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INDC/NEANDC Nuclear Standards File, 1978 Version

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NUCLEAR STANDARDS FILE, 1978 Version

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* A. Michaudon

PREFACE

The objective is a contemporary Nuclear-Standard-Reference-Data File under the auspices of the International Nuclear Data Committee's (INDC) Subcommittee on Standard Reference Data. This file is correlated with the parallel effort under the auspices of the NEA Nuclear Data Committee (NEANDC). The file consists of status components and forms a basis for the review and improvement of this key nuclear-standard information in an international scope. Numerical tabulations are given, but the "file" is not an explicit numerical reference file. The insert-notebook format is chosen to encourage upgrading while at the same time retaining the continuity of a formal status file. From time to time additions and/or deletions will be made as warranted by new information.

The subsequent sections consist of reviews undertaken under the auspices of the INDC. In addition, remarks may be appended to the respective titles by the Subcommittee Chairman and/or Executive Secretary as warranted; e.g. by new information. The Chairman welcomes concise remarks relative to the file content. The file will be revised as new primary contributions become available, nominally at nine month intervals consistent with NEANDC-INDC meeting schedule. All primary contributions will not be edited for more than style.

The status of standard quantities is best assessed relative to a generally accepted reference guideline. Such a guideline is provided by the ENDF/B evaluated standard file. That file is available on a world-wide basis via the 4-Center network. In order to make comparisons with the ENDF/B guidelines more convenient, sections of the present document contain numerical values taken from the respective ENDF/B file sections. These values are from

ENDF/B Version V. Where available in easily readable form at the time of distribution, numerical uncertainty estimates are included. In addition, brief comments documenting the ENDF/B file and the numerical formats are given where available. It is hoped that the quality of these ENDF/B numerical files will be critically assessed and that new measurements will be stimulated generally leading to file improvement. A feedback mechanism for incorporating review comments and new results in future file revisions has been set up with the objective of a steadily improving standard file usable on a world-wide basis.

A. B. Smith: Subcommittee Chairman

W. P. Poenitz: Subcommittee Executive Secretary

9/79

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[a]Observer

*As active at the 10th INDC Meeting.

NEANDC-Subcommittee Chrm., F. Perey NEA

INDC REFERENCE-DATA-TYPE AND REVIEW RESPONSIBILITIES (1978)

	Reference-Data-Type	Responsibility	
		National	Current Personnel
I.	H(n;n)H	U. K.	C. Uttley
II.	^{6}Li(n;t)^{4}He	U. S.	A. Smith/H. Motz
III.	^{10}B(n;α)^{7}Li	CEE	E. Wattecamps
IV.	C(n;n)C	U. S.	A. Smith
V.	^{197}Au(n;γ)^{198}Au	U. S.	A. Smith
VI.	^{235}U(σ_f)	USSR	B. Kuzminov
VII.	^{252}Cf Fission Spec	USSR	B. Kuzminov
VIII.	$\bar{\nu}$ of ^{252}Cf	IAEA	H. Lemmel
IX.	$\tau_{1/2}$; ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu	IAEA	A. Lorenz
X.	Thermal Constants: ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu	IAEA	H. Lemmel
XI.	γ-ray Standards	France	A. Michaudon/J. Legrand
XII.	X-ray Standards	France/CEE	J. Legrand/B. Rose
XIII.	Neutron Flux Methods	France	A. Michaudon/G. Grenier
XIV.	Neutron Energy Standards	U. K.	D. James
XV.	^{27}Al(n;α)	IAEA	J. Schmidt/H. Vonach
XVI.	^{237}Np(σ_f)	IAEA	J. Schmidt
XVII.	Standard Fission-foils and Fission tranfer Instruments	U. K./U. S.	A. Ferguson/A. Smith

I. THE H(n,n)H CROSS SECTION

The cross section is used as a standard-neutron-scattering cross section relative to which other elastic cross sections are measured in the MeV region. It is also the primary cross section for neutron flux measurements above about 0.5 MeV and is used for this purpose in several ways which tegether require a knowledge of the angular distribution in both hemispheres. Detecting proton recoils from hydrogeneous radiators involves the cross section at backward angles, while a common method of measuring the relative response of organic scintillators to neutron energy is to scatter an incident monoenergetic neutron beam from hydrogeneous samples.

In the case of organic scintillators frequent use is also made of computer codes for calculating the neutron detection efficiency for different thresholds as a function of energy and in these calculations the differential scattering cross section is needed as input data.

A. Status

Until recently frequent use was made of the simple prescription by Gammel in which the angular distribution of scattering is symmetrical about 90°. The parameterization of all relevant n-p and p-p data in terms of phase shifts by Hopkins and Breit (Nuclear Data Tables A9, 137 (1971)) indicates a degree of anisotropy and asymmetry about 90° in n-p scattering, even below 10 MeV, which is important in practical application. Recent angular-distribution data confirm the Hopkins and Breit calculations and the recommendation is that the evaluation based on these calculations by Stewart, LeBauve and Young (LA-4574) below 20 MeV should be adopted. This status report is concerned with recent developments in the total and differential n-p scattering cross sections below 30 MeV.

B. Accuracy of the Total Cross Section

A more detailed tabulation of the recommended Hopkins and Breit calculations is given in the Los Alamos report LA-4574. The estimated standard deviation in the total cross section is ±1% and is in agreement with the measurement of Davis and Barschall (Phys. Rev. C3, 1978 (1971)) between 1.5 MeV and 27.5 MeV. A recent evaluation of the effective range parameters Lomon and Wilson (Phys. Rev., C9, 1329 (1974)) gives total cross sections which do not differ significantly from the Hopkins and Breit values in the MeV region. A recent measurement of σ_T at 132 eV by Dilg (Phys. Rev., C11, 103 (1975)) results in effective range parameters which disagree significantly with the evaluation of Lomon and Wilson, but a measurement at 24 keV by Fujita et al. (NEANDC(J)-42L) agrees with the cross section based on the evaluated parameters. These disagreements of a fraction of a percent in the low energy total cross section are unlikely to materially affect the recommended values in the region of practical interest.

C. Accuracy of the Differential Scattering Cross Section

Until recently few measurements of the differential n-p scattering cross section have been made over an adequate angular range below 30 MeV with which to test the analysis of Hopkins and Breit. Their analysis was based on energy dependent phase shift analyses by the Yale (Phys. Rev., 165, 1579 (1968)) and Livermore (Phys. Rev., 182, 1714 (1969)) Groups. The agreement between the two analyses as represented by Hopkins and Breit up to 30 MeV is better than 2% for $\sigma(0)$ and with 1% for $\sigma(180)$. The values of $\sigma(180) - \sigma(0)$ from 1 to 30 MeV vary by as much as 22%, however, and indicate the uncertainty in the p-wave phases, particularly $\delta(^1P_1)$, which determine the asymmetry in scattering at low energies. The uncertainty on $\delta(^1P_1)$ and its energy dependence has been stressed recently by Binstock (Phys. Rev., 10C, 10 (1974)) and by Voignier (Saclay Report CEA-R-4632 (1974)).

A single energy phase shift anlaysis of nucleon-nucleon scattering data near 50 MeV by Bryan and Binstock (Phys. Rev., 10D, (1974)) illustrates the sensitivity of the value of $\delta(^1P_1)$ to the differential n-p scattering data included in the analysis. They point out the need for new and more precise differential n-p scattering data both at 50 MeV and in the energy range 20-30 MeV, especially at forward angles, so that better comparison can be made with model predictions of $\delta(^1P_1)$.

The relative differential cross section data at 24 MeV by Rothenberg (Phys. Rev., C1, 1226 (1970)) and by Burrows (Phys. Rev., C7, 1306 (1973)) over the (C of M) angular ranges 89° to 164° and 71° to 158°, respectively, have been normalized to the total cross section recommended by Hopkins and Breit. When these data are included with those of Masterson (Phys. Rev., C6, 690 (1972)), who measured the absolute cross section at 39° and 50.5° at the same energy, they agree closely with the Yale phase parameterization.

Recent n-p polarization data at 21.1 MeV by Morris et al. (Phys. Rev., C9, 924 (1974)) and by Jones and Brooks (Nucl. Phys., A222, 79 (1974)) have been included with the Wisconsin data of Rothenberg, Burrows and Masterson in a phase shift analysis of nucleon-nucleon scattering data in the energy range 20-30 MeV by Bohannon et al. (Phys. Rev., C13, 1816 (1976)). The relative differential scattering data at 25.8 MeV by Montgomery et al. (Phys. Rev., C16, 499 (1977)) over a (C of M) angular range 20° to almost 180° has also been included in a phase shift analysis by Arndt et al. (Phys. Rev., C15, 1002 (1977)). In this work both a single energy analysis of data between 20 and 30 MeV has been carried out and an energy dependent analysis of all data between 0 and 425 MeV. The phase parameters obtained from the two recent analyses by Bohannon et al. and Arndt et al. at 25 MeV are in agreement but the large uncertainties on the values of $\delta(^1P_1)$ of $-5.18 \pm 0.47°$ (Bohannon) and $-4.49 \pm 0.94°$ (Arndt) indicate that more differential-scattering data are needed over a wide angular range. These recent values of $\delta(^1P_1)$ are also in reasonable agreement with those of $-4.90 \pm 0.48°$ and $-4.61 \pm 0.08°$ obtained from the Yale and Livermore (constrained) analyses, respectively, on which the Hopkins and Breit analysis is based.

New data on the 180° cross section for n-p scattering between 23 and 29 MeV were reported by Drosg (Conf. on the Interaction of Neutrons with Nuclei, Univ. of Lowell, July 1976) who measured values $(5.7 \pm 3.3)\%$ lower than those calculated from the recommended Yale phase shifts. However, recent measurements by Drosg have not confirmed these low values. These results have an important bearing on the accuracy of neutron flux measurements using proton recoil counter telescopes.

D. New Measurements

The measurement at Harwell of the angular distribution for n-p scattering at 27.3 MeV over the C of M range 34° to 116° has been completed. In this experiment the scattered neutrons were detected and the data have been normalized to those of Burrows at the same energy in which the angular distribution between 71° and 158° was measured by detecting recoil protons. The relative cross section $\sigma(\theta_c)/\sigma(\pi/2)$ has been compared with the predictions from the phase shift analyses of Bohannon et al., Arndt et al. and the Livermore (constrained) phase shift set. In addition a comparison is made with the parameterization of Binstock (Phys. Rev., 10C, 19 (1974)) based on phases calculated from the Bryan-Gersten one-boson-exchange model. The data favour the asymmetry in scattering expected from the phase shift analyses rather than the model calculation, which predicts a smaller value of $\delta(^1P_1)$ and therefore greater asymmetry about $\pi/2$.

The n-p analyzing - power data at 16.9 MeV recently reported by Tornow et al. (Phys. Rev. Lett., 39, 915 (1977)) appear to have a much higher accuracy than earlier measurements involving the scattering of polarized neutrons below 30 MeV. In particular the analyzing power at large angles in the C of M is shown to be significantly smaller than the predictions from the Yale, Livermore and Arndt phase shift analyses. The data at large angles are sensitive to the f-wave contribution to the n-p interaction and imply an appreciable change in at least one of the triplet-f phases at low energies from those determined from phase shift anlayses or meson-exchange models.

E. Comments and Recommendations

The most recent relative cross section data over a wide angular range in the C of M are in agreement with the calculations of Hopkins and Breit based on the Yale and Livermore (constrained) phases. The angular distribution predicted by the phase shift analysis of data between 20 and 30 MeV by Bohannon et al. are close to those calculated from the Yale phase parameters. The 180° cross sections in mb/sr predicted at 27 MeV are 31.27 (Yale), 31.16 (Livermore), 31.68 (Bohannon) and 31.16 (Arndt). However if the discrepancies noted by Tornow et al. between experimental and predicted n-p analyzing-power measurements are confirmed, some changes in the n-p scattering cross section at extreme forward and backward angles will occur.

C. A. Uttley
Nuclear Physics Division
Building 477
AERE, Harwell
6/79

GUIDELINE NUMERICAL FILE

The following tables are reproduced from the ENDF/B-V standard file. They define the angle-integrated H(n;n) elastic scattering cross sections, the relative elastic-scattering differential distributions in the center-of-mass system and associated uncertainties. The differential distributions have been converted from the point values of the File to Legendre expansions in an effort to make them more readily usable as a reference standard. The elastic scattering cross sections are based upon the theoretical analysis of Hopkins and Breit (Nucl. Data, A9, 137 (1971) and as further described in LA-7899-MS). The more complete documentation of these numerical files is generally set forth in the Brookhaven National Lab. Report BNL-NCS-50464 (Ed. B. Magurno) available from the National Nuclear Data Center and the subsequent ENDF-V documentation (to be published). The recommended range of applicability is 2 keV to 20 MeV.

H-1(NN) TØTAL CRØSS SECTIØNS

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
1.0	20,3290	2.0	20.1980	3,0	20.0680	4,0	19.9410
5,0	19,8150	6.0	19,6910	8,0	19,4430	10,0	19,2130
15,0	18,6510	20,0	18,1260	25,0	17,6340	30,0	17.1720
35,0	16,7370	40,0	16,3270	45,0	15,9410	50,0	15,5750
55,0	15,2280	60,0	14,9000	65,0	14,5870	70,0	14,2910
75,0	14,0080	80,0	13,7380	85,0	13,4810	90,0	13.2350
95,0	12,9990	100,0	12,7740	110,0	12,3510	120,0	11,9640
130,0	11,6070	140,0	11.2750	150,0	10,9650	160,0	10,6730
170,0	10,3960	180,0	10,1400	190,0	9,8980	200,0	9,6710
220,0	9,2580	240,0	8,8920	260,0	8,5620	280,0	8,2620
300,0	7,9870	320,0	7,7340	340,0	7,5010	360,0	7,2840
380,0	7,0830	400,0	6,8970	420,0	6,7250	440,0	6,5650
460,0	6,4150	480,0	6,2750	500,0	6,1430	550,0	5,8450
600,0	5,5840	650,0	5,3540	700,0	5,1480	750,0	4,9640
800,0	4,7970	850,0	4,6450	900,0	4,5060	950,0	4,3780
1000,0	4,2610	1100,0	4,0510	1200,0	3,8680	1300,0	3,7060
1400,0	3,5610	1500,0	3,4290	1600,0	3,3090	1700,0	3,1980
1800,0	3,0970	1900,0	3,0030	2000,0	2,9150	2200,0	2,7590
2400,0	2,6220	2600,0	2,5010	2800,0	2,3920	3000,0	2,2930
3200,0	2,2030	3400,0	2,1200	3600,0	2,0430	3800,0	1,9730
4000,0	1,9070	4200,0	1,8450	4400,0	1,7880	4600,0	1,7340
4800,0	1,6830	5000,0	1,6350	5200,0	1,5890	5400,0	1,5470
5600,0	1,5060	5800,0	1,4670	6000,0	1,4300	6200,0	1,3950
6400,0	1,3620	6600,0	1,3290	6800,0	1,2990	7000,0	1,2690
7500,0	1,2010	8000,0	1,1390	8500,0	1,0830	9000,0	1,0320
9500,0	,9859	10000,0	,9432	10500,0	,9035	11000,0	,8665
11500,0	,8323	12000,0	,8005	12500,0	,7710	13000,0	,7433
13500,0	,7173	14000,0	,6929	14500,0	,6698	15000,0	,6480
15500,0	,6274	16000,0	,6078	16500,0	,5893	17000,0	,5717
17500,0	,5549	18000,0	,5390	18500,0	,5238	19000,0	,5093
19500,0	,4955	20000,0	,4823	,0	,0000	,0	,0000

H-1(NN) RELATIVE ELASTIC SCATTERING ANGULAR DISTRIBUTIØNS,
EXPRESSED IN FØRM (1+SUM(C*P)) WHERE C IS THE I-TH CØNSTANT
AND P THE I-TH LEGENDRE PLØYNØMIAL, VALUES IN CENTER-ØF-
MASS SYSTEM, FØRMAT(7E10,4),E(MEV),C-1,C-2,C-3,C-4,C-5 AND C-6,

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,1000E 00 ,0000E 00
,5000E 00-,2409E-02 ,5819E-04
,1000E 01-,4418E-02-,1179E-06
,2000E 01-,7873E-02-,1012E-03
,4000E 01-,1383E-01-,3539E-03
,6000E 01-,1899E-01 ,3649E-03-,5981E-03 ,2795E-04
,8000E 01-,2342E-01 ,7230E-03-,1234E-02 ,3530E-03
,1000E 02-,2784E-01 ,3954E-02-,2189E-02 ,5618E-03
,1200E 02-,3241E-01 ,7820E-02-,3543E-02 ,1329E-02
,1400E 02-,3590E-01 ,1285E-01-,4431E-02 ,1872E-02-,9613E-03 ,4032E-03
,1600E 02-,3854E-01 ,1895E-01-,5936E-02 ,3075E-02-,1509E-02 ,6216E-03
,1800E 02-,4042E-01 ,2638E-01-,7158E-02 ,4466E-02-,2397E-02 ,9664E-03
,2000E 02-,4160E-01 ,3492E-01-,8503E-02 ,6347E-02-,3234E-02 ,1570E-02
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II. STATUS OF THE ^{6}Li(n,α)t CROSS SECTION

A. Status

The status of the ^{6}Li(n,α)t cross section is summarized by the relevant portions of the ENDF/B-V and documentation, prepared by G. Hale, L. Stewart and P. Young, as follows:

The previous evaluation for ^{6}Li was extensively revised for Version V of ENDF/B. All major cross-section files except radiative capture were updated. A new R-matrix analysis including recent experimental results was performed up to a neutron energy of 1 MeV, which includes the standards region for the ^{6}Li(n,t)^{4}He reaction. Extensive revisions were made in the MeV region to include a more precise representation of the (n,n'd) reaction.

B. Standards Data

The ^{6}Li(n,α) cross section is regarded as a standard below E_n=100 keV. The Version V cross sections for ^{6}Li below 1 MeV were obtained from multi-channel, multilevel R-matrix analyses of reactions in the ^{7}Li system, similar to those from which the Version IV evaluation were taken. New data have become available since Version IV was released and most of this new experimental information has been incorporated into the Version V analysis.

For Version IV, the ^{6}Li(n,α) cross section was determined mainly by fitting the Harwell total cross section (Ref. 3 below), since this was presumably the most accurately known data included in the analysis. However, in addition to the Harwell total, the data base for the analysis included the shapes of the n-^{6}Li elastic angular distributions and polarizations, ^{6}Li(n,α)T angular distributions and integrated cross sections (normalized), and t-α elastic angular distributions.

Since the time of the Version IV analysis, new data have become available whose precision equals or betters that of the Harwell total cross section. The present analysis includes the following new measurements while retaining most of the data from the previous analysis:

Measurement	References	Approximate Precision
n-^{6}Li σ_T	Harvey, ORNL[4]	0.5-1%
^{6}Li(n,α) integrated cross section	Lamaze, NBS[21]	1-2% (relative)
^{4}He(t,t)^{4}He differential cross section	Jarmie, LASL[35]	0.4-1%
^{4}He($\vec{t}$,t)^{4}He analyzing power	Hardekopf, LASL[36]	1%

Fits to the (n,α) data included in the Version V analysis are shown in Figs. 1 and 2. In Fig. 1, the data are plotted as $\sigma\cdot\sqrt{E_n}$; in both figures, the Version IV evaluation is represented by the dashed curves. The good agreement with Lamaze's new ^{6}Li(n,α) integrated cross section measurement[21] is particularly encouraging, since these are close to the values most consistent with the accurate new t + α measurements.[35,36] On the other hand, a shape difference persists between the fit and measurements of the total cross section in the region of the precursor dip and at the peak of the 245-keV resonance. However, we feel that including these precise new data in the analysis has reduced the uncertainty of the new ^{6}Li(n,α) cross section significantly (to the order of 3%) over that of previous evaluations in the region of the resonance.

References explicitly related to the standard (n,α) reaction and, more generally, to the full evaluation of the n + ^{6}Li process are:

1. G. M. Hale, L. Stewart, and P. G. Young, LA-6518-MS (1976).

2. G. M. Hale, Proc. Internat. Specialists Symposium on Neutron Standards and Applications, Gaithersburg (1977).

3. K. M. Diment and C. A. Uittley, AERF-PR/NP 15 and AERE-PR/NP 16 (1969). Also private communication to L. Stewart.

4. J. A. Harvey and N. W. Hill, Proc. Conf. on Nuclear Cross Sections and Technology, 1, 244 (1975).

5. H. H. Knitter, C. Budtz-Jorgensen, M. Mailly, and R. Vogt, CBNM-VG (1976).

6. C. A. Goulding and P. Stoler, EANDC(US)-176U, 161 (1972).

7. D. G. Foster and D. W. Glasgow, Phys. Rev., C3, 576 (1971).

8. A. Bratenahl, J. M. Peterson, and J. P. Stoering, Phys. Rev., 110, 927 (1958), J. M. Peterson, A. Bratenahl, and J. P. Stoering, Phys. Rev., 120, 521 (1960).

9. R. O. Lane, Ann. Phys., 12, 135 (1961).

10. H. H. Knitter and A. M. Coppola, FANDC(E)-57U (1967). Also Ref. 5 above.

11. D. S. Mather and L. F. Pain, AWRE-O-47/69 (1969).

12. V. J. Ashby et al., Phys. Rev., 129, 1771 (1963).

13. J. C. Hopkins, D. M. Drake, and H. Condé, Nucl. Phys., A107, 139 (1968), and J. C. Hopkins, D. M. Drake, and H. Condé, LA-3765 (1967).

14. J. A. Cookson and D. Dandy, Nucl. Phys., A91, 273 (1967).

15. E. T. Jurney, LASL, private communication (1973).

16. E. D. Pendlebury, AWRE-O-60/64 (1964).

17. R. Bass, C. Bindhardt, and K. Kruger, EANDC(E)-57U (1965).

18. G. M. Frye, Phys. Rev., 93, 1086 (1954).