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EVALUATION OF NEUTRON CROSS SECTIONS FOR BORON-10

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The neutron cross sections for ^{10}B have been evaluated from 10^{-4} eV to 15 MeV. The existing experimental data are reviewed, and theoretical calculations and other reasoning are used to fill in the gaps. A complete and consistent set of cross sections is presented and an explanation is given for the choices made in developing this cross-section set.

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INTRODUCTION

As a part of the cooperative effort by the Cross Section Evaluation Working Group to assemble a useful library of neutron cross sections, the cross sections for ^{10}B were evaluated and tabulated in the ENDF/B format. The evaluation was made in September, 1966, and covered experimental data published up to that date. In the descriptions below the data sources for each cross section are outlined, and the choices made for the final evaluated data are listed, with comments on the reasoning involved in the evaluation.

Each cross section was originally represented at a set of energy values which adequately described the evaluated curve. A common energy mesh was then formed from the union of all the energy values used in describing the individual cross sections. Interpolated values were obtained so that all cross sections are represented at each point of the final mesh.

An edit of the cross section values (ENDF material 1009) and plots of the evaluated data are included as appendices to this report.

TOTAL CROSS SECTION

Data for the total cross section were obtained from BNL-325,¹ from the second supplement to BNL-325,² and from the report of Mooring et al.³

From 10^{-4} eV to 500 keV, the total cross section was determined by the sum of the elastic and the (n,α) cross sections. This was found to be in agreement with the experimental data, especially the recent measurements of Mooring et al.³

From 500 keV to 14 MeV the cross section was taken from smooth curves through the data presented in BNL-325 and its supplement. This curve largely follows the data of Bockelman et al.^{4,5} to 3.5 MeV and the data of Fossan et al.⁶ above 3.5 MeV.

ELASTIC CROSS SECTION

Mooring et al.³ present data on the elastic cross section, including measurements by Lane et al.⁷ In addition, a value of 2.43 barns for the potential scattering at 0.0253 eV was obtained by Hibdon and Muelhause.⁸

From 10^{-4} eV to 500 keV the elastic cross section was read from the smooth curve presented by Mooring et al.³ The data are in excellent agreement with the results of Lane et al.⁷ Below 1 keV the cross section was held constant at 2 barns.

From 500 keV to 15 MeV, the elastic cross section was determined by the difference between the total and the nonelastic cross sections. The total and nonelastic cross sections were evaluated independently and subtracted to produce the elastic cross section. This procedure resulted in some apparently spurious wiggles in the elastic cross section above 4 MeV. The elastic cross section was then smoothed and small adjustments were made in the total and nonelastic cross sections to keep them consistent. These adjustments were minor, and, if anything, improved the fits of the evaluated total and nonelastic cross sections to the experimental data.

NONELASTIC CROSS SECTION

There has been only one measurement of the nonelastic cross section, 0.56 barn at 14.2 MeV by MacGregor et al.⁹

The nonelastic cross section was determined by the sum of the (n,α) , (n,d) , $(n,t)2\alpha$, and (n,n') cross sections. The 14-MeV measurement was used to fix the value of the (n,n') cross section at that energy.

INELASTIC CROSS SECTION

The results of Day¹⁰ and of Day and Walt¹¹ on excitation of the first excited level are presented in BNL-325, Supplement 2,² and some preliminary results of Nellis and Morgan appear in WASH-1064.¹² In addition, BNL-325 contains the work of Frye and Gammel¹³ on the $(n,n'd)2\alpha$ reaction.

The first level excitation function as determined by Day was used as the total inelastic cross section up to 4.5 MeV. The data of Day and of Nellis and Morgan are in quite good agreement. Above 4.5 MeV a smooth curve was used to join these data to the value at 14 MeV obtained from

subtraction of the (n,α) , (n,d) , and $(n,t)2\alpha$ cross sections from the non-elastic. The $(n,n'd)2\alpha$ data were ignored since this reaction is included as a part of the total inelastic reaction at the higher energies.

PARASITIC ABSORPTION CROSS SECTION

The parasitic absorption cross section is the sum of the (n,α) , (n,d) , and $(n,t)2\alpha$ cross sections.

(n,d) CROSS SECTION

There have been two measurements of the differential (n,d) cross section at 14 MeV: one by Ribe and Seagrave¹⁴ and another by Valkovic et al.¹⁵ In addition, there are some measurements by Siemssen et al.¹⁶ and Bardes and Owen¹⁷ for the inverse reaction ${}^9\text{Be}(d,n){}^{10}\text{B}_{\text{g.s.}}$

The differential cross section of Valkovic was integrated to obtain the value $\sigma(n,d) = 0.063$ barn at 14.3 MeV. The Ribe and Seagrave data were ignored because they do not extend beyond 90 deg and are older than the Valkovic data. The Ribe and Seagrave data are slightly lower than the Valkovic data, with differences ranging from 0 to 40%.

A smooth curve was drawn through the Bardes and Owen data and the Siemssen data for 1.1- to 3.15-MeV incident deuteron energy. Three data points were picked from this curve and values of the ${}^{10}\text{B}(n,d)$ cross section at 5.7, 6.6, and 7.5 MeV were calculated by detailed balance. A threshold of 4.8 MeV was obtained from UCRL-14000¹⁸ and a smooth curve was drawn from the threshold through the data points and up to the value at 14 MeV.

$(n,t)2\alpha$ CROSS SECTION

Data have been reported on the $(n,t)2\alpha$ cross section by Davis et al.,¹⁹ Wyman et al.,²⁰ Frye and Gammel,¹³ and Perkin.²¹ These data are shown in Fig. 1. It is easily seen that the data of Wyman et al., Frye and Gammel, and Perkin are in fairly good agreement, but that the values of Davis et al. are substantially lower than the other values. From comparisons made in evaluating the (n,α) cross section (see below), it was felt that the data of Davis et al. are definitely low. Consequently their data were ignored and a smooth curve was passed through the Wyman, Frye, and Perkin data.

Fig. 1. The $(n,t)2\alpha$ Cross Section for ^{10}B .

The cross section was given a threshold at 1.2 MeV, where the Davis et al. data reaches a threshold.

(n, α) CROSS SECTION

There have been many measurements of the $^{10}\text{B}(n,\alpha)$ cross section: Bilpuch et al.,²² Bichsel and Bonner,²³ Davis et al.,¹⁹ Mooring et al.,³ and Cox.²⁴ In addition, it is possible to calculate values by means of detailed balance from the Macklin and Gibbons measurement of the $\text{Li}(\alpha,n)$ cross section²⁵ and their branching ratio measurements.²⁶ Several measurements of the thermal (n, α) cross section are given in the second supplement of BNL-325.²

From 10^{-4} eV to 50 keV, the (n, α) cross section was taken to be $610/\sqrt{E}$. This gives a 0.0253-eV value of 3837 barns, as recommended in the second supplement to BNL-325.² From 50 to 500 keV, the data of Mooring et al.,³ and of Cox,²⁴ together with those derived from Gibbons and Macklin,^{26,25} were put on a plot of $\sigma(n,\alpha) \times \sqrt{E}$ versus E (Fig. 2). A smooth curve was drawn through these points and the cross-section values obtained from the curve.

The data of Mooring et al., Cox, and Gibbons and Macklin are in reasonable agreement in this range. The data of Bichsel and Bonner²³ are not, being considerably lower, especially near 500 keV. The Bichsel and Bonner data agree reasonably well with those of Davis et al.¹⁹ over their region of overlap. However, these two sets of data always appear low when compared to another set of data. Thus we find that:

(1) Compared to the data of Mooring et al., Cox and Gibbons and Macklin, the (n, α) data of Bichsel and Bonner are low by 20-30 percent in the region from 150 keV to 500 keV.

(2) Compared to the data of Wyman et al., Frye and Gammel, and Perkin, the (n,t) 2α data of Davis et al. are too low by 50 to 150 mb.

(3) Compared to the data derived from the inverse measurements of Gibbons and Macklin, the (n, α_0) data of Davis et al. are too low by 50 mb, from 200 to 1000 keV.

Fig. 2. The (n, α) Cross Section for ^{10}B .

(4) Compared to the data of Nellis and Morgan,¹² the (n,α) data of Davis et al. are too low by approximately 60 mb from 1 to 5 MeV.

The conclusion that the data of Bichsel and Bonner and of Davis et al. are unreasonably low is inescapable. Therefore, these data have been largely ignored in making the evaluation. However, for the (n,α) cross section from 500 keV to 14 MeV, the Davis et al. data were the only data available. Since the comparisons of their (n,α) data to the data of Nellis and Morgan and their (n,α_0) data to those of Gibbons and Macklin showed that the data of Davis et al. had in general the proper shape but was roughly a total of 110 mb too low, 110 mb was added to the Davis et al. data and the sum was taken to be the (n,α) cross section from 0.5 to 7.5 MeV. From 7.5 to 14 MeV the (n,α) cross section was allowed to decrease smoothly.

BRANCHING RATIO

The branching ratio $\sigma(n,\alpha_0)/\sigma(n,\alpha)$, that is, the percentage of (n,α) reactions which leave the ${}^7\text{Li}$ nucleus in its ground state, has been measured many times for thermal neutrons. (A complete table of values and references may be found in ref. 27.) The best value seems to be .065 obtained by averaging the three most recent and most accurate measurements, those of DeJuren and Rosenwasser,²⁸ Brinkmann and Greber,²⁹ and Malmskog.²⁷

Above thermal energy there are measurements by Sowerby,³⁰ Macklin and Gibbons,²⁸ Davis et al.,¹⁹ and Petree et al.³¹ which are in reasonable agreement. The data are shown in Fig. 3, along with the evaluation which was obtained by drawing a smooth curve through the experimental points.

Values of the evaluated branching ratio along with the (n,α_0) and (n,α_1) cross sections which may be obtained from the (n,α) data by means of the branching ratio are shown on Table 1. This information, while included in the evaluation, was not put on the ENDF tape, since there seemed to be no adequate way of expressing the data in the existing format.

Fig. 3. Branching Ratio for ^{10}B .

Table 1. Values of ^{10}B Branching Ratio and (n, α_0) and (n, α_1) Cross Sections.

Energy	Branching Ratio	Cross Section (barns)	
		$^{10}\text{B}(n, \alpha)^7\text{Li}_{g.s.}$	$^{10}\text{B}(n, \alpha)^7\text{Li}^*$
0.0253 eV	0.065	249.	3588.
50 keV	0.065	0.177	2.55
70 keV	0.065	0.152	2.19
80 keV	0.066	0.145	2.06
90 keV	0.067	0.140	1.95
100 keV	0.069	0.137	1.85
120 keV	0.074	0.137	1.71
150 keV	0.084	0.142	1.55
200 keV	0.100	0.150	1.35
250 keV	0.120	0.160	1.17
275 keV	0.130	0.159	1.06
300 keV	0.140	0.148	0.912
325 keV	0.149	0.142	0.808
350 keV	0.158	0.141	0.751
360 keV	0.162	0.141	0.729
400 keV	0.177	0.152	0.708
500 keV	0.210	0.174	0.656
600 keV	0.250	0.155	0.465
700 keV	0.285	0.138	0.347
800 keV	0.330	0.131	0.267
900 keV	0.375	0.126	0.209
1.0 MeV	0.43	0.136	0.181
1.2 MeV	0.53	0.153	0.136
1.4 MeV	0.64	0.198	0.111
1.6 MeV	0.70	0.2975	0.1275
1.85 MeV	0.70	0.392	0.168
3.0 MeV	0.70	0.347	0.149
2.1 MeV	0.667	0.307	0.153
2.4 MeV	0.583	0.185	0.132
2.5 MeV	0.56	0.180	0.141
2.8 MeV	0.74	0.233	0.082
3.15 MeV	0.684	0.183	0.084
3.8 MeV	0.604	0.156	0.102
4.0 MeV	0.584	0.159	0.113
4.2 MeV	0.565	0.158	0.122
4.5 MeV	0.54	0.136	0.115
5.0 MeV	0.63	0.129	0.076
5.5 MeV	0.72	0.138	0.053
6.6 MeV	0.72	0.120	0.047
7.0 MeV	0.72	0.113	0.044
10.0 MeV	0.72	0.0497	0.0193
14.0 MeV	0.72	0.0144	0.0056

AVERAGE COSINE OF ELASTIC SCATTERING IN LABORATORY SYSTEM

Values for the average cosine of elastic scattering in the laboratory system, $\bar{\mu}$, were obtained from the center-of-mass Legendre coefficients for elastic scattering using the transformation matrix given.

ELASTIC SCATTERING ANGULAR DISTRIBUTION

Legendre coefficients from experimental measurements in the range 1 to 2 MeV were supplied by Atomics International.³² Data from a measurement at 14 MeV are presented by Valkovic *et al.*¹⁵ but the investigators are not identified. Measurements by Lane *et al.*⁷ below 0.5 MeV show the distribution to be isotropic.

In addition, recent calculations by Agee and Rosen³³ provide optical model predictions for the angular distribution from 1 to 16 MeV, including an estimate of the shape elastic contribution (but only to 11 MeV), as well as the compound elastic contribution. Normally one would not expect that a nuclide as light as boron could be well described by the optical model. However, the Agee and Rosen calculation is in beautiful agreement with the measured data. Figure 4 shows the comparison for f_1 . Thus, it seems to be most reasonable to use the Agee and Rosen values.

The elastic angular distribution was taken to be isotropic in the center-of-mass system up to 0.5 MeV. From 0.5 to 11 MeV the results of the Agee and Rosen calculation were used. At 14 MeV the measured data presented by Valkovic were used. The distribution was represented by eight Legendre coefficients. It is everywhere positive.

The transformation matrix for converting the center-of-mass coefficients to laboratory coefficients was supplied by Atomics International.³²

INELASTIC SCATTERING ENERGY DISTRIBUTION

Beyond the results of Day¹⁰ and Day and Walt¹¹ concerning excitation of the first level, there are no data available on the energy distribution resulting from inelastic scattering.

Since the inelastic cross section was taken up to 4.5 MeV to be equal to Day's measurements on excitation of the 0.717-MeV level, the

Fig. 4. First Legendre Coefficients for ^{10}B (Center-of-Mass System).

secondary energy distribution was taken to be a discrete energy loss of 0.717 MeV from threshold to 4.5 MeV. For lack of anything better, the energy distribution above 4.5 MeV is assumed to be that of a simple evaporation model,³⁴

$$P(E) dE = N e^{-E/\theta} dE,$$

where

$$\theta = \theta(E_{in}) = \sqrt{E_{in}} / (.31 \sqrt{A}) = 0.9728 \sqrt{E_{in}} \quad (E_{in} \text{ in MeV}).$$

APPENDIX A. TABULATED DATA

This appendix presents tabulated values of the ^{10}B neutron cross sections as follows:

<u>Cross Section</u>	<u>ENDF/B File No.</u>	<u>ENDF/B Section No.</u>	<u>Page No.</u>
Total	3	1	18
Elastic	3	2	19
Nonelastic	3	3	20
Inelastic	3	4	21
Absorption	3	101	22
n,d	3	104	23
n,T	3	105	24
n, α	3	107	25

The following data are also included:

	<u>ENDF/B File No.</u>	<u>ENDF/B Section No.</u>	<u>Page No.</u>
$\bar{\mu}$, average cosine of elastic scattering (lab. sys.)	3	251	26
Elastic scattering angular distribution	4	2	27
Inelastic scattering energy distribution			
Discrete energy loss	5	4	28
Maxwellian distribution	5	4	29

Total Cross Section, Number of Points = 94

ENERGY	CROSS SECTION	ENERGY	CROSS SECTION	ENERGY	CROSS SECTION
1.00000e+04	6.10000e+04	1.95000e+06	2.12000e+00	6.30000e+06	1.50600e+00
2.53000e+02	3.83900e+03	2.00000e+06	2.06000e+00	6.50000e+06	1.51000e+00
1.00000e+01	1.93100e+03	2.10000e+06	1.95000e+00	6.60000e+06	1.51400e+00
1.00000e+00	6.12000e+02	2.20000e+06	1.90000e+00	7.00000e+06	1.52000e+00
1.00000e+01	1.94900e+02	2.25000e+06	1.89000e+00	7.50000e+06	1.52000e+00
1.00000e+02	6.30000e+01	2.30000e+06	1.90000e+00	7.70000e+06	1.51600e+00
1.00000e+03	2.13000e+01	2.35000e+06	1.92000e+00	8.00000e+06	1.51000e+00
1.00000e+04	8.18000e+00	2.40000e+06	1.97000e+00	8.50000e+06	1.49000e+00
2.00000e+04	6.47000e+00	2.45000e+06	2.04000e+00	9.00000e+06	1.46000e+00
5.00000e+04	5.13000e+00	2.55000e+06	2.20000e+00	9.50000e+06	1.45000e+00
1.00000e+05	4.79000e+00	2.60000e+06	2.27000e+00	1.00000e+07	1.45000e+00
1.50000e+05	4.81000e+00	2.65000e+06	2.35000e+00	1.05000e+07	1.45000e+00
2.00000e+05	4.90000e+00	2.70000e+06	2.37000e+00	1.10000e+07	1.45000e+00
2.25000e+05	4.93000e+00	2.75000e+06	2.39000e+00	1.40000e+07	1.45000e+00
2.50000e+05	4.93000e+00	2.80000e+06	2.38000e+00		
2.75000e+05	4.90000e+00	2.85000e+06	2.33000e+00		
3.00000e+05	4.80000e+00	2.90000e+06	2.26000e+00		
3.25000e+05	4.74000e+00	2.95000e+06	2.20000e+00		
3.60000e+05	4.68000e+00	3.00000e+06	2.12000e+00		
4.00000e+05	4.60000e+00	3.15000e+06	1.90000e+00		
4.50000e+05	4.52000e+00	3.20000e+06	1.85000e+00		
5.00000e+05	4.40000e+00	3.25000e+06	1.80000e+00		
6.00000e+05	4.08000e+00	3.30000e+06	1.77000e+00		
7.00000e+05	3.62000e+00	3.35000e+06	1.74000e+00		
8.00000e+05	3.21000e+00	3.40000e+06	1.71000e+00		
9.00000e+05	2.85000e+00	3.50000e+06	1.66000e+00		
1.00000e+06	2.59000e+00	3.65000e+06	1.61000e+00		
1.20000e+06	2.25000e+00	3.80000e+06	1.62000e+00		
1.25000e+06	2.18000e+00	3.90000e+06	1.64000e+00		
1.35000e+06	2.07000e+00	4.00000e+06	1.70000e+00		
1.40000e+06	2.02000e+00	4.20000e+06	1.77000e+00		
1.45000e+06	1.99000e+00	4.30000e+06	1.82000e+00		
1.50000e+06	1.97000e+00	4.35000e+06	1.80000e+00		
1.53000e+06	1.96000e+00	4.50000e+06	1.75000e+00		
1.60000e+06	2.00000e+00	4.80000e+06	1.60000e+00		
1.70000e+06	2.23000e+00	5.00000e+06	1.55000e+00		
1.75000e+06	2.29000e+00	5.50000e+06	1.45000e+00		
1.80000e+06	2.28000e+00	5.60000e+06	1.46000e+00		
1.85000e+06	2.22000e+00	5.70000e+06	1.47000e+00		
1.90000e+06	2.17000e+00	6.00000e+06	1.49000e+00		

ENERGY INTERPOLATION TABLE
NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY UPPER ENERGY INTERPOLATION

1.00000e+04 1.40000e+07

5

Elastic Cross Section, Number of Points = 94

ENERGY	CROSS SECTION	ENERGY	CROSS SECTION	ENERGY	CROSS SECTION
1.00000e+04	2.00000e+00	1.95000e+06	1.50500e+00	6.30000e+06	9.62300e+01
2.53000e+02	2.00000e+00	2.00000e+06	1.47200e+00	6.50000e+06	9.86500e+01
1.00000e+01	2.00000e+00	2.10000e+06	1.40900e+00	6.60000e+06	9.95600e+01
1.00000e+00	2.00000e+00	2.20000e+06	1.42000e+00	7.00000e+06	1.00800e+02
1.00000e+01	2.00000e+00	2.25000e+06	1.43500e+00	7.50000e+06	1.01350e+02
1.00000e+02	2.00000e+00	2.30000e+06	1.46900e+00	7.70000e+06	1.01100e+02
1.00000e+03	2.00000e+00	2.35000e+06	1.51050e+00	8.00000e+06	1.00600e+02
1.00000e+04	2.08000e+00	2.40000e+06	1.57900e+00	8.50000e+06	9.83000e+01
2.00000e+04	2.16000e+00	2.45000e+06	1.64500e+00	9.00000e+06	9.49100e+01
5.00000e+04	2.40000e+00	2.55000e+06	1.79800e+00	9.50000e+06	9.35200e+01
1.00000e+05	2.80000e+00	2.60000e+06	1.86500e+00	1.00000e+07	9.30000e+01
1.50000e+05	3.12000e+00	2.65000e+06	1.94600e+00	1.05000e+07	9.26600e+01
2.00000e+05	3.40000e+00	2.70000e+06	1.96600e+00	1.10000e+07	9.23000e+01
2.25000e+05	3.51000e+00	2.75000e+06	1.98700e+00	1.40000e+07	8.88000e+01
2.50000e+05	3.60000e+00	2.80000e+06	1.97700e+00		
2.75000e+05	3.68000e+00	2.85000e+06	1.93350e+00		
3.00000e+05	3.74000e+00	2.90000e+06	1.86800e+00		
3.25000e+05	3.79000e+00	2.95000e+06	1.81150e+00		
3.60000e+05	3.81000e+00	3.00000e+06	1.73500e+00		
4.00000e+05	3.74000e+00	3.15000e+06	1.52300e+00		
4.50000e+05	3.67000e+00	3.20000e+06	1.47500e+00		
5.00000e+05	3.57000e+00	3.25000e+06	1.42100e+00		
6.00000e+05	3.46000e+00	3.30000e+06	1.38900e+00		
7.00000e+05	3.13500e+00	3.35000e+06	1.35600e+00		
8.00000e+05	2.81200e+00	3.40000e+06	1.32600e+00		
9.00000e+05	2.51500e+00	3.50000e+06	1.27900e+00		
1.00000e+06	2.27300e+00	3.65000e+06	1.22630e+00		
1.20000e+06	1.96100e+00	3.80000e+06	1.22700e+00		
1.25000e+06	1.88600e+00	3.90000e+06	1.23100e+00		
1.35000e+06	1.76380e+00	4.00000e+06	1.27200e+00		
1.40000e+06	1.70320e+00	4.20000e+06	1.30800e+00		
1.45000e+06	1.64760e+00	4.30000e+06	1.34700e+00		
1.50000e+06	1.59600e+00	4.35000e+06	1.32350e+00		
1.53000e+06	1.56590e+00	4.50000e+06	1.26200e+00		
1.60000e+06	1.55650e+00	4.80000e+06	1.08920e+00		
1.70000e+06	1.72800e+00	5.00000e+06	1.02100e+00		
1.75000e+06	1.75100e+00	5.50000e+06	8.82500e+01		
1.80000e+06	1.70200e+00	5.60000e+06	8.86600e+01		
1.85000e+06	1.59300e+00	5.70000e+06	8.96700e+01		
1.90000e+06	1.54600e+00	6.00000e+06	9.22000e+01		

ENERGY INTERPOLATION TABLE

NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY UPPER ENERGY INTERPOLATION

1.00000e+04 1.40000e+07 5

Nonelastic Cross Section, Number of Points = 94

ENERGY	CROSS SECTION	ENERGY	CROSS SECTION	ENERGY	CROSS SECTION
1.00000e+04	6.10000e+04	1.95000e+06	6.15000e+01	6.30000e+06	5.43700e+01
2.53000e+02	3.83700e+03	2.00000e+06	5.88000e+01	6.50000e+06	5.23500e+01
1.00000e+01	1.92900e+03	2.10000e+06	5.41000e+01	6.60000e+06	5.18400e+01
1.00000e+00	6.10000e+02	2.20000e+06	4.80000e+01	7.00000e+06	5.12000e+01
1.00000e+01	1.92900e+02	2.25000e+06	4.55000e+01	7.50000e+06	5.06500e+01
1.00000e+02	6.10000e+01	2.30000e+06	4.31000e+01	7.70000e+06	5.05000e+01
1.00000e+03	1.93000e+01	2.35000e+06	4.09500e+01	8.00000e+06	5.04000e+01
1.00000e+04	6.10000e+00	2.40000e+06	3.91000e+01	8.50000e+06	5.07000e+01
2.00000e+04	4.31000e+00	2.45000e+06	3.95000e+01	9.00000e+06	5.10900e+01
5.00000e+04	2.73000e+00	2.55000e+06	4.02000e+01	9.50000e+06	5.14800e+01
1.00000e+05	1.99000e+00	2.60000e+06	4.05000e+01	1.00000e+07	5.20000e+01
1.50000e+05	1.69000e+00	2.65000e+06	4.04000e+01	1.05000e+07	5.23400e+01
2.00000e+05	1.50000e+00	2.70000e+06	4.04000e+01	1.10000e+07	5.27000e+01
2.25000e+05	1.42000e+00	2.75000e+06	4.03000e+01	1.40000e+07	5.62000e+01
2.50000e+05	1.33000e+00	2.80000e+06	4.03000e+01		
2.75000e+05	1.22000e+00	2.85000e+06	3.96500e+01		
3.00000e+05	1.06000e+00	2.90000e+06	3.92000e+01		
3.25000e+05	9.50000e-01	2.95000e+06	3.88500e+01		
3.60000e+05	8.70000e-01	3.00000e+06	3.85000e+01		
4.00000e+05	8.60000e-01	3.15000e+06	3.77000e+01		
4.50000e+05	8.50000e-01	3.20000e+06	3.75000e+01		
5.00000e+05	8.30000e-01	3.25000e+06	3.79000e+01		
6.00000e+05	6.20000e-01	3.30000e+06	3.81000e+01		
7.00000e+05	4.85000e-01	3.35000e+06	3.84000e+01		
8.00000e+05	3.98000e-01	3.40000e+06	3.84000e+01		
9.00000e+05	3.35000e-01	3.50000e+06	3.81000e+01		
1.00000e+06	3.17000e-01	3.65000e+06	3.83700e+01		
1.20000e+06	2.89000e-01	3.80000e+06	3.93000e+01		
1.25000e+06	2.94000e-01	3.90000e+06	4.09000e+01		
1.35000e+06	3.06200e-01	4.00000e+06	4.28000e+01		
1.40000e+06	3.16800e-01	4.20000e+06	4.62000e+01		
1.45000e+06	3.42400e-01	4.30000e+06	4.73000e+01		
1.50000e+06	3.74000e-01	4.35000e+06	4.76500e+01		
1.53000e+06	3.94050e-01	4.50000e+06	4.88000e+01		
1.60000e+06	4.43500e-01	4.80000e+06	5.10800e+01		
1.70000e+06	5.02000e-01	5.00000e+06	5.29000e+01		
1.75000e+06	5.39000e-01	5.50000e+06	5.67500e+01		
1.80000e+06	5.78000e-01	5.60000e+06	5.73400e+01		
1.85000e+06	6.27000e-01	5.70000e+06	5.73300e+01		
1.90000e+06	6.24000e-01	6.00000e+06	5.68000e+01		

ENERGY INTERPOLATION TABLE

NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
1.00000e+04	1.40000e+07	5

Inelastic Cross Section, Number of Points = 66

ENERGY	CROSS SECTION	ENERGY	CROSS SECTION
1.25000e+06	0	3.90000e+06	5.40000e+02
1.35000e+06	1.20000e+03	4.00000e+06	6.10000e+02
1.40000e+06	1.80000e+03	4.20000e+06	7.70000e+02
1.45000e+06	2.40000e+03	4.30000e+06	8.30000e+02
1.50000e+06	3.00000e+03	4.35000e+06	8.55000e+02
1.53000e+06	4.05000e+03	4.50000e+06	9.40000e+02
1.60000e+06	6.50000e+03	4.80000e+06	1.04800e+01
1.70000e+06	1.00000e+02	5.00000e+06	1.12000e+01
1.75000e+06	1.90000e+02	5.50000e+06	1.31500e+01
1.80000e+06	2.80000e+02	5.60000e+06	1.35400e+01
1.85000e+06	4.70000e+02	5.70000e+06	1.39300e+01
1.90000e+06	6.60000e+02	6.00000e+06	1.51000e+01
1.95000e+06	7.60000e+02	6.30000e+06	1.62700e+01
2.00000e+06	6.70000e+02	6.50000e+06	1.70500e+01
2.10000e+06	5.20000e+02	6.60000e+06	1.74400e+01
2.20000e+06	4.40000e+02	7.00000e+06	1.90000e+01
2.25000e+06	4.20000e+02	7.50000e+06	2.09000e+01
2.30000e+06	3.90000e+02	7.70000e+06	2.16000e+01
2.35000e+06	3.75000e+02	8.00000e+06	2.27500e+01
2.40000e+06	3.60000e+02	8.50000e+06	2.46000e+01
2.45000e+06	3.60000e+02	9.00000e+06	2.65000e+01
2.55000e+06	3.60000e+02	9.50000e+06	2.80000e+01
2.60000e+06	3.60000e+02	1.00000e+07	2.95000e+01
2.65000e+06	3.60000e+02	1.05000e+07	3.10000e+01
2.70000e+06	3.60000e+02	1.10000e+07	3.25000e+01
2.75000e+06	3.60000e+02	1.40000e+07	3.90000e+01
2.80000e+06	3.60000e+02		
2.85000e+06	3.65000e+02		
2.90000e+06	3.70000e+02		
2.95000e+06	3.85000e+02		
3.00000e+06	4.00000e+02		
3.15000e+06	4.60000e+02		
3.20000e+06	4.80000e+02		
3.25000e+06	5.10000e+02		
3.30000e+06	5.10000e+02		
3.35000e+06	5.20000e+02		
3.40000e+06	5.10000e+02		
3.50000e+06	4.70000e+02		
3.65000e+06	4.50000e+02		
3.80000e+06	5.00000e+02		

ENERGY INTERPOLATION TABLE

NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
1.25000e+06	1.40000e+07	2

Absorption Cross Section, Number of Points = 94

ENERGY	CROSS SECTION	ENERGY	CROSS SECTION	ENERGY	CROSS SECTION
1.00000e+04	6.10000e+04	1.95000e+06	5.39000e+01	6.30000e+06	3.81000e+01
2.53000e+02	3.83700e+03	2.00000e+06	5.21000e+01	6.50000e+06	3.53000e+01
1.00000e+01	1.92900e+03	2.10000e+06	4.89000e+01	6.60000e+06	3.44000e+01
1.00000e+00	6.10000e+02	2.20000e+06	4.36000e+01	7.00000e+06	3.22000e+01
1.00000e+01	1.92900e+02	2.25000e+06	4.13000e+01	7.50000e+06	2.97500e+01
1.00000e+02	6.10000e+01	2.30000e+06	3.92000e+01	7.70000e+06	2.89000e+01
1.00000e+03	1.93000e+01	2.35000e+06	3.72000e+01	8.00000e+06	2.76500e+01
1.00000e+04	6.10000e+00	2.40000e+06	3.55000e+01	8.50000e+06	2.61000e+01
2.00000e+04	4.31000e+00	2.45000e+06	3.59000e+01	9.00000e+06	2.45900e+01
5.00000e+04	2.73000e+00	2.55000e+06	3.66000e+01	9.50000e+06	2.34800e+01
1.00000e+05	1.99000e+00	2.60000e+06	3.69000e+01	1.00000e+07	2.25000e+01
1.50000e+05	1.69000e+00	2.65000e+06	3.68000e+01	1.05000e+07	2.13400e+01
2.00000e+05	1.50000e+00	2.70000e+06	3.68000e+01	1.10000e+07	2.02000e+01
2.25000e+05	1.42000e+00	2.75000e+06	3.67000e+01	1.40000e+07	1.72000e+01
2.50000e+05	1.33000e+00	2.80000e+06	3.67000e+01		
2.75000e+05	1.22000e+00	2.85000e+06	3.66000e+01		
3.00000e+05	1.06000e+00	2.90000e+06	3.55000e+01		
3.25000e+05	9.50000e-01	2.95000e+06	3.50000e+01		
3.60000e+05	8.70000e-01	3.00000e+06	3.45000e+01		
4.00000e+05	8.60000e-01	3.15000e+06	3.31000e+01		
4.50000e+05	8.50000e-01	3.20000e+06	3.27000e+01		
5.00000e+05	8.30000e-01	3.25000e+06	3.28000e+01		
6.00000e+05	6.20000e-01	3.30000e+06	3.30000e+01		
7.00000e+05	4.85000e-01	3.35000e+06	3.32000e+01		
8.00000e+05	3.98000e-01	3.40000e+06	3.33000e+01		
9.00000e+05	3.35000e-01	3.50000e+06	3.34000e+01		
1.00000e+06	3.17000e-01	3.65000e+06	3.38700e+01		
1.20000e+06	2.89000e-01	3.80000e+06	3.43000e+01		
1.25000e+06	2.94000e-01	3.90000e+06	3.55000e+01		
1.35000e+06	3.05000e-01	4.00000e+06	3.67000e+01		
1.40000e+06	3.15000e-01	4.20000e+06	3.85000e+01		
1.45000e+06	3.40000e-01	4.30000e+06	3.90000e+01		
1.50000e+06	3.71000e-01	4.35000e+06	3.91000e+01		
1.53000e+06	3.90000e-01	4.50000e+06	3.94000e+01		
1.60000e+06	4.37000e-01	4.80000e+06	4.06000e+01		
1.70000e+06	4.92000e-01	5.00000e+06	4.17000e+01		
1.75000e+06	5.20000e-01	5.50000e+06	4.36000e+01		
1.80000e+06	5.50000e-01	5.60000e+06	4.38000e+01		
1.85000e+06	5.80000e-01	5.70000e+06	4.34000e+01		
1.90000e+06	5.58000e-01	6.00000e+06	4.17000e+01		

ENERGY INTERPOLATION TABLE
NUMBER OF INTERPOLATION REGIONS = 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
1.00000e+04	1.40000e+07	5

(n,d) Cross Sections, Number of Points = 20

ENERGY CROSS SECTION	
4.80000e+06	0
5.00000e+06	6.00000e-03
5.50000e+06	1.60000e-02
5.60000e+06	1.90000e-02
5.70000e+06	2.00000e-02
6.00000e+06	2.50000e-02
6.30000e+06	2.90000e-02
6.50000e+06	3.20000e-02
6.60000e+06	3.30000e-02
7.00000e+06	3.60000e-02
7.50000e+06	3.90000e-02
7.70000e+06	4.00000e-02
8.00000e+06	4.10000e-02
8.50000e+06	4.30000e-02
9.00000e+06	4.40000e-02
9.50000e+06	4.50000e-02
1.00000e+07	4.70000e-02
1.05000e+07	4.90000e-02
1.10000e+07	5.00000e-02
1.40000e+07	6.20000e-02

ENERGY INTERPOLATION TABLE
NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
4.80000e+06	1.40000e+07	2

(n,T) Cross Section, Number of Points = 67

ENERGY	CROSS SECTION	ENERGY	CROSS SECTION
1.20000e+06	0	3.80000e+06	8.50000e+02
1.25000e+06	1.00000e-03	3.90000e+06	9.00000e+02
1.30000e+06	4.00000e-03	4.00000e+06	9.50000e+02
1.40000e+06	6.00000e-03	4.20000e+06	1.05000e+01
1.45000e+06	7.00000e-03	4.30000e+06	1.17000e+01
1.50000e+06	9.00000e-03	4.35000e+06	1.24000e+01
1.53000e+06	1.00000e-02	4.50000e+06	1.43000e+01
1.60000e+06	1.20000e-02	4.80000e+06	1.84000e+01
1.70000e+06	1.50000e-02	5.00000e+06	2.06000e+01
1.75000e+06	1.60000e-02	5.50000e+06	2.29000e+01
1.80000e+06	1.80000e-02	5.60000e+06	2.30000e+01
1.85000e+06	2.00000e-02	5.70000e+06	2.28000e+01
1.90000e+06	2.10000e-02	6.00000e+06	2.13000e+01
1.95000e+06	2.30000e-02	6.30000e+06	1.79000e+01
2.00000e+06	2.50000e-02	6.50000e+06	1.52000e+01
2.10000e+06	2.90000e-02	6.60000e+06	1.44000e+01
2.20000e+06	3.20000e-02	7.00000e+06	1.29000e+01
2.25000e+06	3.30000e-02	7.50000e+06	1.22500e+01
2.30000e+06	3.50000e-02	7.70000e+06	1.21000e+01
2.35000e+06	3.60000e-02	8.00000e+06	1.18500e+01
2.40000e+06	3.80000e-02	8.50000e+06	1.16000e+01
2.45000e+06	4.00000e-02	9.00000e+06	1.12500e+01
2.50000e+06	4.30000e-02	9.50000e+06	1.11000e+01
2.60000e+06	4.40000e-02	1.00000e+07	1.09000e+01
2.65000e+06	4.60000e-02	1.05000e+07	1.06000e+01
2.70000e+06	4.80000e-02	1.10000e+07	1.03000e+01
2.75000e+06	5.00000e-02	1.40000e+07	9.00000e+02
2.80000e+06	5.20000e-02		
2.85000e+06	5.30000e-02		
2.90000e+06	5.50000e-02		
2.95000e+06	5.70000e-02		
3.00000e+06	5.90000e-02		
3.15000e+06	6.40000e-02		
3.20000e+06	6.60000e-02		
3.25000e+06	6.70000e-02		
3.30000e+06	7.00000e-02		
3.35000e+06	7.20000e-02		
3.40000e+06	7.30000e-02		
3.50000e+06	7.50000e-02		
3.65000e+06	8.00000e-02		

ENERGY INTERPOLATION TABLE

NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
1.20000e+06	1.40000e+07	2

(n,α) Cross Section, Number of Points = 94

ENERGY	CROSS SECTION	ENERGY	CROSS SECTION	ENERGY	CROSS SECTION
1.00000e+04	6.10000e+04	1.95000e+06	5.16000e+01	6.30000e+06	1.73000e+01
2.53000e+02	3.83700e+03	2.00000e+06	4.96000e+01	6.50000e+06	1.69000e+01
1.00000e+01	1.92900e+03	2.10000e+06	4.60000e+01	6.60000e+06	1.67000e+01
1.00000e+00	6.10000e+02	2.20000e+06	4.04000e+01	7.00000e+06	1.57000e+01
1.00000e+01	1.92900e+02	2.25000e+06	3.80000e+01	7.50000e+06	1.36000e+01
1.00000e+02	6.10000e+01	2.30000e+06	3.57000e+01	7.70000e+06	1.28000e+01
1.00000e+03	1.93000e+01	2.35000e+06	3.36000e+01	8.00000e+06	1.17000e+01
1.00000e+04	6.10000e+00	2.40000e+06	3.17000e+01	8.50000e+06	1.02000e+01
2.00000e+04	4.31000e+00	2.45000e+06	3.19000e+01	9.00000e+06	8.94000e+02
5.00000e+04	2.73000e+00	2.55000e+06	3.23000e+01	9.50000e+06	7.88000e+02
1.00000e+05	1.99000e+00	2.60000e+06	3.25000e+01	1.00000e+07	6.90000e+02
1.50000e+05	1.69000e+00	2.65000e+06	3.22000e+01	1.05000e+07	5.84000e+02
2.00000e+05	1.50000e+00	2.70000e+06	3.20000e+01	1.10000e+07	4.90000e+02
2.25000e+05	1.42000e+00	2.75000e+06	3.17000e+01	1.40000e+07	2.08000e+02
2.50000e+05	1.33000e+00	2.80000e+06	3.15000e+01		
2.75000e+05	1.22000e+00	2.85000e+06	3.07000e+01		
3.00000e+05	1.06000e+00	2.90000e+06	3.00000e+01		
3.25000e+05	9.50000e-01	2.95000e+06	2.93000e+01		
3.60000e+05	8.70000e-01	3.00000e+06	2.86000e+01		
4.00000e+05	8.60000e-01	3.15000e+06	2.67000e+01		
4.50000e+05	8.50000e-01	3.20000e+06	2.61000e+01		
5.00000e+05	8.30000e-01	3.25000e+06	2.61000e+01		
6.00000e+05	6.20000e-01	3.30000e+06	2.60000e+01		
7.00000e+05	4.85000e-01	3.35000e+06	2.60000e+01		
8.00000e+05	3.98000e-01	3.40000e+06	2.60000e+01		
9.00000e+05	3.35000e-01	3.50000e+06	2.59000e+01		
1.00000e+06	3.17000e-01	3.65000e+06	2.58700e+01		
1.20000e+06	2.89000e-01	3.80000e+06	2.58000e+01		
1.25000e+06	2.93000e-01	3.90000e+06	2.65000e+01		
1.35000e+06	3.07000e-01	4.00000e+06	2.72000e+01		
1.40000e+06	3.09000e-01	4.20000e+06	2.80000e+01		
1.45000e+06	3.33000e-01	4.30000e+06	2.73000e+01		
1.50000e+06	3.62000e-01	4.35000e+06	2.67000e+01		
1.53000e+06	3.80000e-01	4.50000e+06	2.51000e+01		
1.60000e+06	4.25000e-01	4.80000e+06	2.22000e+01		
1.70000e+06	4.77000e-01	5.00000e+06	2.05000e+01		
1.75000e+06	5.04000e-01	5.50000e+06	1.91000e+01		
1.80000e+06	5.32000e-01	5.60000e+06	1.89000e+01		
1.85000e+06	5.60000e-01	5.70000e+06	1.86000e+01		
1.90000e+06	5.87000e-01	6.00000e+06	1.79000e+01		

ENERGY INTERPOLATION TABLE
NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
1.00000e+04	1.40000e+07	5

$\bar{\mu}$, Average Cosine of Elastic Scattering
(Laboratory System)

ENERGY	$\bar{\mu}$
1.00000e-04	6.72700e-02
5.00000e+05	6.72700e-02
1.00000e+06	1.48560e-01
2.00000e+06	1.71440e-01
3.00000e+06	1.97010e-01
4.00000e+06	2.42980e-01
5.00000e+06	2.99700e-01
6.00000e+06	3.55700e-01
7.00000e+06	4.37470e-01
8.00000e+06	5.01910e-01
9.00000e+06	5.55650e-01
1.00000e+07	5.97770e-01
1.10000e+07	6.32120e-01
1.40000e+07	7.17280e-01

ENERGY INTERPOLATION TABLE
NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
1.00000e-04	1.40000e+07	2

Elastic Secondary Angular Distributions

LEGENDRE COEFFICIENT REPRESENTATION

DATA GIVEN IN C SYSTEM

10 X 10 TRANSFORMATION MATRIX GIVEN

NUMBER OF ENERGY POINTS= 14

ENERGY	F1	F2	F3	F4
0	0	0	0	0
5.000000E+05	0	0	0	0
1.000000E+06	8.400000E-02	3.300000E-02	0	0
2.000000E+06	1.120000E-01	1.080000E-01	1.000000E-02	5.000000E-03
3.000000E+06	1.420000E-01	1.740000E-01	3.600000E-02	1.500000E-02
4.000000E+06	1.910000E-01	2.180000E-01	7.200000E-02	3.000000E-02
5.000000E+06	2.500000E-01	2.500000E-01	1.090000E-01	4.500000E-02
6.000000E+06	3.080000E-01	2.780000E-01	1.470000E-01	6.500000E-02
7.000000E+06	3.930000E-01	3.220000E-01	1.850000E-01	8.300000E-02
8.000000E+06	4.600000E-01	3.570000E-01	2.170000E-01	1.030000E-01
9.000000E+06	5.160000E-01	3.880000E-01	2.440000E-01	1.210000E-01
1.000000E+07	5.600000E-01	4.140000E-01	2.660000E-01	1.380000E-01
1.100000E+07	5.960000E-01	4.370000E-01	2.840000E-01	1.540000E-01
1.400000E+07	6.850000E-01	4.910000E-01	3.380000E-01	1.910000E-01

ENERGY	F5	F6	F7	F8
0	0	0	0	0
5.000000E+05	0	0	0	0
1.000000E+06	0	0	0	0
2.000000E+06	0	0	0	0
3.000000E+06	1.000000E-03	0	0	0
4.000000E+06	2.000000E-03	0	0	-1.000000E-03
5.000000E+06	4.000000E-03	0	-1.000000E-03	-2.000000E-03
6.000000E+06	9.000000E-03	1.000000E-03	0	0
7.000000E+06	1.300000E-02	1.000000E-03	-2.000000E-03	-3.000000E-03
8.000000E+06	2.100000E-02	2.000000E-03	-2.000000E-03	-4.000000E-03
9.000000E+06	2.900000E-02	5.000000E-03	-3.000000E-03	-5.000000E-03
1.000000E+07	3.900000E-02	7.000000E-03	-3.000000E-03	-6.000000E-03
1.100000E+07	5.000000E-02	1.100000E-02	-3.000000E-03	-7.000000E-03
1.400000E+07	7.800000E-02	3.000000E-02	7.000000E-03	-7.000000E-03

ENERGY INTERPOLATION TABLE

NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
0	1.400000E+07	2

Inelastic Secondary Energy Distributions

DISCRETE ENERGY LOSS
THETA= 7.17000e+05
NUMBER OF POINTS= 4

ENERGY	P(E)
1.25000e+06	1.00000e+00
4.50000e+06	1.00000e+00
4.50000e+06	0
1.40000e+07	0

ENERGY INTERPOLATION TABLE
NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
1.25000e+06	1.40000e+07	2

Inelastic Secondary Energy Distributions

MAXWELLIAN DISTRIBUTION THETA = THETA(E)

NUMBER OF POINTS= 4

ENERGY	P(E)
1.25000e+06	0
4.50000e+06	0
4.50000e+06	1.00000e+00
1.40000e+07	1.00000e+00

ENERGY INTERPOLATION TABLE

NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
1.25000e+06	1.40000e+07	2

NUMBER OF POINTS= 2

ENERGY	THETA(E)
4.50000e+06	2.06000e+06
1.40000e+07	3.64000e+06

ENERGY INTERPOLATION TABLE

NUMBER OF INTERPOLATION REGIONS= 1

LOWER ENERGY	UPPER ENERGY	INTERPOLATION
4.50000e+06	1.40000e+07	5

APPENDIX B. PLOTTED DATA

This appendix presents graphs of ^{10}B cross-section data as follows:

<u>Cross Section</u>	<u>Page No.</u>
Total	31
Elastic	32
Nonelastic	33
Inelastic	34
Absorption	35
n,d	36
n,T	37
n, α	38

Legendre coefficients are also plotted as follows:

<u>Legendre Coefficient</u>	<u>Page No.</u>
f_1	39
f_2	40
f_3	41
f_4	42

BORON-10 TOTAL

ORNL-DWG 67-10327

BORON-10 ELASTIC

ORNL-DWG 67-10328

BORON-10 NONELASTIC

ORNL-DWG 67-10325

BORON-10 ABSORPTION

ORNL-DWG 67-10326

BORON-10 (N α ALPHA)

ORNL-DWG 67-10329

ORNL-DWG 67-10333

ORNL-DWG 67-10334
BORON-10 F4

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