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TABLES OF RECOMMENDED STANDARD DATA

Neutron yields from alpha particle induced reactions  
on lithium, beryllium, boron, carbon, oxygen and  
fluorine nuclei for energies up to 10 MeV

V.A. Vukolov, F.E. Chukreev  
I.V. Kurchatov Atomic Energy Institute

Translated for the IAEA by A. Lorenz  
from a manuscript in Russian dated Moscow 1988

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Neutron yields from alpha particle induced reactions on lithium, beryllium, boron, carbon, oxygen and fluorine nuclei for energies up to 10 MeV.

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### Introduction

The problems of nuclear technology are many: one of them is the development of analytical methods for the control and protection from nuclear fuel radiation, another is the production of neutron and isotopic energy sources based on alpha emitting radionuclides. This latter application requires the knowledge of the yield of neutrons resulting from the absorption of alpha particles by nuclei of light elements. According to the world request list [1], this information must be known to an accuracy of approximately 10% for alpha particle energies ranging from reaction thresholds to 10 MeV for target nuclei with  $Z \leq 20$ .

This report presents recommended thick target neutron yield values for Li, Be, C,  $^{17}\text{O}$ ,  $^{18}\text{O}$  and  $^{19}\text{F}$ . These data are based on the analysis of measurements published in the literature up to the year 1987. The international generalized EXFOR data base was the main source of information used in this analysis.

### Method Used to Obtain Recommended Standard Data

The neutron yield data were obtained from calculations using  $(\alpha, n)$  reaction data evaluated by the authors [2,3] and data on the stopping power of alpha particles in matter [4].

#### 1. Evaluation of $(\alpha, n)$ reaction cross-section values.

1.1. The sets of experimental data were compared in given energy intervals. First, averaged cross-section values were determined by taking the characteristics of the excitation function of the reaction in question into account, namely the structural

characteristics of their alpha particle energy dependence. The averaging was done over energy intervals of 100 keV for alpha particle energies up to 5 MeV, and over 0.5 MeV intervals for energies above 5 MeV.

1.2. Values for the weighted average cross-sections based on  $n$  measured values were determined for each energy interval using the expression for  $\bar{\sigma}$ -bar:

$$\bar{\sigma} = \frac{\sum_{i=1}^n w_i \sigma_i}{\sum_{i=1}^n w_i}$$

where

$$w_i = \frac{1}{(\Delta\sigma_i)^2}$$

is the weight given to the experimental value on the basis of the

fractional standard deviation 
$$\Delta\sigma_{FSD} = \frac{1}{\sqrt{\sum_{i=1}^n w_i}}$$

and the standard error 
$$\Delta\sigma_{SD} = \sqrt{\frac{1}{(n-1)} \frac{\sum w_i (\sigma_i - \bar{\sigma})^2}{\sum w_i}}$$

1.3. Birge's criterion was used to resolve inconsistencies between measured values:

$$K = (n-1) \frac{|(\Delta\sigma_I)^2 - (\Delta\sigma_E)^2|}{(\Delta\sigma_I)^2 \sqrt{2}}$$

For  $K < 2$ , the value of the weighted average cross-section was taken to be  $\bar{\sigma}$ -bar with an uncertainty equal to the larger of the two uncertainty values  $\Delta\sigma_I$  and  $\Delta\sigma_E$ . For those cases where  $K > 2$ , it is evident that there is an unaccounted systematic error in the given set of data. Based on the  $K$  criterion, these results were subjected to a thorough analysis over the entire range of the measurement. In order to arrive at a consistent set of data, these results were either included in the analysis with a smaller weight by increasing the uncertainty assigned by the author, or were omitted from the analysis altogether. If it was not possible to satisfy the  $K < 2$  condition in the course of the analysis, then the

value of the cross-section in this interval was taken to be equal to the arithmetic mean with an uncertainty equal to:

$$\Delta\sigma = t_p(n) \cdot \sqrt{\frac{1}{n(n-1)} \sum_I (\sigma_I - \bar{\sigma})^2}$$

where  $t_p$  is the Student's distribution coefficient for  $(n-1)$  degrees of freedom and a confidence probability  $P$  equal to 0.32.

1.4. The evaluated cross-section values which were thus determined for each interval were either used directly to determine the excitation function over the energy range being investigated, or used as normalizing values for the determination of the excitation function in those energy regions where there were only single measurements.

## 2. Algorithm for the calculation of the stopping power of alpha particles in target materials.

The stopping power data used in this analysis were those of Anderson and Ziegler [4], which had been derived from a wide body of experimental information and are considered nowadays to be the most reliable. Their recommended uncertainty is considered to be 5%. The values of the stopping power ( $\mathcal{E}$ ) as a function of alpha particle energy  $E$  (in MeV) were calculated using the empirical expression:

$$\mathcal{E} = \frac{S_L S_H}{S_L + S_H}$$

where

$$S_L = A_1 (10^{-3} E)^{A_2}$$

and

$$S_H = \left(\frac{A_3}{E}\right) \cdot \ln\left(1 + \frac{A_4}{E} + A_5 E\right)$$

The recommended coefficients ( $A_1$  to  $A_5$ ) are listed in Table I.

TABLE I. RECOMMENDED DATA FOR THE CALCULATION OF STOPPING POWERS OF ALPHA PARTICLES IN MATTER

Element	Coefficients				
	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	A <sub>4</sub>	A <sub>5</sub>
Lithium	1.42	0.49	12.25	32.	9.161
Beryllium	2.206	0.51	15.32	0.25	8.995
Boron	3.691	0.4128	18.48	50.72	9.
Carbon	4.232	0.3877	22.99	35.	7.993
Oxygen	2.717	0.4858	32.88	25.88	4.336
Fluorine	2.616	0.4708	41.2	28.07	2.458

### 3. Neutron yield calculation.

The following equation was used to calculate the neutron yield:

$$Y(E_0) = \int_0^{E_0} \frac{\sigma(E)}{dE/dx} dE$$

where  $dE/dx$  is the stopping power  $\mathcal{E}$  of the target material in units of  $eV/10^{15}$  atoms·cm<sup>2</sup>. The following two algorithms were used to calculate the yield  $Y$  and its uncertainty  $DY$ :

$$Y(I) = \sum_{i=2}^I \frac{\sigma(i) - \sigma(i-1)}{\mathcal{E}(i) - \mathcal{E}(i-1)} [(E(i) - E(i-1))]$$

$$DY(I) = Y(I) \sqrt{\sum_I \left( \frac{\Delta\sigma_i}{\sigma_i} \right)^2 \cdot \frac{\sigma_i}{\Sigma\sigma_i} + \left( \frac{\Delta\mathcal{E}}{\mathcal{E}} \right)^2}$$

Recommended reference data on the yields of neutrons ( $Y$ ) and their uncertainties ( $DY$ ) are given in Tables II-VIII for elements ranging from lithium to fluorine. Also included in these tables are the ( $\alpha,n$ ) cross-sections ( $SIG$ ), their errors ( $DS$ ) and the stopping power ( $STOP$ ) given as a function of alpha particle energy. As stated above, the neutron yield data which are most important are the ones that are produced at alpha particle energies of 4 to 8 MeV, corresponding to the energies of alpha particles emitted by transactinides. Consequently, the recommended data above 4 MeV are also represented analytically in the form of Chebyshev polynomials:



$$\varphi(x) = \sum_I C_i P_i(x) ;$$

$$P_0 = 1; P_1 = x;$$

$$P_n = P_{n-1} \cdot 2x - P_{n-2} ;$$

$$x = (E-A)/B$$

where E is given in units of MeV.

The values of the polynomial coefficients for the considered reactions are listed in Table IX. The uncertainties in the yields given by the resulting curves do not exceed 2% for alpha particle energies above 4 MeV.

TABLE II. RECOMMENDED REFERENCE DATA.  
NEUTRON YIELD FROM LITHIUM TARGET.

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NEUTRONS FROM (ALPHA, N) REACTION  
\*\*\*\*\*

E MEV	SIG MB	DS MB	STOP EV/E+15AT/CM**2	E MEV	Y N/A	DY N/A
4.39	0.89	0.29	+0.9641E+01	4.38	+0.000E+00	+0.000E+00
4.45	3.19	0.09	+0.9611E+01	4.40	+0.186E-08	+0.630E-09
4.55	5.59	0.19	+0.9465E+01	4.50	+0.354E-07	+0.588E-08
4.65	8.79	0.29	+0.9325E+01	4.60	+0.950E-07	+0.111E-07
4.75	12.19	1.09	+0.9189E+01	4.70	+0.190E-06	+0.180E-07
4.85	15.59	1.59	+0.9057E+01	4.80	+0.323E-06	+0.318E-07
4.95	19.69	1.89	+0.8930E+01	4.90	+0.497E-06	+0.516E-07
5.05	28.00	4.49	+0.8806E+01	5.00	+0.719E-06	+0.757E-07
5.15	36.09	0.99	+0.8687E+01	5.10	+0.103E-05	+0.132E-06
5.25	31.89	0.89	+0.8571E+01	5.20	+0.145E-05	+0.163E-06
5.35	28.69	0.79	+0.8458E+01	5.30	+0.183E-05	+0.190E-06
5.45	26.79	0.79	+0.8349E+01	5.40	+0.217E-05	+0.213E-06
5.55	30.59	0.89	+0.8243E+01	5.50	+0.249E-05	+0.235E-06
5.65	42.59	1.29	+0.8140E+01	5.60	+0.287E-05	+0.260E-06
5.75	49.49	1.49	+0.8040E+01	5.70	+0.339E-05	+0.294E-06
5.85	56.89	1.69	+0.7943E+01	5.80	+0.401E-05	+0.333E-06
5.95	66.19	1.89	+0.7848E+01	5.90	+0.473E-05	+0.379E-06
6.05	78.69	3.69	+0.7756E+01	6.00	+0.558E-05	+0.431E-06
6.15	87.89	4.59	+0.7666E+01	6.10	+0.660E-05	+0.502E-06
6.25	94.39	4.59	+0.7579E+01	6.20	+0.775E-05	+0.586E-06
6.35	101.99	4.99	+0.7494E+01	6.30	+0.901E-05	+0.674E-06
6.45	120.00	5.99	+0.7410E+01	6.40	+0.103E-04	+0.770E-06
6.75	184.99	8.99	+0.7329E+01	6.50	+0.120E-04	+0.886E-06
7.25	227.99	10.99	+0.6952E+01	7.00	+0.249E-04	+0.182E-05
7.75	156.99	7.99	+0.6615E+01	7.50	+0.417E-04	+0.303E-05
8.25	135.99	6.99	+0.6313E+01	8.00	+0.539E-04	+0.390E-05
8.75	130.99	6.99	+0.6040E+01	8.50	+0.649E-04	+0.469E-05
			+0.5792E+01	9.00	+0.759E-04	+0.550E-05

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TABLE III. RECOMMENDED REFERENCE DATA.  
NEUTRON YIELD FROM BERYLLIUM TARGET.

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NEUTRONS FROM (ALPHA,N) REACIION  
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E MEV	SIG MB	DS MB	STOP EV/E+15AT/CM**2	E MEV	Y N/A	DY N/A
1.55	9.69	0.49	+0.2112F+02	1.50	+0.579E-06	+0.173E-08
1.65	20.00	1.00	+0.2058E+02	1.60	+0.523E-07	+0.637E-08
1.75	92.00	5.00	+0.2006E+02	1.70	+0.150E-06	+0.163E-07
1.85	260.00	13.00	+0.1956F+02	1.80	+0.615E-06	+0.697E-07
1.95	243.00	12.00	+0.1909F+02	1.90	+0.195E-05	+0.214E-06
2.05	184.00	9.00	+0.1864F+02	2.00	+0.324E-05	+0.309E-06
2.15	172.00	9.00	+0.1821F+02	2.10	+0.424E-05	+0.365E-06
2.25	162.00	8.00	+0.1779F+02	2.20	+0.520E-05	+0.432E-06
2.35	148.00	7.00	+0.1740F+02	2.30	+0.612E-05	+0.495E-06
2.45	144.00	7.00	+0.1702F+02	2.40	+0.698E-05	+0.551E-06
2.55	148.00	7.00	+0.1666F+02	2.50	+0.783E-05	+0.610E-06
2.65	132.00	7.00	+0.1631E+02	2.60	+0.873E-05	+0.674E-06
2.75	112.00	6.00	+0.1598F+02	2.70	+0.955E-05	+0.728E-06
2.85	96.00	5.00	+0.1566F+02	2.80	+0.102E-04	+0.773E-06
2.95	90.00	5.00	+0.1536F+02	2.90	+0.108E-04	+0.811E-06
3.05	90.00	5.00	+0.1506E+02	3.00	+0.114E-04	+0.853E-06
3.15	94.00	5.00	+0.1478E+02	3.10	+0.120E-04	+0.898E-06
3.25	100.00	5.00	+0.1451F+02	3.20	+0.127E-04	+0.946E-06
3.35	104.00	5.00	+0.1425F+02	3.30	+0.134E-04	+0.999E-06
3.45	114.00	6.00	+0.1400F+02	3.40	+0.141E-04	+0.105E-05
3.55	128.00	6.00	+0.1376F+02	3.50	+0.149E-04	+0.111E-05
3.65	146.00	7.00	+0.1353E+02	3.60	+0.159E-04	+0.118E-05
3.75	168.00	8.00	+0.1330E+02	3.70	+0.169E-04	+0.127E-05
3.85	200.00	10.00	+0.1308E+02	3.80	+0.182E-04	+0.137E-05
3.95	316.00	16.00	+0.1287E+02	3.90	+0.198E-04	+0.149E-05
4.05	344.00	17.00	+0.1267E+02	4.00	+0.222E-04	+0.172E-05
4.15	330.00	16.00	+0.1248F+02	4.10	+0.250E-04	+0.193E-05
4.25	352.00	18.00	+0.1229E+02	4.20	+0.276E-04	+0.212E-05
4.35	376.00	19.00	+0.1210F+02	4.30	+0.305E-04	+0.234E-05
4.45	392.00	20.00	+0.1193E+02	4.40	+0.336E-04	+0.257E-05
4.55	390.00	20.00	+0.1175E+02	4.50	+0.369E-04	+0.282E-05
4.65	386.00	19.00	+0.1159F+02	4.60	+0.403E-04	+0.306E-05
4.75	401.00	20.00	+0.1143E+02	4.70	+0.436E-04	+0.330E-05
4.85	433.00	22.00	+0.1127E+02	4.80	+0.472E-04	+0.356E-05
4.95	468.00	23.00	+0.1112E+02	4.90	+0.510E-04	+0.386E-05
5.05	488.00	24.00	+0.1097E+02	5.00	+0.553E-04	+0.418E-05
5.15	494.00	25.00	+0.1083E+02	5.10	+0.598E-04	+0.451E-05
5.25	521.00	26.00	+0.1069F+02	5.20	+0.643E-04	+0.484E-05
5.35	552.00	28.00	+0.1055E+02	5.30	+0.692E-04	+0.521E-05
5.45	573.00	29.00	+0.1042E+02	5.40	+0.745E-04	+0.560E-05
5.55	584.00	29.00	+0.1029E+02	5.50	+0.800E-04	+0.601E-05
5.65	610.00	30.00	+0.1016E+02	5.60	+0.857E-04	+0.643E-05
5.75	618.00	31.00	+0.1004F+02	5.70	+0.918E-04	+0.687E-05
5.85	596.00	30.00	+0.9928E+01	5.80	+0.980E-04	+0.732E-05
5.95	576.00	29.00	+0.9813F+01	5.90	+0.104E-03	+0.774E-05
6.25	560.00	28.00	+0.9700F+01	6.00	+0.109E-03	+0.815E-05
6.75	574.00	29.00	+0.9175F+01	6.50	+0.139E-03	+0.103E-04
7.25	576.00	29.00	+0.8708F+01	7.00	+0.171E-03	+0.126E-04
7.75	649.00	32.00	+0.8291E+01	7.50	+0.205E-03	+0.151E-04
8.25	653.00	33.00	+0.7914F+01	8.00	+0.245E-03	+0.181E-04
8.75	716.00	36.00	+0.7573E+01	8.50	+0.287E-03	+0.212E-04
9.25	747.00	37.00	+0.7263F+01	9.00	+0.336E-03	+0.248E-04
9.75	708.00	35.00	+0.6979F+01	9.50	+0.388E-03	+0.287E-04
			+0.6718F+01	10.00	+0.440E-03	+0.324E-04

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TABLE IV. RECOMMENDED REFERENCE DATA.  
NEUTRON YIELD FROM BORON TARGET.

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NEUTRONS FROM (ALPHA,N) REACTION  
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E MEV	SIG MB	DS MB	STOP. EV/E+15AT/CM**2	E MEV	Y N/A	DY N/A
0.25	0.39	0.19	+0.5537E+00	0.00	+0.000E+00	+0.000E+00
0.75	3.00	0.59	+0.3756E+02	0.50	+0.104E-07	+0.527E-08
1.25	7.09	0.69	+0.3469E+02	1.00	+0.520E-07	+0.134E-07
1.75	18.59	2.00	+0.2926E+02	1.50	+0.163E-06	+0.282E-07
2.25	26.00	2.79	+0.2481E+02	2.00	+0.506E-06	+0.713E-07
2.75	35.29	3.59	+0.2149E+02	2.50	+0.106E-05	+0.139E-06
3.25	55.19	5.69	+0.1900E+02	3.00	+0.193E-05	+0.241E-06
3.75	102.00	9.00	+0.1708E+02	3.50	+0.346E-05	+0.419E-06
4.20	85.00	5.00	+0.1556E+02	4.00	+0.659E-05	+0.746E-06
4.60	138.00	7.00	+0.1455E+02	4.40	+0.885E-05	+0.931E-06
4.90	130.00	14.00	+0.1368E+02	4.80	+0.127E-04	+0.123E-05
5.10	185.00	20.00	+0.1329E+02	5.00	+0.146E-04	+0.149E-05
5.30	163.00	22.00	+0.1292E+02	5.20	+0.175E-04	+0.185E-05
5.50	110.00	22.00	+0.1258E+02	5.40	+0.200E-04	+0.227E-05
5.70	154.00	23.00	+0.1226E+02	5.60	+0.218E-04	+0.275E-05
5.90	167.00	26.00	+0.1195E+02	5.80	+0.243E-04	+0.318E-05
6.25	122.00	13.00	+0.1166E+02	6.00	+0.272E-04	+0.367E-05
6.75	81.00	12.00	+0.1101E+02	6.50	+0.325E-04	+0.435E-05
7.25	93.00	14.00	+0.1043E+02	7.00	+0.363E-04	+0.490E-05
			+0.9926E+01	7.50	+0.409E-04	+0.558E-05

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TABLE V. RECOMMENDED REFERENCE DATA.

NEUTRON YIELD FROM CARBON TARGET.

NEUTRONS FROM (ALPHA,N) REACTION

E MEV	SIG MB	DS MB	STOP EV/E+15AT/CM**2	E MFV	Y N/A	DY N/A
1.05	0.49	0.09	+0.3606E+02	1.00	+0.299E-10	+0.899E-11
1.15	0.59	0.09	+0.3511E+02	1.10	+0.455E-10	+0.125E-10
1.25	0.99	0.19	+0.3413E+02	1.20	+0.647E-10	+0.164E-10
1.35	1.59	0.29	+0.3314E+02	1.30	+0.977E-10	+0.248E-10
1.45	2.19	0.39	+0.3216E+02	1.40	+0.151E-09	+0.381E-10
1.55	2.89	0.59	+0.3171E+02	1.50	+0.228E-09	+0.562E-10
1.65	4.69	0.89	+0.3030E+02	1.60	+0.333E-09	+0.819E-10
1.75	7.59	1.49	+0.2942E+02	1.70	+0.507E-09	+0.125E-09
1.85	13.99	2.99	+0.2859E+02	1.80	+0.798E-09	+0.198E-09
1.95	20.99	5.99	+0.2779E+02	1.90	+0.134E-08	+0.343E-09
2.05	41.19	2.89	+0.2704E+02	2.00	+0.219E-08	+0.593E-09
2.15	57.29	3.99	+0.2632E+02	2.10	+0.340E-08	+0.972E-09
2.25	91.09	6.39	+0.2565E+02	2.20	+0.635E-08	+0.147E-08
2.35	77.59	5.39	+0.2501E+02	2.30	+0.103E-07	+0.230E-08
2.45	62.69	4.39	+0.2440E+02	2.40	+0.138E-07	+0.277E-08
2.55	32.39	2.29	+0.2382E+02	2.50	+0.166E-07	+0.305E-08
2.65	40.39	2.79	+0.2328E+02	2.60	+0.182E-07	+0.284E-08
2.75	36.49	2.59	+0.2276E+02	2.70	+0.201E-07	+0.319E-08
2.85	35.09	2.39	+0.2226E+02	2.80	+0.219E-07	+0.333E-08
2.95	23.59	1.59	+0.2179E+02	2.90	+0.237E-07	+0.350E-08
3.05	49.89	3.49	+0.2135E+02	3.00	+0.249E-07	+0.340E-08
3.15	43.89	3.09	+0.2092E+02	3.10	+0.275E-07	+0.419E-08
3.25	93.00	6.49	+0.2051E+02	3.20	+0.299E-07	+0.434E-08
3.35	109.89	7.69	+0.2012E+02	3.30	+0.349E-07	+0.575E-08
3.45	67.49	4.09	+0.1975E+02	3.40	+0.410E-07	+0.675E-08
3.55	6.79	0.49	+0.1939E+02	3.50	+0.448E-07	+0.646E-08
3.65	8.09	0.59	+0.1905E+02	3.60	+0.452E-07	+0.488E-08
3.75	5.39	0.39	+0.1872E+02	3.70	+0.457E-07	+0.497E-08
3.85	2.00	0.09	+0.1841E+02	3.80	+0.460E-07	+0.491E-08
3.95	3.29	0.19	+0.1811E+02	3.90	+0.462E-07	+0.480E-08
4.05	8.79	0.59	+0.1782E+02	4.00	+0.464E-07	+0.486E-08
4.15	8.00	1.00	+0.1753E+02	4.10	+0.469E-07	+0.511E-08
4.25	5.99	0.39	+0.1726E+02	4.20	+0.474E-07	+0.515E-08
4.35	53.99	3.89	+0.1700E+02	4.30	+0.478E-07	+0.511E-08
4.45	45.79	3.19	+0.1675E+02	4.40	+0.514E-07	+0.688E-08
4.55	16.19	1.09	+0.1651E+02	4.50	+0.544E-07	+0.699E-08
4.65	27.00	1.89	+0.1627E+02	4.60	+0.555E-07	+0.619E-08
4.75	28.19	2.00	+0.1605E+02	4.70	+0.573E-07	+0.673E-08
4.85	27.00	1.89	+0.1583E+02	4.80	+0.593E-07	+0.696E-08
4.95	57.29	3.00	+0.1561E+02	4.90	+0.612E-07	+0.711E-08
5.25	129.00	9.00	+0.1541E+02	5.00	+0.653E-07	+0.841E-08
5.75	162.00	11.00	+0.1446E+02	5.50	+0.113E-06	+0.169E-07
6.25	193.00	13.00	+0.1364E+02	6.00	+0.177E-06	+0.271E-07
6.75	202.00	13.00	+0.1292E+02	6.50	+0.257E-06	+0.398E-07
7.25	246.00	16.00	+0.1228E+02	7.00	+0.346E-06	+0.524E-07
7.75	318.00	21.00	+0.1170E+02	7.50	+0.459E-06	+0.707E-07
8.25	258.00	17.00	+0.1119E+02	8.00	+0.613E-06	+0.971E-07
8.75	251.00	17.00	+0.1072E+02	8.50	+0.744E-06	+0.108E-06
9.25	262.00	32.00	+0.1029E+02	9.00	+0.876E-06	+0.123E-06
9.75	250.00	32.00	+0.9909E+01	9.50	+0.102E-05	+0.144E-06
			+0.9550E+01	10.00	+0.116E-05	+0.162E-06

TABLE VI. RECOMMENDED REFERENCE DATA.  
NEUTRON YIELD FROM OXYGEN-17 TARGET.

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NEUTRONS FROM (ALPHA,N) REACTION  
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E	SIG	DS	STOP	F	Y	DY
MEV	MB	MB	EV/E+15AT/CM**2	MEV	N/A	N/A
0.50	0,00	0,00	+0,2914E+00	0,00	+0,000E+00	+0,000E+00
1.05	0,01	0,00	+0,4613E+02	1,00	+0,223E-13	+0,337E-14
1.15	0,02	0,00	+0,4512E+02	1,10	+0,312E-13	+0,344E-14
1.25	0,02	0,00	+0,4399E+02	1,20	+0,486E-13	+0,528E-14
1.35	0,10	0,00	+0,4280E+02	1,30	+0,725E-13	+0,820E-14
1.45	0,08	0,00	+0,4159E+02	1,40	+0,168E-12	+0,181E-13
1.55	0,13	0,01	+0,4038E+02	1,50	+0,244E-12	+0,271E-13
1.65	0,32	0,02	+0,3920E+02	1,60	+0,374E-12	+0,425E-13
1.75	1,39	0,14	+0,3805E+02	1,70	+0,641E-12	+0,754E-13
1.85	1,09	0,09	+0,3694E+02	1,80	+0,207E-11	+0,238E-12
1.95	4,59	0,49	+0,3588E+02	1,90	+0,318E-11	+0,355E-12
2.05	8,69	0,89	+0,3487E+02	2,00	+0,600E-11	+0,930E-12
2.15	19,00	2,00	+0,3391E+02	2,10	+0,173E-10	+0,200E-11
2.25	14,00	1,49	+0,3299E+02	2,20	+0,383E-10	+0,445E-11
2.35	12,00	1,19	+0,3213E+02	2,30	+0,542E-10	+0,633E-11
2.45	9,00	1,00	+0,3130E+02	2,40	+0,682E-10	+0,790E-11
2.55	10,00	1,00	+0,3052E+02	2,50	+0,790E-10	+0,921E-11
2.65	24,00	2,49	+0,2979E+02	2,60	+0,913E-10	+0,105E-10
2.75	14,00	1,49	+0,2908E+02	2,70	+0,121E-09	+0,140E-10
2.85	12,00	1,19	+0,2842E+02	2,80	+0,139E-09	+0,162E-10
2.95	49,00	5,00	+0,2779E+02	2,90	+0,155E-09	+0,179E-10
3.05	88,00	9,00	+0,2719E+02	3,00	+0,221E-09	+0,254E-10
3.15	92,00	9,00	+0,2661E+02	3,10	+0,342E-09	+0,392E-10
3.25	44,00	4,59	+0,2607E+02	3,20	+0,471E-09	+0,535E-10
3.35	32,00	3,29	+0,2555E+02	3,30	+0,534E-09	+0,608E-10
3.45	65,00	6,69	+0,2506E+02	3,40	+0,581E-09	+0,661E-10
3.55	68,00	7,00	+0,2458E+02	3,50	+0,678E-09	+0,772E-10
3.65	121,00	12,00	+0,2413E+02	3,60	+0,781E-09	+0,890E-10
3.75	144,00	14,00	+0,2370E+02	3,70	+0,968E-09	+0,109E-09
3.85	140,00	14,00	+0,2328E+02	3,80	+0,119E-08	+0,134E-09
3.95	108,00	11,00	+0,2288E+02	3,90	+0,141E-08	+0,159E-09
4.05	173,00	17,00	+0,2250E+02	4,00	+0,159E-08	+0,179E-09
4.15	154,00	15,49	+0,2214E+02	4,10	+0,188E-08	+0,211E-09
4.25	121,00	12,00	+0,2178E+02	4,20	+0,214E-08	+0,240E-09
4.35	105,00	10,00	+0,2144E+02	4,30	+0,234E-08	+0,263E-09
4.45	81,00	8,00	+0,2112E+02	4,40	+0,253E-08	+0,283E-09
4.55	80,00	8,00	+0,2080E+02	4,50	+0,267E-08	+0,299E-09
4.65	133,00	13,00	+0,2050E+02	4,60	+0,281E-08	+0,315E-09
4.75	125,00	12,00	+0,2020E+02	4,70	+0,305E-08	+0,341E-09
4.85	122,00	12,00	+0,1992E+02	4,80	+0,329E-08	+0,367E-09
4.95	129,00	13,00	+0,1965E+02	4,90	+0,351E-08	+0,392E-09
5.25	187,00	19,00	+0,1938E+02	5,00	+0,376E-08	+0,419E-09
5.75	206,00	21,00	+0,1817E+02	5,50	+0,560E-08	+0,625E-09
6.25	230,00	23,00	+0,1713E+02	6,00	+0,776E-08	+0,868E-09
6.75	258,00	26,00	+0,1622E+02	6,50	+0,103E-07	+0,115E-08
7.25	285,00	29,00	+0,1542E+02	7,00	+0,133E-07	+0,149E-08
7.75	315,00	32,00	+0,1470E+02	7,50	+0,168E-07	+0,188E-08
8.50	350,00	35,00	+0,1405E+02	8,00	+0,208E-07	+0,234E-08
9.50	403,00	40,00	+0,1294E+02	9,00	+0,304E-07	+0,341E-08
			+0,1201E+02	10,00	+0,424E-07	+0,475E-08

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TABLE VII. RECOMMENDED REFERENCE DATA.  
NEUTRON YIELD FROM OXYGEN-18 TARGET.

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NEUTRONS FROM (ALPHA, N) REACTION  
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E	SIG	DS	STOP	F	Y	DY
MEV	MB	MB	EV/E+15AT/CM**2	MEV	N/A	N/A
0.80	0.00	0.00	+0.4716E+02	0.80	+0.000E+00	+0.000E+00
1.05	0.01	0.00	+0.4613E+02	1.00	+0.524E-14	+0.586E-15
1.15	0.00	0.00	+0.4512E+02	1.10	+0.544E-13	+0.565E-14
1.25	0.00	0.00	+0.4399E+02	1.20	+0.600E-13	+0.872E-14
1.35	0.04	0.00	+0.4280E+02	1.30	+0.106E-12	+0.118E-13
1.45	0.05	0.00	+0.4159E+02	1.40	+0.309E-12	+0.336E-13
1.55	0.55	0.05	+0.4038E+02	1.50	+0.588E-12	+0.666E-13
1.65	0.83	0.07	+0.3920E+02	1.60	+0.345E-11	+0.405E-12
1.75	0.83	0.07	+0.3805E+02	1.70	+0.789E-11	+0.684E-12
1.85	1.39	0.09	+0.3694E+02	1.80	+0.124E-10	+0.137E-11
1.95	0.70	0.06	+0.3588E+02	1.90	+0.203E-10	+0.208E-11
2.05	1.89	0.19	+0.3487E+02	2.00	+0.243E-10	+0.253E-11
2.15	4.00	0.39	+0.3391E+02	2.10	+0.356E-10	+0.384E-11
2.25	5.89	0.59	+0.3299E+02	2.20	+0.600E-10	+0.656E-11
2.35	5.89	0.59	+0.3213E+02	2.30	+0.970E-10	+0.107E-10
2.45	27.00	3.00	+0.3130E+02	2.40	+0.134E-09	+0.150E-10
2.55	86.00	9.00	+0.3052E+02	2.50	+0.313E-09	+0.367E-10
2.65	27.00	3.00	+0.2979E+02	2.60	+0.894E-09	+0.104E-09
2.75	59.00	6.00	+0.2908E+02	2.70	+0.108E-08	+0.126E-09
2.85	60.00	6.00	+0.2842E+02	2.80	+0.150E-08	+0.174E-09
2.95	101.00	10.00	+0.2779E+02	2.90	+0.193E-08	+0.223E-09
3.05	21.00	2.00	+0.2719E+02	3.00	+0.268E-08	+0.306E-09
3.15	75.00	7.00	+0.2661E+02	3.10	+0.284E-08	+0.323E-09
3.25	116.00	12.00	+0.2607E+02	3.20	+0.342E-08	+0.385E-09
3.35	136.00	14.00	+0.2555E+02	3.30	+0.434E-08	+0.491E-09
3.45	87.00	9.00	+0.2506E+02	3.40	+0.543E-08	+0.616E-09
3.55	236.00	24.00	+0.2458E+02	3.50	+0.615E-08	+0.698E-09
3.65	269.00	27.00	+0.2413E+02	3.60	+0.812E-08	+0.922E-09
3.75	249.00	25.00	+0.2370E+02	3.70	+0.104E-07	+0.117E-08
3.85	316.00	32.00	+0.2328E+02	3.80	+0.125E-07	+0.142E-08
3.95	266.00	27.00	+0.2288E+02	3.90	+0.153E-07	+0.173E-08
4.05	245.00	25.00	+0.2250E+02	4.00	+0.177E-07	+0.200E-08
4.15	250.00	25.00	+0.2214E+02	4.10	+0.200E-07	+0.226E-08
4.25	360.00	37.00	+0.2178E+02	4.20	+0.223E-07	+0.252E-08
4.35	394.00	40.00	+0.2144E+02	4.30	+0.257E-07	+0.291E-08
4.45	300.00	30.00	+0.2112E+02	4.40	+0.295E-07	+0.333E-08
4.55	410.00	41.00	+0.2080E+02	4.50	+0.324E-07	+0.366E-08
4.65	409.00	41.00	+0.2050E+02	4.60	+0.364E-07	+0.411E-08
4.75	258.00	26.00	+0.2020E+02	4.70	+0.405E-07	+0.457E-08
4.85	400.00	40.00	+0.1992E+02	4.80	+0.431E-07	+0.487E-08
4.95	341.00	34.00	+0.1965E+02	4.90	+0.473E-07	+0.533E-08
5.25	403.00	41.00	+0.1938E+02	5.00	+0.508E-07	+0.573E-08
5.75	440.00	45.00	+0.1817E+02	5.50	+0.727E-07	+0.820E-08
6.25	470.00	48.00	+0.1713E+02	6.00	+0.981E-07	+0.110E-07
6.75	494.00	50.00	+0.1622E+02	6.50	+0.126E-06	+0.143E-07
7.25	515.00	52.00	+0.1542E+02	7.00	+0.158E-06	+0.179E-07
7.75	535.00	56.00	+0.1470E+02	7.50	+0.193E-06	+0.218E-07
8.50	575.00	59.00	+0.1405E+02	8.00	+0.231E-06	+0.261E-07
9.50	610.00	63.00	+0.1294E+02	9.00	+0.318E-06	+0.360E-07
			+0.1201E+02	10.00	+0.418E-06	+0.473E-07

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TABLE VIII. RECOMMENDED REFERENCE DATA.  
NEUTRON YIELD FROM FLUORINE TARGET.

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NEUTRONS FROM (ALPHA,N) REACTION  
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E MEV	SIG MB	DS MB	STOP EV/E+15AT/CM**2	E MEV	Y N/A	DY N/A
2.38	0,16	0,01	+0,3397E+02	2,36	+0,000E+00	+0,000E+00
2.45	0,89	0,09	+0,3364E+02	2,40	+0,201E-09	+0,257E-10
2.55	1,69	0,19	+0,3283E+02	2,50	+0,290E-08	+0,357E-09
2.65	1,79	0,19	+0,3206E+02	2,60	+0,814E-08	+0,102E-08
2.75	5,69	0,59	+0,3132E+02	2,70	+0,138E-07	+0,171E-08
2.85	6,39	0,59	+0,3061E+02	2,80	+0,322E-07	+0,386E-08
2.95	6,00	0,59	+0,2993E+02	2,90	+0,533E-07	+0,613E-08
3.05	2,29	0,19	+0,2928E+02	3,00	+0,736E-07	+0,840E-08
3.15	8,79	0,89	+0,2860E+02	3,10	+0,815E-07	+0,921E-08
3.25	14,00	1,00	+0,2807E+02	3,20	+0,117E-06	+0,127E-07
3.35	14,89	1,49	+0,2751E+02	3,30	+0,162E-06	+0,173E-07
3.45	16,00	1,59	+0,2696E+02	3,40	+0,217E-06	+0,234E-07
3.55	30,99	3,09	+0,2644E+02	3,50	+0,277E-06	+0,301E-07
3.65	28,69	2,89	+0,2595E+02	3,60	+0,395E-06	+0,433E-07
3.75	74,59	7,49	+0,2547E+02	3,70	+0,507E-06	+0,559E-07
3.85	26,39	2,59	+0,2501E+02	3,80	+0,802E-06	+0,890E-07
3.95	47,00	4,69	+0,2458E+02	3,90	+0,909E-06	+0,100E-06
4.05	62,00	6,19	+0,2416E+02	4,00	+0,110E-05	+0,122E-06
4.15	49,29	5,00	+0,2375E+02	4,10	+0,136E-05	+0,151E-06
4.25	68,89	7,00	+0,2336E+02	4,20	+0,157E-05	+0,174E-06
4.35	75,69	7,59	+0,2299E+02	4,30	+0,186E-05	+0,208E-06
4.45	99,89	10,00	+0,2263E+02	4,40	+0,219E-05	+0,245E-06
4.55	87,19	8,69	+0,2229E+02	4,50	+0,264E-05	+0,295E-06
4.65	149,00	15,00	+0,2195E+02	4,60	+0,303E-05	+0,339E-06
4.75	96,39	10,00	+0,2163E+02	4,70	+0,372E-05	+0,416E-06
4.85	117,00	12,00	+0,2132E+02	4,80	+0,417E-05	+0,467E-06
4.95	109,00	11,00	+0,2102E+02	4,90	+0,472E-05	+0,530E-06
5.25	165,00	16,00	+0,2073E+02	5,00	+0,524E-05	+0,589E-06
5.75	207,00	21,00	+0,1942E+02	5,50	+0,935E-05	+0,104E-05
6.25	244,00	24,00	+0,1830E+02	6,00	+0,148E-04	+0,166E-05
6.75	287,00	29,00	+0,1732E+02	6,50	+0,216E-04	+0,242E-05
7.25	317,00	32,00	+0,1647E+02	7,00	+0,301E-04	+0,338E-05
7.75	342,00	35,00	+0,1571E+02	7,50	+0,400E-04	+0,448E-05
8.25	294,00	30,00	+0,1503E+02	8,00	+0,511E-04	+0,574E-05
8.75	307,00	31,00	+0,1442E+02	8,50	+0,611E-04	+0,687E-05
9.25	406,00	41,00	+0,1386E+02	9,00	+0,719E-04	+0,809E-05
9.75	412,00	42,00	+0,1336E+02	9,50	+0,868E-04	+0,977E-05
			+0,1289E+02	10,00	+0,102E-03	+0,115E-04

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TABLE IX a. RECOMMENDED VALUES FOR THE POLYNOMIAL COEFFICIENTS

Coeff.	Reactions			
	Li( $\alpha, n$ )	Be( $\alpha, n$ )	B( $\alpha, n$ )	C( $\alpha, n$ )
A	6.7	7.0	5.75	6.45
B	2.3	3.0	1.75	3.55
C <sub>0</sub>	0.298E-4	0.200E-3	0.236E-4	0.435E-6
C <sub>1</sub>	0.409E-4	0.210E-3	0.180E-4	0.574E-6
C <sub>2</sub>	0.965E-5	0.310E-4	-0.326E-4	0.171E-6
C <sub>3</sub>	-0.368E-5	0.926E-4	-0.131E-5	-0.134E-7
C <sub>4</sub>	-0.218E-5	0.106E-5	-	-0.212E-7
C <sub>5</sub>	0.115E-5	-0.150E-5	-	0.549E-8
C <sub>6</sub>	0.157E-5	-0.786E-6	-	0.258E-8
C <sub>7</sub>	0.496E-6	+0.150E-6	-	0.417E-8
C <sub>8</sub>	-	-0.762E-6	-	0.530E-8
C <sub>9</sub>	-	-0.641	-	-

TABLE IX b. RECOMMENDED VALUES FOR THE POLYNOMIAL COEFFICIENTS

Coeff.	Reactions		
	<sup>17</sup> O( $\alpha, n$ )	<sup>18</sup> O( $\alpha, n$ )	F( $\alpha, n$ )
A	6.5	6.5	6.5
B	3.5	3.5	3.5
C <sub>0</sub>	0.151E-7	0.168E-6	0.180E-3
C <sub>1</sub>	0.193E-7	0.209E-6	0.216E-3
C <sub>2</sub>	0.450E-8	0.420E-7	0.444E-4
C <sub>3</sub>	-0.143E-9	-0.782E-9	-0.217E-5
C <sub>4</sub>	-0.301E-10	0.464E-9	0.200E-5
C <sub>5</sub>	0.582E-9	-0.109E-8	-0.829E-6
C <sub>6</sub>	0.902E-9	-	-0.158E-5
C <sub>7</sub>	0.922E-9	-	0.326E-6
C <sub>8</sub>	0.374E-9	-	0.809E-6
C <sub>9</sub>	-	-	0.791



#### 4. Literature sources.

The following references were used in the analysis and evaluation of these data:

lithium: [6,7,8,9,10]

beryllium: [6,10,11,13,14,15]

boron: [6,10,15,16,17]

carbon: [10,18,15,19]

oxygen: [10,18,20,21,22,23,24]

fluorine: [10,16,25,26,27].

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