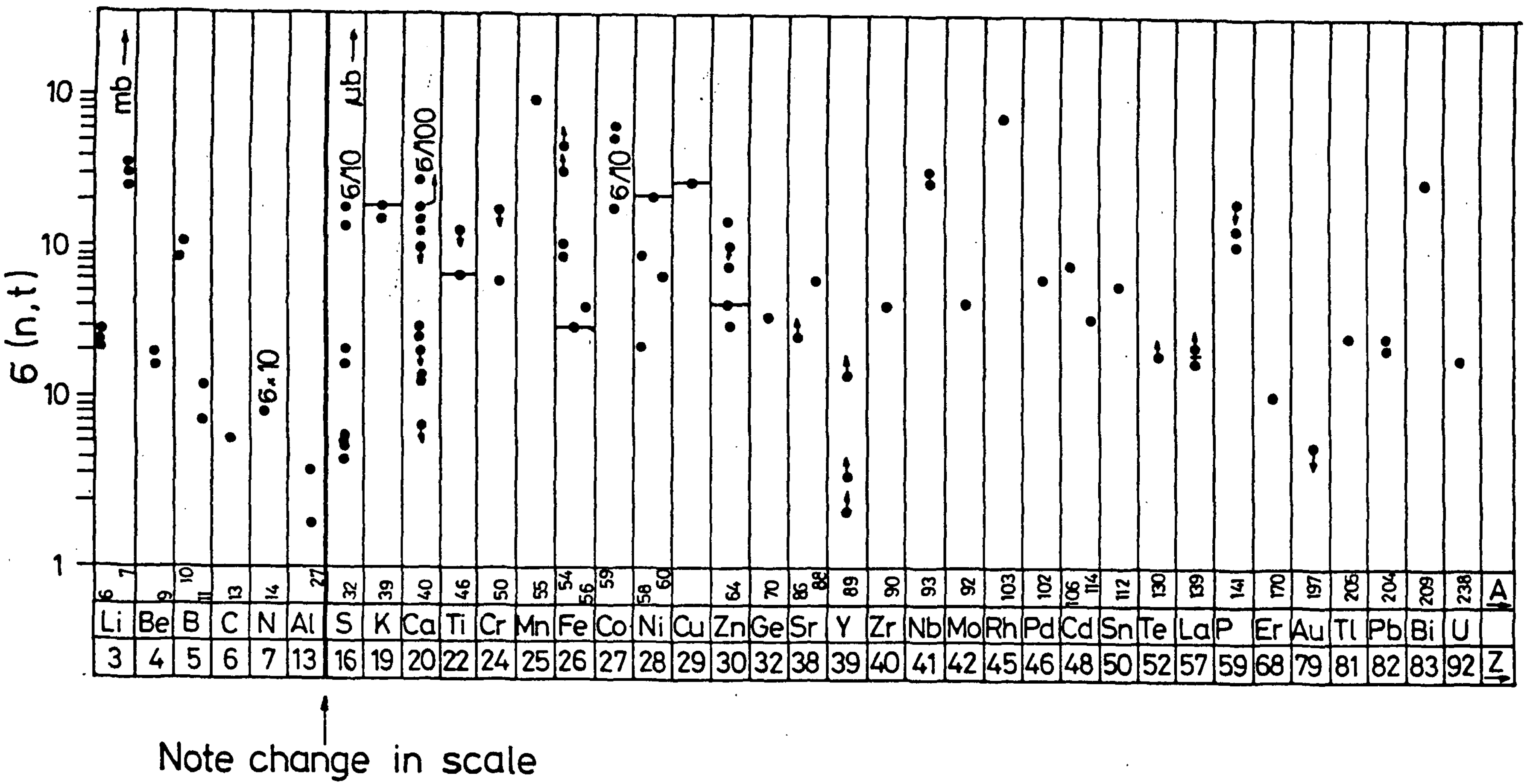


Fig. 1.

Cross sections for (n,t) reactions at 14 MeV

/Here 6x10 or 6/10 means that the respective 6 is multiplied or divided by ten; ⇞ means lower while ⇟ means upper limit; in the cases of ^{197}Au and ^{40}Ca the points mean partial cross sections only; ◆ means that the cross section refers to the element./

INTRODUCTION

A compilation and evaluation programme has been started to survey the available /n,t/ cross-section data [1], [2]. Some of the findings are given below:

1/ The vast majority of measurements deals with the lightest elements /Li, Be, B/. For example, about one third of the measurements relate to the ^{6}Li /n,t/ process if one takes into account the data at all energies.

2/ For other elements the experimental data are very scarce.

3/ Neglecting cross sections integrated over a broad energy range /the fission average cross sections of Heinrich and Tanner [3] and those measured by Qaim and Wölfle using deuteron break-up neutrons [4]/, following statements appear to hold for the atomic number range $10 \leq Z \leq 92$:

a/ Measurements were performed only for thirty elements or at least for one isotope of them. /In four cases for two isotopes of the same element./

b/ For more than half of the elements there are no experimental data at all. There are wider atomic number ranges /Z=33-37, 53-56, 62-67 and 69-78/ where no experimental data are available.

c/ In the $14.2 \leq E_n \leq 14.9$ MeV energy range 54 cross section measurements were performed. In addition to this in 7 cases upper limits were given and in 8 cases partial cross sections were determined /lower limits/. See Fig.1.

d/ Excitation functions /measurements for at least two energies/ were determined only in 8 cases.

4/ Cross section measurements by different authors up to 1970 yielded very different results. The maximum discrepancy can reach three order of magnitude /^{32}S, ^{40}Ca/. These cases might be exceptional; however, a one order of magnitude deviation is not unfrequent. The results reported after 1971, mainly from Jülich and Debrecen, are more consistent. Various reasons for discrepancies were discussed by those two groups. In many cases - if activation method is used - high cross-section /n,2n/ or other reactions leading to the same product nucleus can increase the value of the measured /n,t/ cross section. For example, the case of ^{32}S the ^{31}P contamination and in the case of ^{40}Ca the ^{39}K contamination must be less than about 0.01 % in order not to disturbe the results appreciably [5].

A further problem arises if one uses the annihilation radiation; here the separation of the /n,t/ - activation product from some disturbing activities can only be achieved through the difference between the half-lives. For example in the case of ^{40}Ca the activity of /7.7 min/ ^{38}K must be analysed from that on /9.98 min./ ^{13}N resulting from the /n,2n/ reaction of nitrogen present in the air [6]. Extensive studies on /n,t/ reactions on even mass nuclei were carried out at Jülich [6, 7], followed by some measurements at Dallas [8]. The odd mass nuclei were investigated mostly at Debrecen [9, 10]. From those investigations it can be stated that /n,t/ cross sections odd target nuclei are greater by about an order of magnitude than those on even target nuclei. /See Fig.2./ For the atomic number region with $Z \geq 20$ it can be established that all experimental data lie within in the following intervals:

$76\exp\left(-9.2\,\frac{N-Z}{A}\right) \leq \sigma/n,t/ \leq 200\exp\left(-8.3\,\frac{N-Z}{A}\right)$ μb for even,

$4500\exp\left(-23.5\,\frac{N-Z}{A}\right) \leq \sigma/n,t/ \leq 5400\exp\left(-13.9\,\frac{N-Z}{A}\right)$ μb for odd target nuclei.

Qaim and Stöcklin [7] had proposed an empirical formula of the form

$$\sigma/n,t/ = 4.52\left(A^{1/3}+1\right)^2 \exp\left(-10\,\frac{N-Z}{A}\right)\ \mu b$$

which was slightly modified by Woo and Salaita [8] in the following way:

$\sigma/n,t/ = 7.684\left(A^{1/3}+1\right)^2 \exp\left(-13\,\frac{N-Z}{A}\right)\ \mu b$. The quality of these formulae was analysed. It was found that they

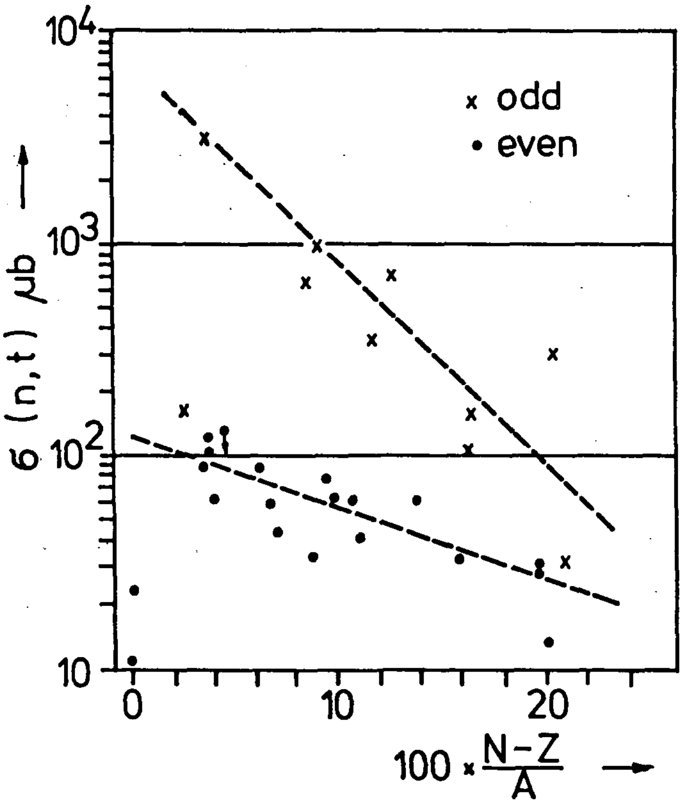


Fig. 2. Depedence of $\sigma_{n,t}$ on $\frac{N-Z}{A}$

are good only for even nuclei; their qualities being about the same.

For the range $20 < Z \leq 44$ the formula of Qaim and Stöcklin [7] is better, while for $Z > 44$ the formula of Woo and Salaita [8] is preferable. For odd nuclei the calculated values should be multiplied by about ten in order to have a reasonable estimate /except ^{205}Tl/.

The measured excitation function data were described by functions of the form

$$\sigma/E_n/ = e^{ax^2+bx+c} \qquad /1/$$

with fitted parameters a, b and c. /See Table 1./

Here

$$x = \left(\frac{A}{A+1} E_n + Q\right)^{-1/2}$$

, where E_n bombarding neutron energy in lab. system;

A: mass number;

Q: reaction energy in c.m. system.

Eq. /1/ with the parameters of Table 1. gives the cross sections in microbarns. The "purely empirical" excitation functions are recommended in the given intervals except for ^{93}Nb. The "semiempirical" excitation functions are the Hauser-Feshbach calculations of Sudár and Csikai [10] fitted to the experimental points.

In order to develop a semi-empirical interpolation formula the logarithmic derivatives of the excitation functions at a fixed excess energy above the threshold /5 MeV/ were plotted against the atomic number Z and a linear /nearly linear/ dependence was established:

$$\left(\frac{d\ln\sigma}{dE}\right)_{E=5\ \mathrm{MeV}} = \alpha + \beta Z, \qquad \text{where } \alpha = -0.667\ \mathrm{MeV}^{-1} \text{ and } \beta = 0.056\ \mathrm{MeV}^{-1}$$

The reason for choosing just 5 MeV excess energy is that around this energy we have a common interval where all /used/ excitation functions have measured values. The above linear form has a theoretical basis: if we want to describe the energy dependence by the product of the Gamow penetration factor

$$e^{-\frac{BZ}{\sqrt{E}}}$$

and a slowly varying function /f/ of E, then we have

$$\left(\frac{d\ln\sigma}{dE}\right)_{E=5\ \mathrm{MeV}} = \left(\frac{f'}{f} + \frac{1}{2}\ \frac{BZ}{E^{3/2}}\right)_{E=5\ \mathrm{MeV}} = \alpha' + \beta' Z$$

with $\beta' = 0.076\ \mathrm{MeV}^{-1}$.

The constant α' cannot be determined without knowing f. It can be seen that although $\beta \neq \beta'$, the two values are not very far from each other.

By using this result for the $13 \leq Z \leq 28$ region, one can estimate a cross-section value σ at $E = E_o + \Delta E$ from the value of the cross section σ_o at E_o. Let us denote by y the quantity $/\alpha + \beta Z/ \Delta E$, then we have

Table 1.

Empirical and semi-empirical excitation function parameters

Target nuclei	Q [MeV]	Parameters a [MeV]	 b [MeV]$^{1/2}$	 c	Energy range [MeV]	Comment	References
^{27}Al	-10.92	-5.00	2.21	8.29	13.5 - 19.5	purely empirical	[10, 11]
^{32}S	-12.72	-30.57	24.39	2.28	14.5 - 20.0	purely empirical	[15, 16, 17], [18, 19, 20,]
^{40}Ca	-12.92	-7.47	4.25	4.71	14.5 - 20.0	purely empirical σ^g only	[1, 6, 8], [20]
^{55}Mn	-9.32	-58.25	37.67	1.74	13.5 - 15.5	semi empirical	[10]
^{59}Co	-8.92	-27.95	10.43	6.90	14.5 - 19.0	semi empirical	[10, 11]
^{58}Ni	-11.12	-34.81	9.31	9.83	13.5 - 15.5	semi empirical	[10, 12, 21]
^{93}Nb	-6.22	214.09	-151.77	32.85	14.5 - 19.0	purely empirical	[10, 11]

$$\sigma = \sigma_0 /1+y/ \qquad \text{for } y > 0, \qquad /2/$$

$$\sigma = \sigma_0 /1+|y|\ /^{-1} \qquad \text{for } y < 0. \qquad /3/.$$

A pure empirical observation that instead of eq. /3/ we can use

$$\sigma = \sigma_0 /1+|y|/ \exp /2y/ \qquad \text{for } y < 0 \qquad /4/$$

and reach a far better result if $|y|$ is nearer the unity than zero. /For small arguments the two formulae yield about the same result./ Otherwise, eq. /2/ has a precision better than 7 % for ΔE=0.5 MeV and better than 15 % for ΔE= 1.0 MeV. Similarly, eq. /3/ gives values within 20 % for ΔE=-0.5 MeV and within 85 % for ΔE= -1.0 MeV. These later two percentages should be compared to 11 % and 20 % obtained from eq. /4/ for the same energy differences.

In order to check the excitation functions of form /1/ with parameters of Table 1. integral /n,t/ data can also be used. Unfortunately, the available integral data are small. In 1961 Heinrich and Tanner [3] measured some /n,t/ cross sections averaged over the thermal fission spectrum of ^{235}U.

The averaged cross section σ_{eff} is defined as

$$\sigma_{eff} = \int_0^\infty \sigma/E/S/E/dE, \qquad /5/$$

where $\sigma/E/$ is the excitation function and S/E/ is the normalized energy spectrum of the bombarding particles.

Heinrich and Tanner suggested to use the formula of Hill [13] and Watt [14] for S /E/ describing the neutron spectrum of the ^{235}U thermal fission:

$$S/E/ = \sqrt{\frac{2}{e\pi}} \cdot e^{-E} \cdot \mathrm{sh}\sqrt{2E} \qquad /E \text{ in MeV}/ \quad /6/$$

By inserting eqs. /1/ and /6/ into eq. /5/ the σ_{eff} values were determined. The results obtained together with the experimental data of Heinrich and Tanner [3] can be found in Table 2. The upper integration limit in eq. /5/ was chosen to be 20 MeV in each case, above this value the contribution to the integral is negligible.

Table 2.

Measured and calculated σ_{eff} values /* estimated/

Target nucleus	σ_{eff} /experimental/ [μb]	σ_{eff} /calculated/ [μb]	$\eta = \frac{\sigma_{eff}/exp/}{\sigma_{eff}/calc/}$
^{27}Al	0.26 ± 0.04	0.30 ± 0.03*	0.87 ± 0.16
^{55}Mn	0.17 ± 0.03	0.094	1.81 ± 0.18
^{57}Co	$0.05 \leq \sigma_{eff} \leq 0.13$	0.058	$0.8 \leq \eta \leq 2.5$
^{58}Ni	$\sigma_{eff} < 0.05$	0.025	$\eta < 2.0$

The experimental and calculated results agree within the error limits for ^{27}Al. If one uses the excitation function for ^{27}Al given in the ENDF/B IV file one obtains a calculated value for σ_{eff} which is three-times as great as the experimental value. The excitation function for /n,t/ reaction on ^{27}Al given in the ENDF/B IV file is wrong as is evidenced by a simple comparison with experimental data /see Fig.3/.

The greater deviation of η from the unity for ^{55}Mn can be explained by the fact that the excitation function is reliable only within the 13.5-15.5 interval /see Table 1/, and the contribution to the integral /5/ from outside this interval is not negligible at all.

In the cases of ^{59}Co and ^{58}Ni the measured and calculated values do not contradict each other. However, these agreements have not any special significance owing to the fact that here the measurements yielded only /lower and upper/ limits of σ_{eff}. In addition, it should also be taken into account that the measurement was made for elemental Ni while the calculation is for ^{58}Ni nuclide.

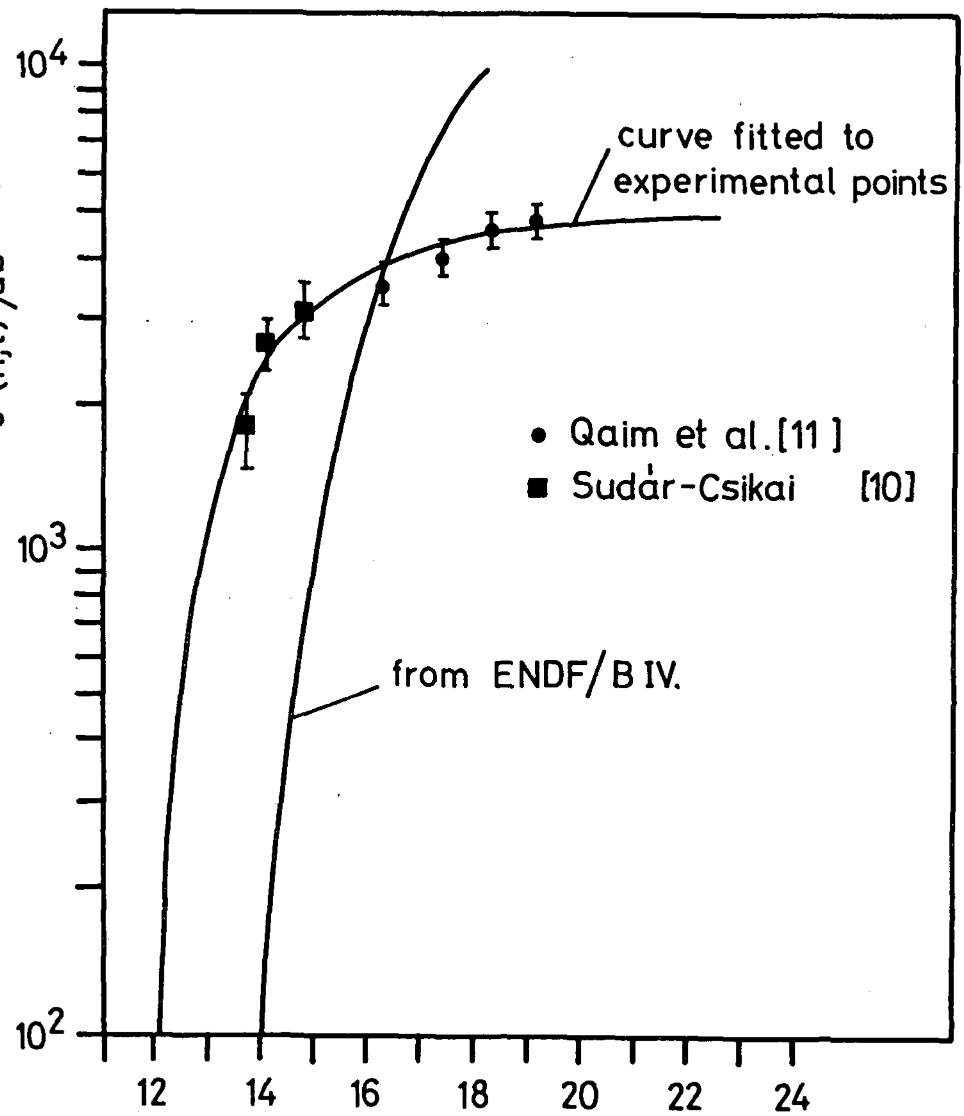


Fig. 3.

Excitation function of ^{27}Al (n,t) reaction

A comparison of the integral data of /n,t/ reactions, induced by fission neutrons, with those deduced from the above equation does not describe an ideal case, because the thresholds of the /n,t/ reactions generally lie above 10 MeV and the contribution of neutrons with $E_n > 10$ MeV in the fission spectrum is rather small. Qaim and Wölfle [4] did extensive studies on /n,t/ reactions using 53 MeV d/Be/ break-up neutrons. However, since the neutron spectrum extends up to 50 MeV, and it is not sure whether the above formulation would be valid up to such a high energy, we did not attempt a comparison with those data. Recent studies at Jülich [24, 23] using 30 MeV d/Be/ break-up neutrons for triton emission cross section measurements are more interesting since they cover

Table 3.

Measured and calculated σ_{eff} values for deuteron break-up neutrons

Target nucleus	σ_{eff} /experimental/ /mb/	σ_{eff} /calculated/ /mb/
^{27}Al	1.40 ± 0.42	1.38
^{55}Mn	0.64 ± 0.20	0.635
^{59}Co	0.64 ± 0.20	0.41

a major energy portion of an /n,t/ reaction. The neutron spectrum was determined by multiple foil activation technique from 2 to 30 MeV using threshold reactions [23]. By inserting this spectrum and eq. /1/ into eq. /5/ the σ_{eff} values were calculated /with a lower limit 2 MeV instead of zero which affects the normalization/ and compared to the experimental data. A preliminary result of this comparison is given in Table 3.

The agreement between experiment and calculation is surprisingly good for ^{27}Al and ^{55}Mn, resp., expecially if one considers that the experimental cross sections contain contributions also from /n,xt/ process while the calculations do not take into account these contributions.

The authors should like to thank the valuable advices of Prof. Csikai and S.M. Qaim /Jülich/, further they wish to acknowledge the financial support of the International Atomic Energy Agency, Vienna under contract No. 3114/RB.

References

[1] Z.T. Bődy, F. Cserpák, J. Csikai, S. Sudár, K. Mihály, Nuclear Data for Sciences and Technology, pp.368-370, 1983. Ed.: K.H. Böckhoff, ECSC,EES, EAEC, Brussels and Luxembourg

/¯2_7 Z.T. Bődy, K. Mihály, Report ZfK-491 /1982/ 201-203

/¯3_7 F. Heinrich, F. Tanner, Helvetia Phys. Acta 36/1963/298

/¯4_7 S.M. Qaim, R. Wölfle, Nucl.Phys. A 295/1978/150

/¯5_7 Thesis of S. Sudár. 1979, Debrecen /in Hungarian/

/¯6_7 S.M. Qaim, G. Stöcklin, J.Inorg. Nucl. Chem. 35/1973/19

/¯7_7 S.M.Qaim and G.Stöcklin, Nucl. Phys. A 257 /1976/ 233

/¯8_7 T.W. Woo, G.N. Salaita, Int. Conf.on Nuclear Cross Sections for Techn. Oct. 22-26/1979/, Knoxwille, USA; NBS Spec.Publ. 594 GC 12/1979/ 853

/¯9_7 T. Biró, S. Sudár, Z. Miligy, Z. Dezső, J. Csikai, J. Inorg. Nucl. Chem. 37/1975/ 1583

/¯10_7 S.Sudár, J. Csikai, Nucl. Phys. A 319/1979/157

/¯11_7 S.M. Qaim, R. Wölfle, H. Liskien, Phys.Rev. C 25/1982/203

/¯12_7 Priv. comm. of S. Sudár and ref. 10.

/¯13_7 D.L. Hill, Phys. Rev. 87/1952/1034

/¯14_7 B.E. Watt, Phys. Rev. 87/1952/ 1037

/¯15_7 A.P. Baerg, G.C. Bowes, Can. J. Chem. 39/1961/ 684

/¯16_7 E. Weigold and R.N. Glover, Nucl.Phys. 32/1962/ 106

/¯17_7 A. Poularikas, D.G. Gardner, A-ARK-63 /1963/ 14
BNL-325, Neutron Cross Sect. Vol.2, Curves, p. 86 /1976/

/¯18_7 M. Bormann, F. Dreyer, P. Jessen, P. Schenka, Nucl. Data Tables A 18

/¯19_7 R. Sacher, H. Warhanek, Acta Phys. Austriaca 23/1966/181

[20] M. Bormann, F. Dreyer, H. Neuert, I. Riehle and U. Zielinski, EANDC /E/66 U, 42/1966/. 1966. Paris Conf.

[21] T.W. Woo, G.N. Salaita, EXFOR 10764 /1978/

[22] Z.T. Bődy, K. Mihály: A calculation of integral /n,t/ cross section data from excitation functions and a comparison with experimental data /in Russian/. VI. Soviet Conference on Neutron Physics, Kiev, Oct.2-6, 1983 /to be published/

[23] R.Wölfle, S. Khatun, S.M.Qaim,(Triton emission cross sections with 30 MeV d/Be/ break-up neutrons.) Nucl. Phys. **A 423/1984/130**

[24] S.M. Qaim, S.Khatun, R. Wölfle, Symp. on Neutron Cross Sections from 10-50 MeV, May 12-14 /1980/ BNL, Upton USA, BNL-NCS-51245 /1980/539

Recommended values
of (n,t) cross-sections around 14 MeV

On the following pages recommended values of (n,t) cross-sections are given for the neutron energies at which experimental data are available. Details are given describing how the recommended values were obtained.

^{6}Li

E (MeV)	σ (mb)
10.5	36.0
10.8	34.8
11.0	34.0
11.5	33.0
12.0	31.0
12.5	29.0
13.0	28.0
13.5	27.0
14.0	26.0
14.5	25.0
15.0	24.0
15.5	23.3

lin. - lin. interpolation
σ error is not more than 10 %

Taken from ENDF/B-5 Standards file (G.Hale, L.Stewart and P.G.Young, 1977; Rev.: 1979)

Data and error are based on
1./ E.D.Pendlebury, AWREO-60/64 (July 1964);
2./ B.D.Kern and W.E.Kreger, Phys. Rev. 112 (1958) 926.

ENDF/B-5 and JENDL-2 (S.Komoda and S.Igarasi, 1977; Rev.:1983) agree within 10 % for the above interval.

^{7}Li

for $^{7}Li(n,nt)$ process !

E (MeV)	σ (mb)
10.1	370
11.4	353
12.7	333
14.1	318
15.5	306

lin. - lin. interpolation
σ error is not more than 6 %

Taken from JENDL-2 file (K.Shibata 1982; Rev.: Nov.1983)

Data and error are mainly based on
1./ M.E.Wyman and M.M.Thorpe, LA-2235 (1958);
2./ P.W.Lisowski et al., LA-8342 (1980);
3./ H.Liskien and A.Paulsen, INDC(EUR) 014/G (1981) p. 14;
4./ D.L.Smith et al., Nucl. Sci. Eng. 78 (1981) 359.
In the above energy region ENDF/B-5 Rev.2 (P.Young,1981, as quoted in ref.5) gives somewhat lower values (by 2 % at 11.4 MeV and by 8 % at 15.5 MeV). See also ref. 5. who measured a value between the two evaluations:
5./ D.L.Smith et al.,ANL/NDM-87(1984).They got 301 mb±5.3 % at 14.74 MeV.
The differences are within the estimated error of 6 %. So, the JENDL-2 evaluation can still be recommended.

^{9}Be

E /MeV/	σ/mb/
13.5	15
14.0	17.7
14.5	20.6
15.0	23.4

lin.-lin. interpolation
σ error is less than 20%

σ was calculated from the formula:

$$\sigma = aE+b \quad \text{with} \quad a = 5.63 \text{ mb/MeV}, \quad b = -61.08 \text{ mb}$$

which was obtained by a straight line least square fitting using the following experimental values:

1./

E/MeV/	σ/mb/
13.55	15.5±2.5
13.83	16 ±2.5
14.10	19.1±2.6
14.39	22.0±2.8
14.63	18.9±4
14.70	22.8±3.4

of Z.T. Bődy, F.Cserpák, J.Csikai, S. Sudár and K. Mihály, Proc. of the Internat. Conf. on Nucl. Data for Sci. and Techn. Sept 6-10, 1982, Antwerp. Proc. ed. by K.H. Böckhoff, 1983. ECSC,EEC,EAEC Brussels and Luxembourg, p.368

2./ E = 14.7 MeV, σ= 20± 4 mb of T. Biró, S. Sudár, Z. Miligy, Z.Dezső and J. Csikai, J.Inorg.Nucl.Chem. 32 /1975/1583

3./ E = 14.1 MeV, σ= 18 ± 1.5 mb of M.E. Wymen, E.M. Fryer and M.M. Thorpe, Phys. Rev. 112 /1958/ 1264.

^{10}B

E (MeV)	σ (mb)
9.0	129
10.0	122
12.0	108
14.0	94
16.0	79
18.0	65
20.0	51

lin. - lin. interpolation

σ error is less than 20 %

σ was calculated from the formula $\sigma = aE + b$ with $a = -7.1$ mb/MeV and $b = 193$ mb valid for the interval $9 \text{ MeV} \leq E \leq 20 \text{ MeV}$. The a and b parameters were obtained by a straight line least square fitting of the following experimental values:

1./

E (MeV)	σ (mb)	
5.6	239 ± 40	G.M.Frye Jr., J.H.Gammel, Phys. Rev.
7.7	131 ± 23	103 (1956) 328
12.2	96 ± 21	taken from
14.1	102 ± 17	EXFOR 11255002
16.1	84 ± 16	For detection boron-loaded nuclear
18.2	81 ± 16	emulsion was used.
19.5	60 ± 12	

2./

E (MeV)	σ (mb)		
4.0 ± 0.2	95 ± 10	M.E.Wyman, E.M.Fryer, M.Thorpe,	
5.60± 0.05	230 ± 25	Phys. Rev. 112 (1958) 1264	
9.60± 0.15	125 ± 15	taken from	Tritium β counting
14.10± 0.10	85 ± 6	EXFOR 11231003	was used.

Only the E > 9 MeV values were used for fitting.

As for the $E \leq 9$ MeV values of the different measurements they are (in addition to formerly mentioned data) :

3./

E (MeV)	σ (mb)	E (MeV)	σ (mb)	E (MeV)	σ (mb)
1.35	5	2.14	26	2.88	26
1.56	7	2.26	15	3.04	24
1.68	15	2.39	15	3.17	25
1.79	16	2.49	22	3.31	25
1.91±0.05	28	2.64	23	3.38	31
2.03	30	2.77	24	3.45	39

E (MeV)	σ (mb)	E (MeV)	σ (mb)	E (MeV)	σ (mb)
3.52	32	4.75	87	6.10	80
3.58	34	4.79	89	6.23	82
3.73	37	4.83	84	6.31	84
3.80	43	4.88	83	6.39	79
3.88	49	4.91	86	6.50	71
4.05	62	4.95	81	6.63	65
4.17±0.08	75	5.01	82	6.76	55
4.29	78	5.07	84	6.88	53
4.33	79	5.17	76	7.03	47
4.39	76	5.26	75	7.15	50
4.43	83	5.33	73	7.31	50
4.47	79	5.42	75	7.46	49
4.51	81	5.48	77	7.59	47
4.55	85	5.63	80	7.75	46
4.60	81	5.80	85	7.90	45
4.63	82	5.88	85	8.05	43
4.67	84	6.000±0.085	82	8.200±0.120	41

E.A.Davis, F.Gabbard, T.W.Bonner, R.Bass, Nucl. Phys. 27 (1961) 448 taken from EXFOR 11195003. The σ errors range from 30 to 60 percent. This is a partial cross section only (three-body breakup through the 4.63 MeV level of ^{7}Li). Detector: grid-type ionization chamber.

4./

E (MeV)	σ (mb)	
5.8 ± 0.2	71^{+22}_{-15}	F. Csérpák (Inst. Exp. Phys., Kossuth University, Debrecen, Hungary) priv.comm.
7.5 ± 0.2	60^{+13}_{-8}	1984. Tritium β counting was used.

One can see that there is a factor of 3 between the smallest and the highest data for values with E less than 9 MeV, so it would be difficult to recommend safely any of them. In addition, it should be noted here (following Csérpák's communication) that if one applies tritium beta counting and omits the substraction of the different background contributions then he can obtain values which are twice as large than that with substraction.

^{11}B

E = 14.1 MeV σ = 15 mb

σ error is about 30%

This is an experimental value of M.E. Wyman et al. Phys. Rev. 112 /1958/1264 who measured

$$\sigma = 15 \pm 5 \text{ mb} \quad \text{at} \quad 14.1 \pm 01 \text{ MeV}$$

The error is an estimated one.

D. Miljanic et al. Nucl.Phys. A 156 /1970/193 obtained differential cross sections from 0° to $64^{\circ}43'$ /c.m/ at 14.4 MeV for the $^{11}B/n,t/^{9}Be$ /g.s/ process. The integration of the differential cross section from 0° to $64^{\circ}43'$ by S. Sudár, Thesis, Kossuth Univ. Debrecen, Hungary, 1979 /in Hungarian/ gave a cross section ~8.1 mb.

^{13}C

E = 14.6 MeV σ = 6.9 mb

σ error is 40%

This is an average a two exp. values:

1./ T. Biró, Thesis, Kossuth Univ. Debrecen, Hungary, 1974 /in Hungarian / measured

$$\sigma = 6 \pm 1 \text{ mb} \quad \text{at} \quad 14.6 \text{ MeV}$$

This value is also mentioned in T. Biró et al. J. Inorg. Nucl. Chem. 37 /1975/1583 /Fig. 3/ and in the Thesis of S. Sudár, Kossuth Univ., Debrecen, Hungary, 1979 / in Hungarian/,

2./ $\sigma = 7.8^{+2.3}_{-1.0}$ mb at 14.6 MeV was measured by F. Cserpák, Kossuth Univ. Debrecen, Hungary /priv. comm. 1983/. From this measurement a preliminary value 38 mb was given in F. Cserpák, T. Biró, J. Csikai, Harwell Conf./1978/ p. 761. The preliminary value has been proven to be too high later, but the method is the same /and different from the one used formerly by Biró et al./.

^{14}N

E = 14.4 MeV	σ = 20 mb
	σ error is /maximally/ 50%

Estimated value using exp. data

I. For the $^{14}N/n,t/^{12}C$ /ground state/process:

1./ At E=14.7 MeV σ_1= 2mb by R.H. Lindsay, J.J. Veit, Phys. Rev. 157/1967/933.

2./ At E = 14.1 MeV $\sigma_2 \simeq$ 4 mb estimated by S. Sudár, Thesis, Kossuth Univ., Debrecen, Hungary, 1979 / in Hungarian/ on the basis of the paper: P. Fassenden, D.R. Maxson, Phys. Rev. 158 /1967/948.

3./ At E = 14.4 MeV σ_3= 6.4±1.2 mb by D. Rendic EXFOR 30194/ diff. cross. s. integrated from 0° to 90° c.m./

From σ_1, σ_2, σ_3 the average is σ_I = 4.1 mb.

II. For the ^{14}N /n,t/^{12}C / 4.43 MeV exc. state/ process D. Rendic EXFOR 30194 gives σ_{II}= 23.4±3 mb /diff. cross. s. integrated from 0° to 90° c.m./.

$$\sigma_{II} \text{ was renormalized by } {}^{r}\sigma_{II} = \sigma_{II}\cdot\frac{\sigma_I}{\sigma_3} = 15.0 \text{ mb}$$

III. For the ^{14}N /n,t/3α process:

At E = 15.7 MeV σ_{III} = 0.8±0.5 mb, by J. Mösner et al. Nucl. Phys. A 103 /1967/238.

$$\sigma = \sigma_I + \sigma_{II} + \sigma_{III} = 19.9 \simeq 20 \text{ mb}$$

The 50% error was estimated on the basis of the paper of S.M. Qaim, R. Wölfe, Nucl.Phys. A 295/1978/150 who gave σ = 30 mb for a higher energy, so the present σ must be less than 30 mb.

^{27}Al

E /MeV/	σ/μb/
13.0	1030
14.0	2270
15.0	3140
16.0	3720
17.0	4110
18.0	4380
19.0	4570
20.0	4710

lin.-lin. interpolation

σ error is about 10%

Calc. from $\sigma = e^{ax^2+bx+c}$

with a = -5.00 MeV

b = 2.21 $MeV^{1/2}$

c = 8.29

$x = /\frac{A}{A+1}E_n+Q/^{-1/2}$, A = 27

Q = -10.92 MeV

The curve was calculated by fitting the experimental points of S.M. Qaim, Phys. Rev. C 25/1982/203, and S. Sudár, J. Csikai, Nucl. Phys. A 319/1979/157

Exp. points:

E/MeV/	σ/μb/	
13.7	1780± 300	Sudár - Csikai 1979
14.1	2680± 300	
14.8	3130± 400	
16.3± 0.6	3500± 270	Qaim, 1982
17.4± 0.5	4050± 300	
18.3± 0.4	4570± 340	
19.1± 0.5	4830± 360	

It is discarded the E = 14.8 MeV, σ< 12.2 μb value of A. Poularikas, A.G. Gardner, EXFOR 11533 /1963/

^{32}S

E/MeV/	σ /μb/
14.5	1.7
15.0	36.0
15.5	163
16.0	377
16.5	618
17.0	837
17.5	1010
18.0	1133
18.5	1211
19.0	1252
19.5	1267

lin.-lin. interpolation
σ error is about 25% for 14.5 - 15.5 MeV and about 15% for 16.0 - 19.5 MeV

Calc. from $\sigma = e^{ax^2+bx+c}$

with $a = -30.57$ MeV
$b = 24.39$ MeV$^{1/2}$
$c = 2.28$

$x = /\frac{A}{A+1}E_n + Q/^{-1/2}$, $A = 32$

$Q = -12.72$ MeV

The curve was calculated by fitting the experimental points of M. Bormann, F. Dreyer, H. Neuert, I. Riehle and U. Zielinsky EXFOR 20898 /1966/

Exp. points:

E/MeV/	σ/μb/	
14.7± 0.35	7.5±0.7	Bormann et al /1966/
16.05±0.95	471 ± 61	
17.05±0.95	737± 96	
$18.00^{+0.7}_{-0.9}$	1000± 130	
$18.70^{+0.50}_{-0.75}$	1260± 160	
$19.60^{+0.20}_{-0.30}$	1380± 180	

The calculated curve is not in disagreement with the following exp. points:

E/MeV/	σ/μb/	
14.6	4± 1	A.P.Baerg,G.C.Bowes, Can.J. Chem. 39 /1961/648
14.7± 0.3	20 ± 5	E.Weigold,R.N. Glover, Nucl. Phys. 32 /1962/106
14.8	<17	A. Poularikas, D.G.Gardner, EXFOR 11533 /1963/
14.7 ±0.2	6.7±1.9	R. Sacher, H. Warhanek, EXFOR 20083 /1966/
14.7 ±0.3	7.2±1.6	S.M. Qaim, G.L. Stöcklin, J. Inorg.Nucl.Chem.35 /1973/19

It is <u>discarded</u> the result of

14.6	154±70	M. Dikšič et al. J. Inorg. Nucl.Chem. 36 /1974/477
14.8	2200±200	C.S.Khurana, I.M.Govil, Nucl.Phys. 69 /1965/153

^{39}K

E/MeV/	σ/μb/	
14.70	187	lin.-lin. interpolation
15.08	218	σ error is 20% at 14.7 MeV
15.45	261	23% at 15.08 MeV,
		24% at 15.45 MeV

The 14.7 MeV value is an experimental one of T. Biró, S. Sudár, Z. Miligy, Z. Dezső and J. Csikai, J. Inorg. Nucl. Chem. <u>37</u> /1975/1583, $\sigma = 187 \pm 37 \mu b$ at 14.7 MeV.

The 15.08 MeV value was calculated by the formula

$$\sigma = \sigma_o / 1 + |y| / e^{2y}$$

with

$y = / \alpha + \beta Z / \Delta E$ $\qquad \alpha = -0.667\ MeV^{-1}$

$E = E_o + \Delta E$ $\qquad \beta = 0.056\ MeV^{-1}$

$Z = 19$

here

E_o = 15.08 MeV / 5 MeV excess energy above threshold/

E = 14.7 MeV $\qquad \sigma = 187\ \mu b$

$y = -0.1458$ $\qquad \sigma_o = 218\ \mu b$

The 15.45 MeV value

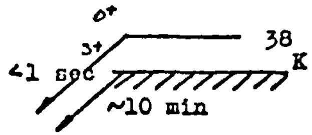
$\sigma = \sigma_o / 1 + y /$ $\qquad$ with $y = 0.1458$

$\sigma = 261\ \mu b$

see Z.T. Bődy, K. Mihály, Report ZfK-491/1982/200.

^{40}Ca

for σ^{g} only!



E /MeV/	σ/μb/
14.5	11.7
15.0	36.5
16.0	92.2
17.0	133
18.0	160
19.0	176
20.0	187

lin.-lin. interpolation
σ error is about 80% for 14.5 MeV, 50% for 15.0 MeV and 15% for 16.0-20.0 MeV

Calc. from $\sigma = e^{ax^2+bx+c}$
with

a = -7.47 MeV $x = /\frac{A}{A+1}E_n+Q/^{-1/2}$

b = 4.25 MeV$^{1/2}$ A = 40

c = 4.71 Q = -12.92 MeV

The curve was calculated by fitting the exp. points of M. Bormann, F. Dreyer, H. Neuert, I. Riehle and U. Zielinsky, EXFOR 20898 /1966/

Exp. points:

E/MeV/	σ/μb/	
$14.9^{+1.4}_{-1.2}$	31 ± 5	Bormann et al. /1966/
16.1 ± 1.4	92 ± 11	
$17.1^{+1.3}_{-1.4}$	135 ± 15	
$17.7^{+1.2}_{-1.4}$	157 ± 17	
$18.0^{+1.0}_{-1.3}$	158 ± 17	
$18.7^{+0.7}_{-1.2}$	188 ± 20	
$19.6^{+0.2}_{-0.3}$	169 ± 18	

The calculated curve is not in strong disagreement with the following exp. points:

E/MeV/	σ/μb/	
14.7 ±02	<7.5	R. Sacher, H. Warhanek, EXFOR 20083 /1966/
14.7 ± 03	27 ± 8	S.M. Qaim, G.L. Stöcklin, J. Inorg. Nucl. Chem. 35 /1973/19
14.7 ± 03	<100	E. Weigold, R.N. Glover, Nucl. Phys. 32/1962/106
14.6	16 ±4	T.W. Woo, G.N. Salaita, Internat. Conf. on Nucl. Cross Sections for Techn. Knoxville, Oct. 22-26, 1979 NBS Spec. Publ. 594 /1980/p.853
14.6	< 20	A.P. Baerg, G.C. Bowes, Can. J. Chem. 39 /1961/648
14.7	3.5± 1.4	Z.T. Bődy, F. Cserpák, J.Csikai, S. Sudár and K. Mihály, Nucl. Data for Sci. and Techn. Internat. Conf. Antwerp. Sept 6-10, 1982. Proc. ed. by K.H. Böckhoff, 1983. ECSC, EEC, EAEC Brussels and Luxembourg p.368.

Discarded data:

14.8	20±4 mb!!	C.S. Khurana, I.M.Govil, Nucl. Phys. 69/1965/153
14.7	150± 50	B. Minetti, A. Pasquarelli. EXFOR 21288
14.2±0.2	180± 20	N.Tiwari, E. Kondaiah, Phys.Rev. 167 /1968/1091
14.6	310±180	M. Dikšič et al. J. Inorg. Nucl. Chem. 36 /1974/477.

^{46}Ti

E = 14.6 MeV σ = 109 μb

σ error is 20%

This is an average of two exp. values

1./ S.M. Qaim, G. Stöcklin, Nucl.Phys. A 257 /1976/233 measured

$$\sigma_1^g = 115 \pm 35\ \mu b \qquad \sigma_1^m < 20\ \mu b \qquad \text{at } E = 14.6 \pm 0.4 \text{ MeV}$$

2./ T.W. Woo, G.N. Salaita, EXFOR 10764 /1978/ measured

$$\sigma_2^g = 91 \pm 28\ \mu b \qquad \sigma_2^m = 9 \pm 3\ \mu b \qquad \text{at } E = 14.6 \text{ MeV}$$

From σ_1^g and σ_2^g we have $\sigma^g = 100 \pm 21.8\ \mu b$,
So

$$\sigma = \sigma^g + \sigma^m = \sigma^g + \sigma_2^m = 109 \pm 22\ \mu b$$

^{50}Cr

E = 14.6 MeV σ = 88 μb

σ error is 25%

This is an average of two exp. values

1./ S.M. Qaim, G.L. Stöcklin, J. Inorg. Nucl. Chem. 35 /1973/19 measured

$$\sigma_1 = 66 \pm 20\ \mu b \qquad \text{at } E = 14.6 \pm 0.4 \text{ MeV}$$

2./ T.W. Woo and. G.N. Salaita, EXFOR 10764 /1978/ measured

$$\sigma_2 = 109 \pm 16\ \mu b \qquad \text{at } E = 14.6 \text{ MeV}$$

From σ_1 and σ_2 one can have the /simple/ mean

$$\sigma = 88 \pm 22\ \mu b$$

^{55}Mn

E /MeV/	σ/μb/
14.0	658
14.5	977
15.0	1300
15.5	1600

lin.-lin. interpolation

σ error is about 15%

Calc. from $\sigma = e^{ax^2+bx+c}$ with

$a = -58.25$ MeV

$b = 37.67$ MeV$^{1/2}$

$c = 1.74$

$x = /\frac{A}{A+1}E_n + Q/^{-1/2}$ $A = 55$

$Q = -9.32$ MeV.

The curve was calculated by fitting the Hauser-Feshbach calculations of S. Sudár, J. Csikai, Nucl.Phys. A 319 /1979/157 /and priv. comm./ normalized to the exp. points obtained by the same authors.

Exp. points:

E /MeV/	σ/μb/	
14.6	990±100	Sudár-Csikai /1979/
14.8	1250±150	

^{54}Fe

E = 14.6 MeV	σ = 112 μb
σ error is 25%	

This is an average of two exp. values.

1./ S.M. Qaim and G.L. Stöcklin, J. Inorg. Nucl.Chem. 35/1973/19 measured

$$\sigma_1 = 105 \pm 35\ \mu b \quad \text{at} \quad E = 14.6 \pm 0.4\ MeV.$$

2./ T.W. Woo and G.N. Salaita, Internat. Conf. on Nucl. Cross Sections for Techn., Knoxville, Oct. 22-26, 1979, NBS Spec. Publ. 594/1980/ p.853 measured

$$\sigma_2 = 122 \pm 42\ \mu b \quad \text{at } E = 14.6\ MeV$$

σ_1 and σ_2 give $\sigma = 112 \pm 27\ \mu b$ as an average.

Discarded data: At E=14.8±0.9 MeV $\sigma^m = 600 \pm 100\ \mu b$ by D.M. Chittenden et al. Phys. Rev. 122/1961/860. This is too high and it refers to the cross section leading to the metastable state only.
At E=14.6 MeV $\sigma^m = 351 \pm 150\ \mu b$, by M. Dikšič et al. J. Inorg. Nucl. Chem. 36/1974/477 is also too high / and also to the metastable state only/.

Note. The above papers give also values for σ^m and σ^g, namely $\sigma_1^m = 95 \pm 30\ \mu b$ and $\sigma_2^m = 10.5 \pm 4.2\ \mu b$, while $\sigma_1^g = 10 \pm 5\ \mu b$ and $\sigma_2^g = 17 \pm 6\ \mu b$.

This is not in contradiction with the result of A.P. Baerg and G.C. Bowes, Can. J. Chem. 39 /1961/648 who gave

$$\sigma^g < 75\ \mu b \text{ at } E = 14.6\ MeV.$$

^{56}Fe

E = 14.6 MeV	σ = 45 μb
σ error is 27%	

This is the exp. value of S.M. Qaim and G. Stöcklin, Nucl. Phys. A 257/1976/233 who measured

$$\sigma = 45 \pm 12\ \mu b \quad \text{at } E = 14.6 \pm 0.4\ MeV$$

^{59}Co

E /MeV/	σ/μb/
14	355
15	617
16	892
17	1153
18	1389
19	1596
20	1774

lin.-lin. interpolation
σ error is 25% for 14 and 15 MeV and 15% for 16-20 MeV

Calc. from $\sigma = e^{ax^2+bx+c}$

with

a = -27.95 MeV

b = 10.43 MeV$^{1/2}$

c = 6.90

$$x = /\frac{A}{A+1}E_n + Q/^{-1/2}$$

A = 59

Q = - 8.92 MeV

The curve was calculated by fitting the Hauser-Feshbach calculations of S. Sudár and J. Csikai, Nucl. Phys. A 319 /1979/157 , / and priv. comm./ " normalized" in a least square sense by the exp. points of the same authors and those of S. M. Qaim, Phys. Rev. C 25/1982/20 and that of T. Biró, S. Sudár, Z. Miligy, Z. Dezső, J. Csikai, J. Inorg. Nucl. Chem. 37/1975/1583.

Exp. results:

E/MeV/	σ /μb/	
14.5	690± 130	Sudár-Csikai /1979/
14.5	590± 120	
14.8	1270± 250	
16.3± 0.6	860± 80	Qaim /1982/
17.7± 0.8	1220±110	
19.0± 0.6	1610± 150	
14.7	650± 130	Biró et al. /1975/

Discarded data:

E = 14.8 MeV σ = 2100±200μb C.S. Khurana, I.M.Govil, Nucl.Phys. 69 /1965/153

E = 14.8 MeV σ = 19±14 μb A. Poularikas, A.G. Gardner EXFOR 11533 /1963/

^{58}Ni

E /MeV/	σ/μb/
14.0	11.
14.5	54
15.0	167
15.5	380

lin.-lin. interpolation

σ error is about 50%

calc. from $\sigma = e^{ax^2+bx+c}$

with $a = -34.81$ MeV

$b = 9.31$ MeV$^{1/2}$

$c = 9.83$

$$x = \left/\frac{A}{A+1} E_n + Q\right/^{-1/2}$$

Q =-11.12 MeV, A=58

The curve was calculated by fitting the Hauser-Feshbach calculations of S. Sudár and J. Csikai, Nucl.Phys. A 319 /1979/157 /and priv. comm./normalized in a least square sense to the following exp. points:

1./ E = 14.4 MeV $\sigma_1 = 22 \pm 11$ μb by S.Sudár and J.Csikai, Nucl.Phys. A 319 /1979/157

2./ E = 14.6±0.4 MeV $\sigma_2 = 92 \pm 27$ μb by S.M. Qaim, G. Stöcklin, Nucl.Phys. A 257/1976/233

3./ E = 14.6 MeV $\sigma_3 = 111 \pm 23$ μb by T.W. Woo, G.N. Salaita, EXFOR 10764 /1978/

σ_2 and σ_3 were renormalized to

$${}^r\sigma_2 = 86 \pm 25 \text{ μb}$$

$${}^r\sigma_3 = 104 \pm 22 \text{ μb}$$

/For the renormalization see comments at ^{60}Ni/

^{60}Ni

E = 14.6 MeV	σ = 57 μb	σ error is ~30%

This is a renormalized experimental value. S.M.Qaim and G. Stöcklin, Nucl.Phys. A 257/1976/233 measured σ = 61±20 μb at 14.6±0.4 Mev; the renormalized value: 57±19 μb.

Renormalization: Qaim and Stöcklin used the reaction ^{58}Ni/n,p/ with cross section of 370±40 mb. On the basis of the BNL-325/1976/ the eight different values for this reaction at 14.5-14.8 MeV gives an average value of 347±8 mb. This value was used for renormalization here and also in the case of ^{58}Ni/n,t/ measured by the same authors with the same standard and also for the ^{58}Ni/n,t/ measured by Woo with the same standard.

^{64}Zn

E /MeV/	σ/μb/	
14.60	75	lin.-lin. interpolation
15.44	216	σ error is 20% at 14.6 MeV,
16.28	395	25% at 15.4 MeV and
		27% at 16.2 MeV.

The 14.6 MeV value is an average of two exp. values after renormalization:

σ_1 measured by S.M.Qaim, G.Stöcklin, J.Inorg.Nucl.Chem. 35 /1974/477.

σ_2 measured by M. Dikšič at al. J. Inorg.Nucl.Chem. 36/1974/477.

/ Both σ_1 and σ_2 were measured at 14.6 MeV/

	Original	Renormalized	
σ_1:	86± 23 μb	86± 23 μb	simple mean:
σ_2:	33± 10 ub	63± 19 μb	σ = 75 μb

The 75 μb value at 14.6 MeV is not in disagreement with the value of J. Csikai, K. Jost, A. Szalay, Acta Phys. Hung. 24 /1968/199 which is 150±100 μb at 14.7 MeV, after renormalization it is 136±90 μb.

The 75 μb value at 14.6 MeV is also agrees with the result of A.P. Baerg, G.C. Bowes, Can.J. Chem. 39/1961/648 which is < 100 μb at 14.6 MeV.

For the renormalization:

The σ_1, σ_2 values and the σ of Csikai et al. were obtained by using the same standard, the $^{64}Zn/n,p/$ cross section. For σ_1 the 159±12 mb, for σ_2 the 83±15 mb and for the σ of Csikai et al. the 175 mb value was used. Now, the 159 mb value was accepted for renormalization.

The 15.4 MeV value was calculated by the formula:

$$\sigma = \sigma_0 /1+ |y| /e^{2y}$$

with $y = /\alpha + \beta Z/\Delta E$ $\qquad \alpha = -0.667\ MeV^{-1}$

$E = E_0 + \Delta E$ $\qquad \beta = 0.056\ MeV^{-1}$

$Z = 30$

here

$E_0 = 15.4$ MeV /5 MeV excess energy above threshold/

$E = 14.6$ MeV $\qquad \sigma = 75$ μb

so $y = -0.8306$ and $\sigma_0 = 216$ μb

The 16.2 MeV value:

$$\sigma = \sigma_0/1 + y/ \qquad \text{with } y = 0.8306$$

$$\sigma = 395\ \mu b$$

see: Z.T. Bödy, K. Mihály, Report ZfK-491 /1982/200.

^{70}Ge

E = 14.7 σ = 36 μb

σ error is 28%

This is an exp. value of S.M. Qaim and G.L. Stöcklin, J. Inorg. Nucl. Chem. 35 /1973/19 who measured

$$\sigma = 36 \pm 10\ \mu b \quad \text{at } E = 14.7 \pm 0.3 \text{ MeV}$$

^{86}Sr σ^{g} only!

E = 14.6 MeV σ = 30 μb

σ error is 27%

This is an exp. value of T.W. Woo and G.N. Salaita, Internat. Conf. on Nucl. Cross Sections for Techn., Knoxville, Oct. 22-26, 1979, NBS Spec. Publ. 594 /1980/p.853, who measured

$$\sigma^{g} = 30 \pm 8\ \mu b \quad \text{at } E = 14.6 \text{ MeV.}$$

This is the cross section of the process leading only to the ground state of the residual nucleus.

^{88}Sr

E = 14.6 MeV σ = 63 μb

σ error is 35%

This is an experimental value of S.M. Qaim and G. Stöcklin, Nucl. Phys. A 257 /1976/233 who measured

$$\sigma = 63 \pm 22\ \mu b \quad \text{at } E = 14.6 \pm 0.4 \text{ MeV}$$

^{89}Y

σ^m only!

E = 14.6 MeV	σ = 2.9 μb
σ error is 30%	

This is the average of two exp. values.

1./ S.M. Qaim and G.L. Stöcklin, J. Inorg. Nucl. Chem. 35 /1973/ 19 measured

$$\sigma_1^m = 3.8 \pm 1.0\ \mu b \quad \text{at} \quad E = 14.7 \pm 0.4\ \text{MeV}$$

2./ T.W. Woo and G.N. Salaita, Internat. Conf on Nucl. Cross Sections for Techn., Knoxville, Oct. 22-26, 1979. NBS Spec. Publ. 594/1980/ p.853 measured

$$\sigma_2^m = 2 \pm 0.6\ \mu b \text{ at } \quad E = 14.6\ \text{MeV}.$$

The present σ is a simple mean of σ_1^m and σ_2^m .

Discarded value: M. Dikšič et al. J. Inorg. Nucl. Chem. 36/1974/477 measured σ^m = 15.4$\pm$10 μb at E=14.6 MeV which is a too high value as compared to the others.

This is the cross section of the /n,t/ process leading only to the 2.8 hr. excited state of the residual nucleus.

^{90}Zr

E = 14.6 MeV	σ = 41 μb
the error of σ is 27%	

This is an exp. value of S.M. Qaim and G. Stöcklin, Nucl. Phys. A 257/1976/233 who measured

$$\sigma = 41 \pm 11\ \mu b \quad \text{at } E = 14.6 \pm 0.4\ \text{MeV}$$

^{93}Nb

lin.-lin. interpolation

σ error is ~ 10%

E /MeV/	σ /μb/
14.5	386
15.0	400
16.0	478
17.0	620
18.0	846
19.0	1185

σ was calculated from the formula:

$$\sigma = e^{ax^2+b+c}$$

with parameters:

a = 214.09 MeV

b = -151.77 $MeV^{1/2}$

c = 32.85

$$x = /\frac{A}{A+1}E_n+Q/^{-1/2}$$

Q = -6.22 MeV

A = 93

The parameters in the formula were determined on the basis of the following experimental data:

1./ E = 14.6 MeV σ= 353±100 μb 1st run
E = 14.6 MeV σ= 390±100 μb 2nd run
by S. Sudár and J.Csikai, Nucl.Phys. A 319/1979/157

2./ E = 16.3±0.6 MeV σ= 460±50 μb
E = 17.7±0.8 MeV σ= 790±90 μb
E = 19.0±0.6MeV σ=1080±120 μb
by S.M. Qaim and R.Wölfe, Phys. Rev. C 25 /1982/203

^{92}Mo

E = 14.6 MeV σ = 62 μb

σ error is ~30%

This is the simple mean of two exp. values with increased error.

1./ σ_1 = 50±23 μb at E = 14.6±0.4 MeV by S.M. Qaim and G.L. Stöcklin, J. Inorg. Nucl. Chem. 35 /1973/19

2./ σ_2 = 73±8 μb at E = 14.6 MeV by T.W. Woo and G.N. Salaita, EXFOR 10764 /1978/.

σ was obtained as a simple mean of σ_1 and σ_2. Because both group used the ^{92}Mo/n,p/ reaction with σ = 60.5±4.5 mb cross section as a standard, and because according to BNL-325 /1976/ p. 239 this /n,p/ cross section is rather uncertain, the error of the present ^{92}Mo/n,t/ cross section has been increased from 20% to 30%.

^{103}Rh

E = 14.7 MeV	σ = 730 μb
σ error is 30%	

This is an exp. value of T. Biró, S. Sudár, Z. Miligy, Z. Dezső and J. Csikai, J. Inorg. Nucl. Chem. 37 /1975/1583 who measured

$$\sigma = 730 \pm 220\ \mu b \quad \text{at} \quad E = 14.7\ MeV$$

^{102}Pd

E = 14.6 MeV	σ = 64 μb
σ error is 34 %	

This is an exp. value of T. W. Woo and G. N. Salaits, Internat. Conf. on Nucl. Cross Sections for Techn., Oct 22-26, 1979, Knoxville, TN, USA, Proc: NBS Spec. Publ. No. 594 /1980/ p. 853. who measured

$$\sigma = 64 \pm 22\ \mu b \quad \text{at } E = 14.6\ MeV$$

^{106}Cd

E = 14.6 MeV	σ = 81 μb
σ error is 17 %	

This is the sum of σ^m and σ^g measured by T.W. Woo and G. N. Salaits, Internat. Conf. on Nucl. Cross Sections for Techn., Oct. 22-26, 1979, Knoxville, TN, USA, Proc.:NBS Spec. Publ. No 594/1980/ p. 853.

For $^{106}Cd\ /n,t/^{104m}Ag$ $\sigma^m = 57 \pm 12\ \mu b$, and for $^{106}Cd\ /n,t/^{104g}Ag$ $\sigma^g = 24 \pm 5\ \mu b$ was obtained, resp. Using σ^m and σ^g we have for

$$\sigma = \sigma^g + \sigma^m = 81 \pm 14\ \mu b.$$

Both cross sections were measured at E = 14.6 MeV.

Note for calculation of the error: In calculating the error of σ we also took into account that for both cross sections the same monitor reaction was used with an error of 8.67%.

^{114}Cd

E = 14.6 MeV	σ = 36 μb
σ error is 22%	

This is an experimental value of T.W. Woo and G.N. Salaita, Internat. Conf. on Nucl. Cross Sections for Techn., Oct. 22-26, 1979, Knoxville, TN, USA, Proc.: NBS Spec. Publ. No. 594 /1980/ p.853. who measured

$$\sigma = 36 \pm 8 \ \mu b \qquad \text{at } E = 14.6 \text{ MeV}$$

^{112}Sn

E = 14.6 MeV	σ = 61 μb
σ error is 16%	

This is the sum of σ^m and σ^G measured by T. W. Woo and G.N. Salaita, Internat. Conf. on Nucl. Cross Sections for Techn., Oct. 22-26, 1979, Knoxville, TN,USA, Proc.: NBS Spec. Publ. No. 594 /1980/ p. 853.

The results of the measurement are:

for $^{112}Sn\ /n,t/^{110m}In$ $\quad \sigma^m = 33 \pm 6\ \mu b$ and

for $^{112}Sn\ /n,t/^{110g}In$ $\quad \sigma^g = 28 \pm 7\ \mu b$.

Now, we have

$$\sigma = \sigma^g + \sigma^m = 61 \pm 10\ \mu b.$$

Both cross section were measured at E = 14.6 MeV.

<u>Note for calculation of the error:</u> In calculating the error of σ we also took into account that for both cross sections the same monitor reaction was used with an error of 7.3%.

^{130}Te

σ^g only!

E = 14.6 MeV	σ^g = 24 μb
σ error is 33%	

This is the exp. value by T.W. Woo and G.N. Salaita, Internat. Conf. on Nucl. Cross Sections for Techn., Oct. 22-26, 1979, Knoxville, TN,USA. Proc.: NBS Spec. Publ. No. 594 /1980/ p. 853 who measured

$$\sigma^g = 24 \pm 8\ \mu b \quad \text{at } E = 14.6 \text{ MeV.}$$

This is the cross section of the ^{130}Te/n,t/^{128g}Sb process leading only to the 8.9 hr. ground state of the residual nucleus!

^{139}La

σ^m only!

E = 14.6 MeV	σ^m = 20 μb
σ error is 20%	

This is the mean of two exp. values.

1./ $\sigma_1^m = 21 \pm 5\ \mu b$ at $E = 14.7 \pm 0.3$ MeV by S. M. Qaim and G.L. Stöcklin, J. Inorg. Nucl. Chem. 35 /1973/19.

2./ $\sigma_2^m = 18 \pm 5\ \mu b$ at E = 14.6 MeV by T.W. Woo and G.N. Salaita, Internat. Conf. on Nucl. Cross Sections for Techn., Oct. 22-26, 1979, Knoxville, TN, USA. Proc.: NBS Spec. Publ. No. 594 /1980/ p. 853.

From σ_1^m and σ_2^m we have

$$\sigma = 19.5 \pm 3.6\ \mu b \approx$$

$$\approx 20 \pm 4\ \mu b = 20\ \mu b\ \pm 20\%.$$

This is the cross section of the ^{139}La /n,t/^{137m}Ba process leading only to a 2.5 min. excited state of the residual nucleus!

^{141}Pr

E = 14.6 MeV	σ = 134 μb
σ error is 22%	

This is mean of two exp. values.

1./ $\sigma_1 = 52\pm15 \mu b$ at E = 14.6±0.4 MeV by S.M.Qaim and G. Stöcklin, Nucl.Phys. A 257 /1976/233 and renormalized by J. Csikai and A.K. Chouak, Radiochim. Acta 26 /1979/135 as

$$^r\sigma_1 = 104\pm30 \mu b$$

2./ $\sigma_2 = 164\pm14 \mu b$ at E = 14.7 MeV by J. Csikai and A.K. Chouak, Radiochim. Acta 26 /1979/135.

σ was calculated as a simple mean of $^r\sigma_1$ and σ_2

as $$\sigma = 134\pm30 \mu b = 134 \mu b \pm22\%$$

This value is not in contradiction with the upper limit $\sigma < 210 \mu b$ at 14.8 MeV by J. Csikai, V.I. Fominich, T. Lakatos. Acta Phys. Hung. 24/1968/233.

^{170}Er

E = 14.8 MeV	σ = 12 μb
σ error is 25%	

This is an exp. value by H. Liljavirta, T. Tuurnala, Physica Scripta 18 /1978/75 and EXFOR 20860 who measured

$$\sigma = 12\pm3 \mu b \quad \text{at } E = 14.8\pm0.7 \text{ MeV}$$

^{205}Tl

E = 14.6 MeV	σ = 33 μb
σ error is 24%	

This is an experimental value of T.W. Woo and G.N. Salaita, Internat. Conf. on Nucl. Cross Sections for Techn., Oct. 22-26, 1979, Knoxville, TN,USA. Proc.:NBS Spec. Publ. No.594 /1980/p. 853 who measured

$$\sigma = 33\pm8 \mu b \quad \text{at } E = 14.6 \text{ MeV.}$$

^{204}Pb

E = 14.6 MeV σ = 30 μb

σ error is 20%

This is the mean of two exp. values.

1./ σ_1 = 32$\pm$10 μb at E = 14.6$\pm$0.4 MeV by S.M. Qaim and G. Stöcklin, Nucl. Phys. A 257 /1976/233.

2./ σ_2 = 29$\pm$7 μb at E = 14.6 MeV by T.W. Woo and G.N. Salaita, Internat. Conf. on Nucl. Cross Sections for Techn., Oct. 22-26, 1979, Knoxville, TN,USA. Proc.: NBS Spec. Publ. No. 594 /1980/ p.853.

σ is the weighted mean of σ_1 and σ_2 as

σ = 30$\pm$6 μb.

^{209}Bi

E = 14.6 MeV σ = 300 μb

σ error is 17%

This is an experimental value of S. Sudár and J. Csikai, Nucl. Phys. A 319 /1979/157 who measured

σ = 300 $\pm$ 50 μb at E = 14.6 MeV.

^{238}U

E = 14 MeV $\sigma \approx$ 20 μb

no σ error was given!

This is an exp. value by N. Trautmann, R. Denig, and G. Hermann, Radiochim. Acta 11 /1969/ who measured

$\sigma \approx$ 20 μb at E = 14 MeV

/ no σ error was given! /