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IAEA-NDS-0015
Rev. 1

ENDF/B-5 STANDARDS DATA LIBRARY

(including modifications made in 1986)

SUMMARY OF CONTENTS AND DOCUMENTATION

Abstract

This document summarizes the contents and documentation of the ENDF/B-5 Standards Data Library (EN5-ST) released in September 1979. The library contains complete evaluations for all significant neutron reactions in the energy range 10-5eV to 20 MeV for H-l, He-3, Li-6, B-10, C-12, Au-197 and U-235 isotopes. In 1986 the files for C-12, Au-191 and U-235 were slightly modified. The entire library or selective retrievals from it can be obtained free of charge from the IAEA Nuclear Data Section.

N. DayDay, H.D. Lemmel

October 1980

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Revised by P.K.McLaughlin IAEA/NDS Jan. 2005

The file was revised to conform with ENDF/B format standards.. The merged file was corrected for format errors and processed through the code CHECKR to ensure, as far as possible, format compatibility.

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<u>Note</u>:

The IAEA-NDS-reports should not be considered as formal publications. When a nuclear data library is sent out by the IAEA Nuclear Data Section, it will be accompanied by an IAEA-NDS-report which should give the data user all necessary documentation on contents, format and origin of the data library.

IAEA-NDS-reports are updated whenever there is additional information of relevance to the users of the data library.

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Neither the originator of the data libraries nor the IAEA assume any liability for their correctness or for any damages resulting from their use.

96/11

Citation guidelines:

ENDF/8-5 Standards Data Library

See also: IAEA Technical Report No.227, Nuclear Data Standards for Nuclear Data Measurements, the 1982 INDC/NEANDC Nuclear Standards File. Specific reactions in specific energy ranges of the ENDF/8-5 Standards Library are internationally recommended standards.

Contents of this document

Page

CONTENTS OF THIS LIBRARY

The ENDF/8-5 Standards Data Library was released in September 1979 by the National Nuclear Data Centre {NNDC) at the 8rookhaven National Laboratory, USA. In 1986 some modifications were received. The Library contains complete evaluations for all significant neutron reactions in the energy range 10-5eV to 20 KeV for H-l, He-3, Li-6, 8-10, C-12, Au-197 and U-235 isotopes, see Table 2. Summary documentations for each evaluation are reproduced in the main part of this document.

For the convenience of users the IAEA version of the ENDF/8-5 Standards File also includes data for Al-27, Fe, U-238 as extracted from the ENDF/8-5 Dosimetry File, version 2 of 1984.

In 1986 some modifications were made for C-12, Au-197, U-235. A computer-produced listing of the differences between the previous version and the modified version of the files is contained in document IAEA-NDS-65.

The entire library contains 22.925 records.

FORMAT

The data format of ENDF/B-V is mainly the same as ENDF/B-IV. A summary of the format differences between versions IV and V is given in the Appendix.

A complete description of the ENDF/B-V format is given in the following report:

R. Kinsey: Data formats and procedures for the evaluated nuclear data file ENDF, BNL-NCS-5O496 (ENDF-lO2), 2nd edition, dated October 1979, issued October 1980.

For quick reference of the ENDF/B format (File numbers and Reaction Type Numbers of the most important data types) see the document IAEA-NDS-l0

TABLE I

SYMBOLS FOR QUANTITIES USED IN TABLE II

A	Angular distribution
E	Energy spectra
GAMMA	Parameter derived in the slowing-down theory of Greuling-Goertzel
I	Integral cross section
KSI	Average logarithmic energy change per collision
K	Photon multiplicities (induced by neutrons)
KU-BAR	Average cosine of the scattering angle of elastically scattered neutrons in the Lab-system
NU-BAR	Average number of neutrons per fission
(N,A)	(n, a) cross section
(N,AO)	(n, a_1) cross section for lst excited state
(N,N3A)	(n, n'3a) cross section
(N,T2A)	(n, t2a) cross section
(N,Al/G)	(n, al/γ) cross section
(N,D)	(n, d) cross section
(N,G)	(n, γ) radiative capture cross section
(N,2N)	(n, 2n) cross section (isomeric state cross section)
(N,3N)	(n, 3n) cross section
(N,NF)	(n, n'f) cross section (second chance fission)
(N,2NF)	(n,2nf) cross section (third chance fission)
(N,NG)	(n, n')y cross section
(N,NP)	(n, n')p cross section
(N,2N)ALPHA	(n, 2n)a cross section
(N,P)	(n, p) cross section
(N,T)	(n, t) cross section
PA	Photon angular distribution (neutron induced)
PE	Photon energy distribution (neutron induced)
PP	Photon production cross sections (neutron induced)
RDFPY	Radioactive decay and fission product yield
RNPH	Radioactive nuclide production -multiplicities
RRP	Resolved resonance parameter
URP	Unresolved (statistical) resonance parameter

T	Thermal neutron scattering law.

LABORATORY CODES

BNL	Brookhaven National Laboratory, Upton, N.Y., USA
LASL	Los Alamos scientific Laboratory, New Mexico, USA
ORNL	Oak Ridge National Laboratory, Tennessee, USA

TABLE II

Nuclide, Mat. No. :	1-H-1 (Free atom), 1301
Energy Range (eV) :	1.0E-5 -2.0E+7
Evaluation Lab.. Date:	LASL. August 1970
Main Reference:	L. Stewart. R.J. Labauve, P.G. Young; LA-4574 (1971)
Cross Section Standard:	Scattering cross section from 1 keV to 20 MeV
Comments:	Changes from version IV to version V; 1) Interpolation rules on total and elastic cross sections 2) Covariance matrices added
Quantity (Data type) :	Total (I), Elastic (I,A). (N.G)(I,M.A). MU-BAR KSI. GAMMA, Inelastic (T)
Covariance:	Covariance matrices for total. elastic and (N.G) cross section

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Nuclide. Mat. No. :	2-He-3. 1146
Energy Range (eV) :	1.0E-5 -2.0E+7
Evaluation Lab., Date:	LASL, June 1968
Main Reference:	L. Stewart; unpublished
Cross Section Standard:	(N,P) cross section from thermal to 50 keV
Comments :	Transferred from ENDF/B-III with no modifications
Quantity (Data type) :	Total (I). Elastic (I.A). (N.P)(I). (N.D)(I), MU-BAR, KSI,

GAMMA

Nuclide, Mat. No. : 3-Li-6, 1303
Energy Range (eV) : 1.0E-5 -2.0E+7
Evaluation Lab., Date: LASL, September 1977
Main Reference: G. Hale, L. Stewart, P.G. Young, LA-6518-KS (1976)
Cross Section Standard: (N,T) cross section from thermal to 100 keV
Comments: Changes from version IV;

1) All cross sections revised except for the (N,G)
2) Pseudo-level representation used for the (N,N')D continuum
3) Covariance file added for cross sections below 1 KeV
4) Angular distribution added for the (N,T)
5) Radioactive nuclide files added for the production of He and tritium

Quantity (Data type) : Total (I), Elastic (I,A), Inelastic (I), (N,2N) ALPHA (I,A,E), (N,N')D continuum (I,A), (N,N') D Discrete levels (I,A) , (N,G) (I,K,A) , (,P) (I,RDFPY,RNPK), (N,T)(I,A,RNPM), KU-8AR, KSI, GAMMA
Covariance: Covariance matrices for total, elastic and (N,T) cross section

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Nuclide, Mat. No. : 5-B -10 (Free atom), 1305
Energy Range (eV) : 1.0E-5 -2.0E+7
Evaluation Lab., Date: LASL, December 1976
Main Reference: G. Hale, L. Stewart, P.G. Young, LA-6518-KS (1976)
Cross Section Standard: (N,A) and (N,Al) cross sections from thermal to 100 keV
Comments: Changes from version IV;

1) (N,G) cross section and spectra added
2) Covariance file added for cross sections below 1 KeV
3) All cross sections except (N,P) and (N,T) changed below 1.5 KeV

Quantity (Data type) : Total (I), Elastic (I,A), Inelastic (I), (N,G) (I,K) , (N,P) (I) , (N,D), (N,A) (I) , (N,T2A) (I) , (N,AO) (I) , (N,Al) (I,K) , (N,NG) (I,A) , (N,NP) (I,A) , (N,AIG) (A)

Covariance Relative covariances for total, elastic, (N,A), (N,AO) and (N,Al) cross sections are given below 1 MeV.

Nuclide, Mat. No. : 6-C-12, 1306 Mod. 2
Energy Range (eV) : 1.0E-5 -2.0E+7
Evaluation Lab., Date: ORNL, December 1973
Main Reference: C.Y. Fu, F.G. Perey; unpublished
Cross Section Standard: Elastic scattering angular distribution up to 1.8 MeV
Comments: New evaluation for version V;
1) Total and elastic scattering from thermal to 4.81 MeV
2) Elastic angular distribution; thermal to 4.81 MeV
3) New representation for (N, N3A) to yield correct energy-angular kinematics
4) Activation file for (N,P)
5) Gas production file
6) Uncertainty file
Quantity (Data type) : Total (I), Elastic (I,A), Inelastic (I), Inelastic (I,A), (N,N3A)(I), (N,G)(I,A,M), (N,P)(I), (N,D)(I), Alpha production (I), MU-BAR, KSI, GAMMA, Evaporation Spectrum with T=O.3 MeV, Activation data following (N,P) reaction, (N,P) cross section leading to activation, Production of 4.439 MeV gamma rays
Covariance: Uncertainty files for main cross sections

Note: Minor modifications were made in 1986

Nuclide, Mat. No. : 13-Al-27, 6313

This was not included in the original ENDF/B-5 Standards Library but added by the IAEA Nuclear Data Section as extracted from the ENDF/B-5 Dosimetry Library, version 2 of 1984

Nuclide, Mat. No. : 26-Fe-56, 6431

This was not included in the original ENDF/8-5 Standards Library but added by the IAEA Nuclear Data Section as extracted from the ENDF/8-5 Dosimetry Library, version 2 of 1984

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Nuclide, Mat. No. : 79-Au-197, 1379 Mod.3

Energy Range (eV) : 1.0E-5 -2.0E+7

Evaluation Lab., Date: BNL, February 1977

Main Reference: S.F. Mughabghab; unpublished

Cross Section Standard: (N,G) cross section from 200 keV to 3.5 MeV

Comments: The total, elastic, and gamma production cross sections in the resonance region are background files which must be added to the cross section calculated from the resonance parameters to give the real cross section

Quantity (Data type) : RRP (from 1.0e-5eV to 2 keV), Thermal cross sections (Capture = 98.718, scattering = 6.84 8, total = 105.558, absorption resonance integral = 15598), Total(I), Elastic(I,A), Inelastic(I) , (N,2N) (I,A,E) , (N,3N) (I,A,E) , (N,G) (I) , (N,P) (I) , (N,A) (I)

Notes: Minor modifications were made in 1986

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Nuclide, Mat. No. : 92-U-235, 1395 Mod. 3

Energy Range (eV) : 1.0E-5 -2.0E+7

Evaluation Lab., Date: BNL, April 1977

Main Reference: M.R. Bhat; BNL-NCS-51184 (March 1980)

Cross Section Standard: (N,F) cross section at thermal, and from 100 keV to 20 MeV

Comments: The total, elastic, fission, and gamma production cross sections in the resonance region are background files which must be added to the cross section calculated from the resonance parameters to give t the real cross section

Quantity (Data type) : NU-BAR, Delayed neutron yields, Prompt nu-bar RRP, URP, Total(I), Elastic(I,A), Nonelastic (PP,PA,PE), Inelastic (I,M,PA), Direct (N,2N) (I,A,E,RDFPY), (N,3N)(I,A,E,RDFPY), Fission (I, A , E , M, PA, PE) , (N , F) (I, A, E) , (N , NF) (I, A, E) , (N,2NF)(I,A,E), (N,G) (I,RDFPY,M,PA,PE) KU-BAR, KSI, GAMMA

Covariance: Error files for nu-bar, fission and (N,G) cross sections

Note: Modifications in 1986 include revised data for the energy release in fission and for the covariance matrix

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Nuclide, Mat. No. : 92-U-238, 6398

This was not included in the original ENDF/B-5 Standards Library but added by the IAEA Nuclear Data Section as extracted from the ENDF/B-5 Dosimetry Library, version 2 of 1984.

APPENDIX

The following is a summary of the format differences between Versions IV and V ENDF/B data tapes. ENDF/B Version V was released about June 1979.

File 1

1. The HEAD card of MT=451 has been changed. NXC, the number of dictionary entries, has been moved to the sixth field of the Hollerith LIST record of HT=451. Field 5 now contains NLIB, the library identifier, and Field 6 now contains NMOD, the material modification number.
2. Following the HEAD card of MT=451 is a new CONT card which contains information about the excitation energy, stability, state number, and isomeric state number of the target nucleus.
3. In the LIST record of MT=451, the LDD and LFP flags have been abolished. The number of dictionary entries, NXC, is now in the sixth field of the first card in this LIST record.
4. The fourth field on each dictionary card in MT=451 is now used to indicate the modification status (MOD) for the section described by the card.
5. Radioactive decay data (MT=453 and 457) has been removed from File 1. Entirely new formats have been devised and the radioactive decay data is given in MF=8, MT=457.
6. The fission product yields section (MT=454) has been removed from File 1. Fission product yield information is now given in File 8 using new formats.
7. A new section to describe energy release in fission (MF = 1, MT= 458) has been implemented.

File 2

1. The Reich-Moore resonance parameter representation is no longer permitted in ENDF/B, only in ENDF/A.

File 3

1. Total "gas production" MT's have been defined for H(203) , D(204), T(205), He-3(206), and He-4(207).
2. The non-elastic cross section (MT = 3) is now optional and no longer required since total gamma ray production must be entered in File 13 and never as multiplicities in File 12.

File 4

1. A simplified format using a new flag, LI, has been introduced to indicate that all angular distributions for an MT are all isotropic.

File 5

1. Only the distribution laws given for LF=l, 5, 7, 9, and 11 are now allowed. LF=11 is a new format for an energy dependent Watt spectrum.

File 8

1. Information may be given for any MT specifying a reaction in which the end product is radioactive. The MT section contains information about the end product and how it decays. Files 9 and 10 may be used to give the cross section for the production of the end product.
2. Fission product yield information is given under MT=454 and 459. The format has been modified to include the 1@ uncertainty of the yields. MT=454 is for the independent yields and MT=459 is for the cumulative yields.
3. The spontaneous radioactive decay data is given in MT=457. This is entirely new format.

Files 9 and 10

1. Isomer production is described in the new File 9 or File 10. In File 9 the cross sections are obtained by the use of multiplicities. In File 10, the absolute cross section is given.

Files 17 and 18

1. Format for time dependent photon production data files have been defined. They may be used in ENDF/A only.

Files 19.20.21. and 22

1. The electron production data files have been implemented.

Files 31. 32. and 33

1. The formats for data covariance files first introduced in Version IV have been extensively modified and expanded. They are now included in this document for the first time.

LA-7663 Jan.1979 SUMMARY DOCUMENTATION FOR ^1H

Equals BNL-NCS-17541

ENDF-201 3rd. ed. by

July 1979.

L. Stewart, R. J. -LaBauve, and P. G. Young

Los Alamos Scientific Laboratory

Los Alamos, New Mexico

I. SUMMARY

The ^1H evaluation for ENDF/B-V (MAT 1301) is. basically the same as the Version IV evaluation. Changes include the addition of correlated error data in MF-33 and different interpolation rules for MT-l and 2 in MF-3. The evaluation covers the energy range 10-5 eV to 20 MeV. and documentation is provided in LA-4574 (1971) and LA-6518-MS (1976).

II. S'l'ANDARDS DATA

The $^1H(n, n)^1$ H elastic scattering cross section and angular distribution (MF-3, 4; MT=2) are standards in the energy region 1 keV -20 MeV. The extensive theoretical analysis of fast-neutron measurements by Hopkins and Breit[1] was used to generate the scattering cross section and angular distributions of the neutrons for the ENDF/B-V file.[2] The code and the Yale phase shifts[3] were obtained from Hopkins[4] in order to obtain, the data on a. fine-energy grid. Pointwise angular distributions were produced to improve the precision over that obtained from the published Legendre coefficients.* The phase shifts were also used to extend the energy range down below 200 keV as represented in the original paper[1].

At 100 eV, the elastic cross section calculated from the phase shifts is 20.449 barns, in excellent agreement with the. thermal value of 20.442 derived by Davis and Barschall[5]. Therefore, for the present evaluation, the free-atom scattering cross section is assumed to be constant below 100 eV and equal to the value calculated from the Yale phase shifts at 100 eV giving a thermal cross section of 20.449 b.

'Total cross-section measurements are compared with the evaluation in Fig. 1 for the energy range from 10 eV to 0.5 MeV. Similarly Figs. 2 and 3 compare the evaluation with measured data for 0.5 :0 to20 MeV. The agreement with the earlier experiments shown in Fig, 2 is quite good over the entire energy range. The 1969 data of Schwartz[6] included in Fig. 3, however, lie slightly below the evaluation over most of the energy range even though agreement with the 1972 results of Clement[7] is quite acceptable.

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*For. E_n = 30 MeV. th,e difference in the 150° cross section is –1% as calculated from the Legendre coefficients[3]. compared to that calculated from the phase shifts.

Unfortunately, few absolute values of the angular dependence of the neutrons (or recoil protons) exist and even the relative measurements are often restricted to less than half of the angular range. The experiment of Oda[8] at 3.1 MeV is not atypical of the earlier distributions which, as shown in Fig. 4, does not agree with the phase-shift predictions. Near 14 MeV, the T(d, n) neutron source has been employed in many experiments to determine the angular distributions. A composite of these measurements is compared with ENDF!B-V in Fig. 5A. Note that most of the experiments are in reasonable agreement on a relative scale, but 10% discrepancies frequently appear among the data sets. The measurements of Cambou[9] average more than 5% lower than the predicted curve and differences of 5% or more are occasionally apparent among the data of a single set. Figure 5B shows the measurements of Galonsky[10] at 17.9 MeV compared with the evaluation. Again, the agreement on an absolute basis is quite poor .

Elastic scattering angular distributions at 0.1, 5, 10, 20, and 30 MeV are provided in Ref. 11 as Legendre expansion coefficients. Using the Bopkins-Breit phase-shift program and the Yale phase shifts, additional and intermediate energy points were calculated for the present evaluation.[2] As shown in Figs. 5-16 of Ref. 2, the angular distributions are neither isotropic below 10 MeV nor symmetric about 90° above 10 MeV as assumed in earlier evaluations. In this evaluation, the angular distribution at 100 keV is assumed to be isotropic since the calculated 180°/0° ratio is very nearly unity, that is, 1.0011. At 500 keV this ratio approaches 1.005. Therefore, the pointwise normalized probabilities as a function of the center-of-mass scattering angle are provided at the following energies: 10^{-5} eV (isotropic), 100 keV (isotropic), 500 keV, and at l-MeV intervals from 1 to 20 MeV.

Certainly the Bopkins-Breit phash shifts reproduce reasonably well the measured angular distributions near 14 MeV. It is important, however, that experiments be made at two or three energies which would, hopefully, further corroborate this analysis. Near 14 MeV, the energy-dependent total cross section is presently assumed to be known to -l% and the angular distribution to ~ 2-3%. At lower energies where the angu1ar distributions approach isotropy, the error estimate on the angular distribution is less than l%.

It should be pointed out that errors involved in using hydrogen as a standard depend upon the experimental techniques employed and. therefore may be significantly larger than the errors placed on the standard cross section. The elastic angular distribution measurements of neutrons scattered by hydrogen, which are available today, seem to indicate. that σ(θ) is difficult to measure with the precision ascribed to the reference standard. If this is the case, then the magnitude of the errors in the σ(θ) measurements might be indicative of error assignments which should be made on hydrogen flux monitors. That is, it is difficult to assume that hydrogen scattering can be implemented as a standard with such higher precision than it can be measured.

Even though better agreement with many past measurements can be reached by renormalizing the absolute scales, such action may not always be warranted.

At this time, no attempt has been made to estimate the effect of errors on the energy scale in ENDF/B .It is clear , however, that a small energy shift would produce a large change in the cross section, especially at low energies. For example, a 50-keV shift in energy near 1 MeV would produce a change in the standard cross section of approximately $2^{1/2}$%. Therefore, precise determination of the incident neutron energy and the energy. spread could be very important in employing hydrogen as a cross-section standard, depending upon the experimental technique.

III. ENDF/B-V FILES

File 1. General Information

MT-451. Descriptive data.

File 2. Resonance Parameters

MT-151. Effective scattering radius -1.27565 x 10-12 cm.

Resonance parameters not given.

File 3. Neutron Cross Sections

MT= l. Total Cross Sections

The total cross sections are obtained by adding the elastic scattering and Radiative capture cross sections at all energies, 1.0E-05 eV to 20 MeV

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MT= 2. Elastic Scattering

Standard - see discussion in Sec. II.

MT = 102. Radiative Capture

These cross sections arc taken from the publication or A. Horsley where a value of 332 mb was adopted for the thermal value. See Ref. 51.

MT-251. Average Value of Cosine of Scattering Angle In Lab System from 1.OE-05 eV

to 20 MeV. (Provided by BNL).

MT-252. Average Logarithmic Energy Change, Per Collision, from 1.0E-05 eV to 20 MeV. (Provided by BNL).

MT-253. Gamma, from 1.0E-05 eV ~o 20 MeV. (Provided by BNL:)

File 4. Neutron Angular Distributions

MT-2. Neutron elastic scattering angular distributions in the center of mass system, given as normalized pointwise probabilities. See Sec. II above.

File 7. Thermal Neutron Scattering Law Data

MT-4. 0.00001 to 5 eV free gas sigma = 20.449 barns.

File 12. Gamma Ray Multiplicities

MT=l02. Radiative Capture multiplicities.

Multiplicity is unity at all neutron energies. LP=2 is now implemented; therefore, all gamma energies must be calculated.

File 14. Gamma Ray Angular Distributions
MT = 102. Radiative capture angular distribution

Assumed isotropic at all neutron energies.

File 33. Correlated Errors
MT = l. Covariance matrix derived from MT-2, 102.

MT = 2 Covariance data added for the elastic scattering by D. G. Foster, Jr. (Jan. 77).
MT = 102. Covariance data for radiative capture added by P. G. Young (Nov. 7, 1978).

REFERENCES

1. J. C~ Hopkins and G. Breit, "The H(n, n)H Scattering Observables Required for High Precision Fast-Neutron Measurements," Nuclear Data A 9, 137 (1971) and private communication prior to publication (1970).
2. L. Stewart, R. J. LaBauve, and P. G. Young, "Evaluated Nuclear Data for Hydrogen in the D..ENDF/B-II Format," LA-4574 (1971). Neither the cross sections nor the angular distributions have been changed since Version II except to .add one more significant figure to the total cross section.
3. R. E~ Seaman, K. A. Friedman, G. Breit, R. D. Haracz, J. M. Bolt, and A. Prakash, Phys. Rev. **165**, 1579 (1968).
4. J. C. Hopkins, private communication to L. Stewart: (1970).
5. J. C. Davis and H. H. Barschall, "Adjustment in the n-p Single~ Effective Range," Phys. Lett. **27B**, 636 (1968) .
6. R. B. Schwartz, R. A. Schrack, and H. T. Heaton, "A Search for Structure in the n-p Scattering Cross Section ," Phys. Lett. **30**, 36 (1969) .
7. J. M. Clement, P. Stoler, C. A. Goulding, and R. W. Fairchild, "Hydrogen and Deuterium Total Neutron Cross Sections in the MeV Region," Nucl. Phys. **183**, 51 (1972) .
8. Y. Oda, J. Sanada, and S. Yamabe, "On the Angular Distribution of 3.1-MeV neutrons Scattered by Protons," Phys. Rev. **80**, 469 (1950).
9. F. Cambou, "Amelioratin des Methods de Spectrometrie des Neutrons Rapids," Thesis – U. of Paris, CEA-N-2.002 (1961) .
10. A. Galonsky an.d J. P. Judish, "~..."Angu1ar Distribution of n-p Scattering at 17.9 MeV," Phys. Rev. **100**, l21 (1955).
11. "ENDF/B Summary Documentation," ENDF-201, Compiled by D. Garber, (October 1975).

12. E. Melkonian, "SloT.1 Neutron Velocity Spectrometer Studies of 02. N2. A. H2. H20, and Seven Hydrocarbons." Phys. Rev. **76**. 1950 {1949).

13. D. H. Frisch, "The Total Cross Sections of Carbon and Hydrogen for Neutrons of Energies from 35 to 490 keV," Phys. Rev. **70**. 589 (1946).

14. W. D. Allen and A. T. G. Ferguson. "The n-p Cross Section in the Range 60- 550 keV,"

Proc. Phys. Soc. {London) **68**. 1077 (1955).

15. E. Bretscher and E. B. Martin. “Determination of the Collision Cross-Section of H, Deuterium, C and O for Fast Neutrons," Helv. Phys. Acta **13** 15 (1950).

16. C. E. Eng1eke, R. E. Benenson. E. Melkoniant and J. M. Lebawitz. "Precision Measurements of the n-p Total cross Section at 0.4926 and 3.205 MeV." Phys.Rev. Y.**129**., 324 {1963).

17. C. L. Bailey, w. E. Bennett. T. Bergstralh. R. G. Nucko~s, H. T. Richards. and J. H. Willams ."The Neutron-Proton and Neutron-Carbon Scattering Cross Sections for Fast. Neutrons," Phys. Rev. **70** 583 {1946).

18. E. E. Lampi, G. Frier, and J. H. Williams. "Total Cross Section of Carbon and Hydrogen for Fast. Neutrons," Phys. Rev. **76**.. 188 (1949).

19. W. E. Good and G. Scharff-Goldhaber. "Total Cross Sections for 900-keV Neutrons" Phys. Rev. **59**, 917 (1941).

20. S. Bash kin, B. Petwee, F. P. Mooring, and R. E. Peterson, "Dependence of –Neutron Cross Sections on Mass Number." Phys. Rev.**77**. 748 {1950).

21. R. E. Fields. R. L. Becker. and R. K. Adair. "Measurment. of the Neutron-Proton Cross Section at. 1.0 and 2.5 MeV." Phys. Rev.**94**. 389 (1954).

22. C. L. Storrs and D. H. Frisch. "Scattering of 1.32 MeV neutrons by Protons." -Phys. Rev. **95**, 1252 (1-954) .

23. D.G. Foster, Jr. and D. W. G1asgow "Neutron Total Cross Sections, 2.5-15 MeV, Part 1 (Experimental).” Nuclr. Instr. and ethods **36, 1 (1967)**

24. R. E. Fields, "The Total Neutron-Proton Scattering Cross Section at 2.5 MeV," Phys. Rev.**89**, 908 (1953).

25. G. Ambrosina and A. Sorriaux, "Total Cross Section Efficiency for Carbon, Gluorine and Vanadium, " Comptes Rendus **160**, 3045 (1965) .

26. W. H. Zinn, S. Seely, and V. W. Cohen, "Collision Cross Sections for D-D Neutrons," Phys. Rev. **56**. 260 (1939) .

27. N. Nereson and S. Darden, "Average Neutron Total Cross Sections in the 3- to 12-MeV Region." Phys. Rev. 2, **94**, 1678 (1954) .

28. E. M. Hafner. W. F. Hornyak. C. E. Falk, G. Snow., and T. Coor, "The Total n-p Scattering Cross Section at. 4.75 MeV." Phys. Rev. **89**.. 204 (1953).

29. W.. Sleator, Jr, "Collision Cross Sections of Carbon and Hydrogen for Fast neutrons," Phys. Rev. **72** 207 (1947).
30. A. Bratenah1. J. M. Peterson, and J. P. Stoering. "Neutron Total Cross Sections in the 7- to 14-MeV Region," UCRL-4980 (1957).
31. A. H. Lasday, "Total Neutron Cross Sections of Several Nuclei at 14 MeV," Phys. Rev. **81**, 139 (1951).
32. L. S. Goodman. "Total Cross Sections for 14-MeV Neutrons," Phys. Rev. **88**, 686 (1952).
33. B. L. Poss, E. 0. Salant, and L. C. L. Yuan, Total Cross Sections of Carbon , and Hydrogen for l4-MeV Neutrons," Phys. Rev. **85** 703 (1951) .
34. M. Tanaka., N. Koori, and S. Shirato, "Differential Cross Sect-ions for Neutron-Proton Scatterting at 14.1 MeV," J. Phys. Soc. (Japan) **28**, 11. (1970).
35. M. E. Battat, R. 0. Bonde1id, J. H. Coon, L. Cranberg. R. B. Dayt F. Edeskuty A. H. Frentrop, R. L. Henkel, R. L. Mills, R. A. Noblest ,J. E. Perryt, D. D. Ynillipst T. R. Roberts, and S. G. Sydoriak," Total Neutron Cross Sections of the Hydrogen and He1ium Isotopes," Nuc1. Phys. **12**, 291 (1959).
36. J. C. Allred, A. H. Armstrong, and L. Rosen, "The Interaction -of 14-MeV Neutrons with Protons and Deuterons," Phys. Rev. .**91**, 90 (1953).
37. C. -F. Cook and T. W. Bonner, "Scattering of Fast Neutrons in Light Nuclei,", Phys. Rev **94**, 651 (1954).
38. H. L. Poss, E. 0. Salant, G. A. Snow, and L. C. L. Yuan, "Total Cross Sections for 14-MeV Neutrons, " Phys. Rev.**87**, 11 (1954).
39. P. H. Bowen, J. P. Scan1on, G. B. Stafford. and J. J. Thresher, "Neutron Total. Cross Sections in the Energy Range 15 to l20 MeV," Nucl. Phys. **22**, 640 (1961).
40. J. M. Peterson, A. Bratenah1t and J. P. Stoering, "Neutron Total Cross Sections in the 17- to 29-MeV Range," Phys. Rev. **120**, 521 (1960).
41. D. F. Groce and B. D. Sowerby, "Neutron-Proton Total Cross Sections Near 20, 24, and 28 MeV," Nucl. Phys. **83**, 199 (1966).
42. M. L. West II, C. M. Jones, and H. B. Willard, "Total Neutron Cross Sections of Hydrogen and Carbon in the 20-30 MeV Region," ORNL-3778, 94 (1965).
43. R.. B. Day, R. L. Mills, J. E. Perry, Jr., and F. Schreb, "Total Cross Section for n-p Scattering at 20 MeV," Phys. Rev. **114**, 209 (1959).
44. R. B. Day and R. L. Henke1, "Neutron Total Cross Sections at 20 MeV ," Phys. Rev. **92**, 358 (1953).

45. M. E. Rem1cy, W. K. Jentschke, and P. G. Kruger, "Neutron-Proton Scattering Using Organic Crysca1 Scintillation Detectors,'. Phys. Rev. **89**, 1194 (1953).
46 J. D. Seagrave, "Recoil Deuterons and Disintegration Procons from the n-d Interaction, and n-p Scattering at E_n = 14.1 MeV," Phys. Rev. **97**, 757 (1955).
47. S. Shirato and K. Saitoh, "an The Differential Cross Section for Neutron-Proton Scattering at 14.1 MeV," J. Phys. Soc. (Japan) **36**, 331 (1974).
48. T. Nakamura, 'Angular Distrlbut!on of n-p Scattering at 14.1 MeV,'. J. Pbys. Soc. (Japan) **15**, 1359 (1960).
49. A. Subami and R. Fox, "Neutron-Proton Small Angle Scattering at 14.1 MeV," Pbys. Lett. **24**, 173 (1967).
50. I. Basar, -“E1astic Scattering of 14.4 MeV Neutrons on Hydrogen Isotopes.” Few Body Problems Light. Nuclei/Nucl. Interactions, Brela. 86-7 (1967).
51. A. Horsley, "Neutron Cross Sections of Hydrogen in the Energy Range 0. 0001 eV-20 MeV. " Nucl. Data **A2**, 243 (1966).

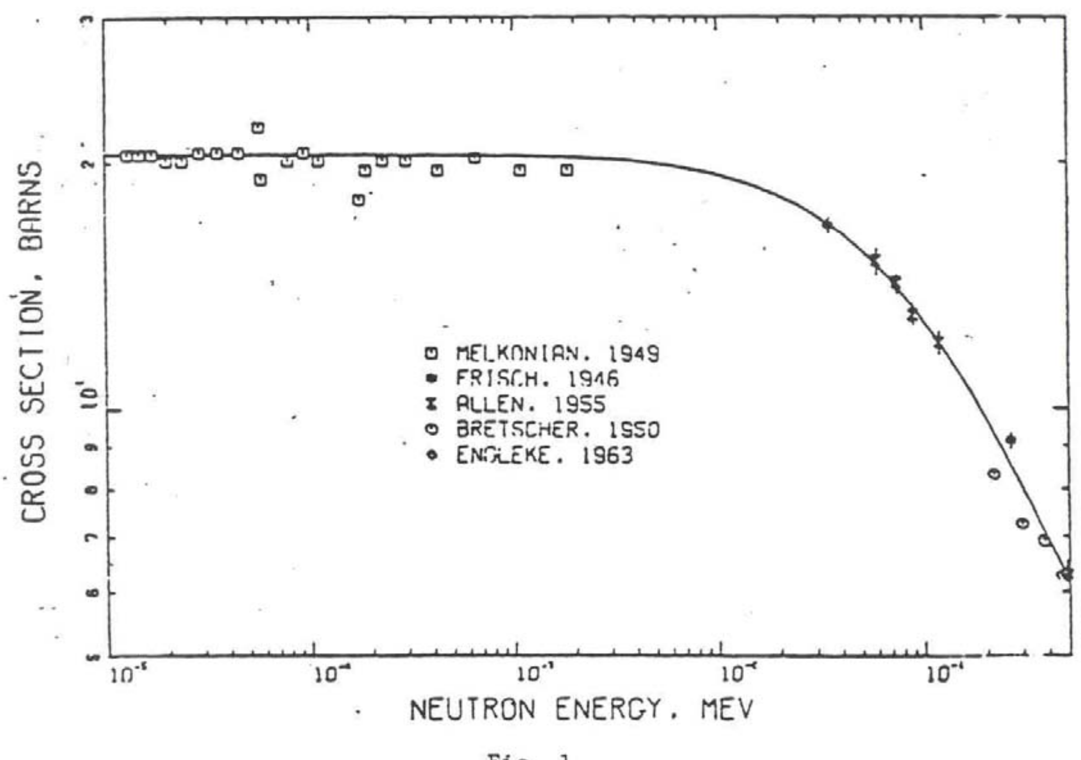

Fig. 1.
Total cross section for hydrogen from 1 x 10^{-5} eV to 500 keV. The ENDF/B-V evaluation is compared to the measurements of Refs. 12-16.

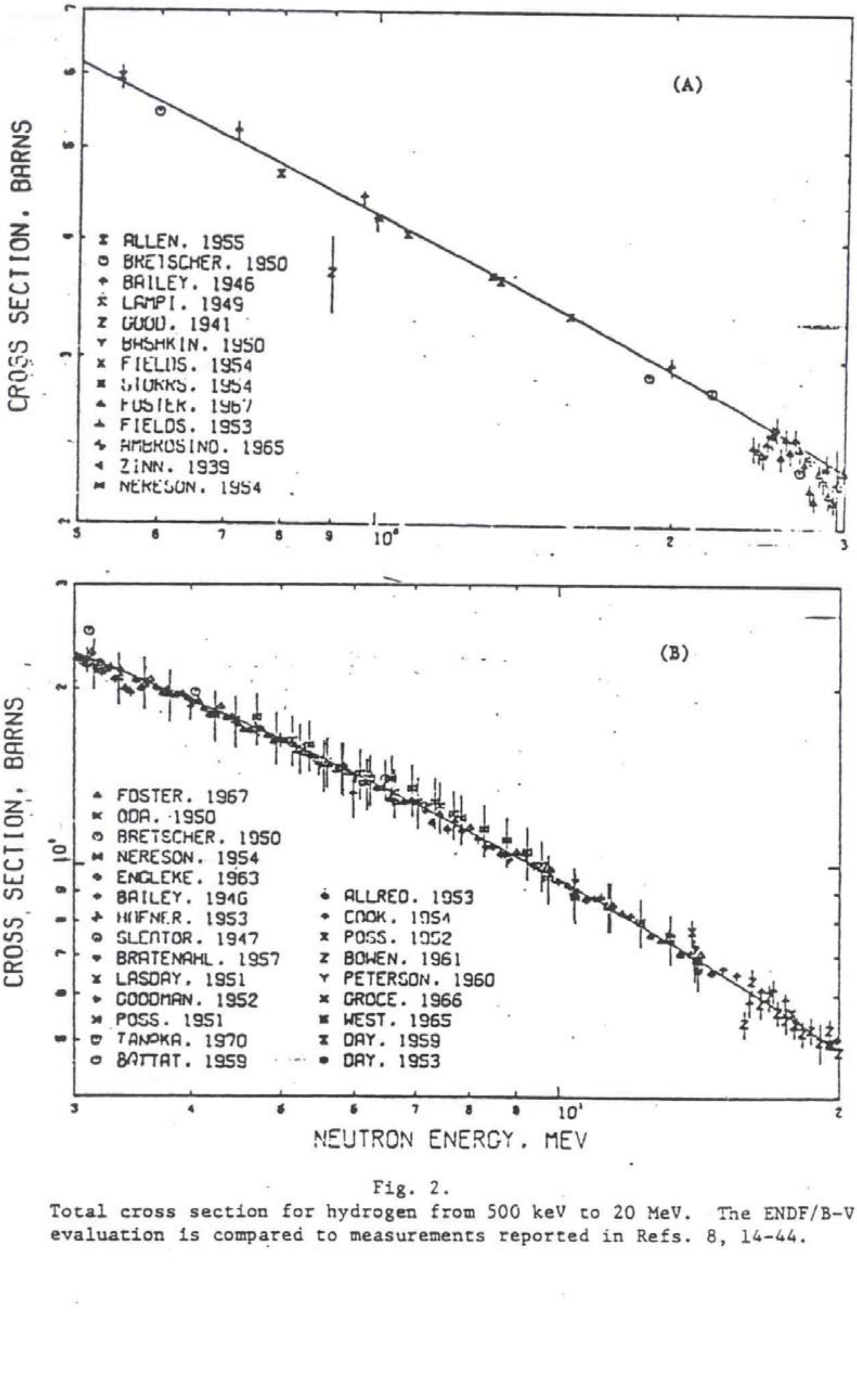

Fig. 2.
Total cross section for hydrogen from 500 keV to 20 MeV. The ENDF/B-V evaluation is compared to measurements reported in Refs. 8, 14-44.

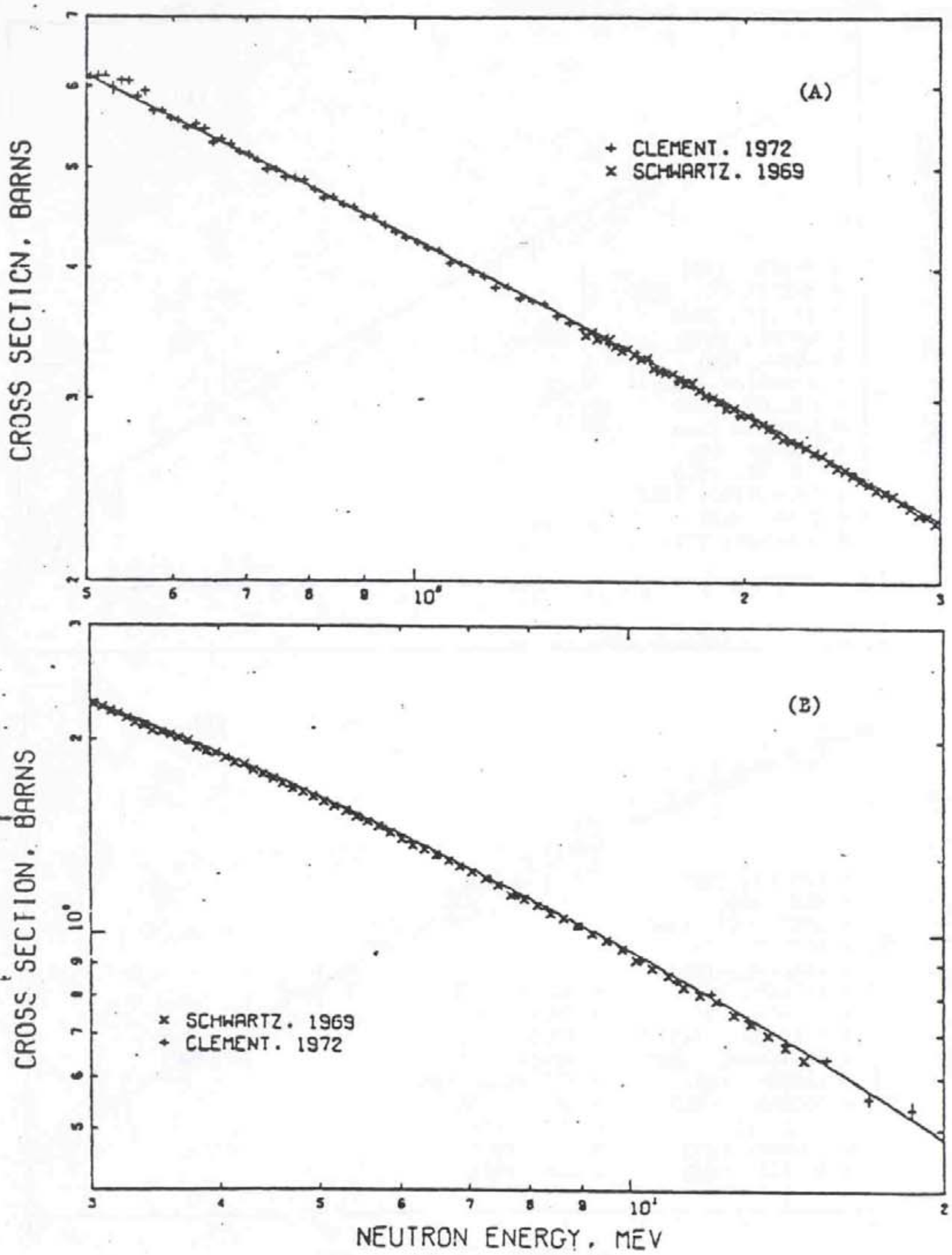

Fig. 3.
Total cross section for hydrogen from 500 keV to 20 MeV. The ENDF/B-V evaluation is compared to measurements reported in Refs. 6 and 7.

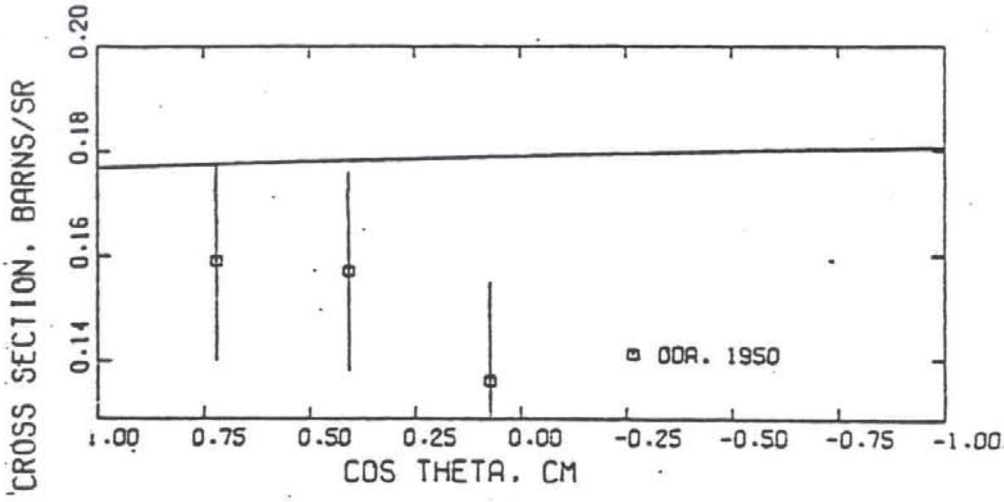

Fig. 4.
Angular distribution of the neutrons elastically scattered from hydrogen at 3.1 MeV. ENDF/B-V is compared with the experimental values of Oda.[8]

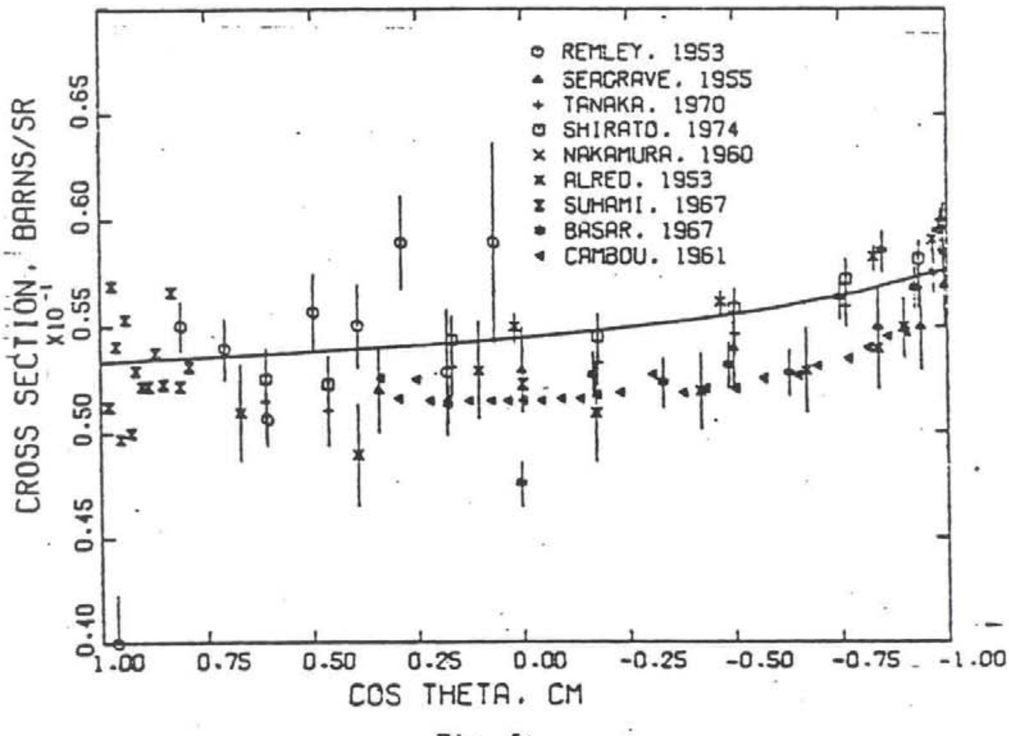

Fig. 5A.
Angular distribution of the neutrons elastically scattered from hydrogen at energies near 14 MeV. The experimental data shown were reported in Refs. 9, 34, 36 and 45-50.

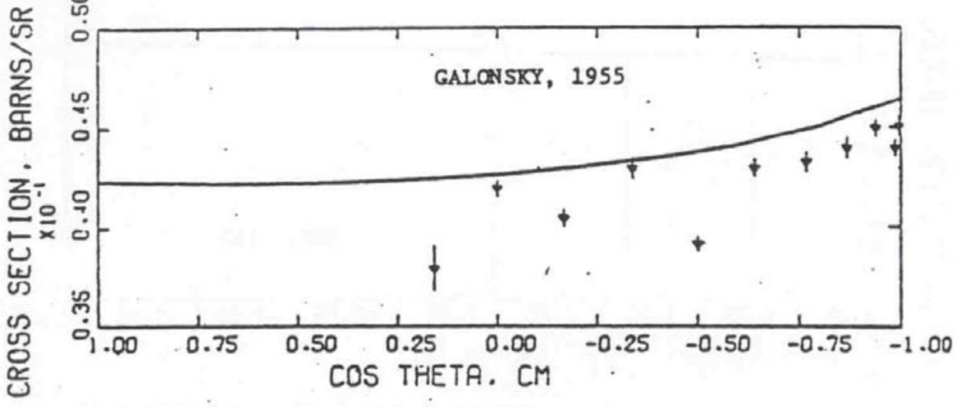

Fig. 5B.
Angular distribution of the neutrons elastically scattered from hydrogen at energies near 17.8 MeV. The experimental data shown were reported in Ref. 10.

SUMMARY DOCUMENATION FOR ^{3}He

by

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I.SUMMARY

The ^{3}He evaluation for ENDF/B-V (MAT-ll46) was carried over intact from Version IV. The evaluated data cover the energy range 10-5 eV t-o 20 MeV, and documentation for t-he standards portion of the data is given in LA-6518MS (1976).

II. STANDARDS DATA

The ^{3}He{n ,p)T cross section (MF-3; MT-103) is recognized as a standard in the neutron energy range from thermal to 1 MeV. -The. present evaluation was performed in 1968 and accepted by the CSEWG Standards Subcommittee for the ENDF/B-III file[1] in 1971. No changes have been recommended for this file; therefore, the present evaluation was carried over from both Versions III and IV of ENDF/B.

The thermal cross section of 5327 b vas derived from precise measurements by Als-Nielsen and Dietrich[2] of the total cross section up to an energy of 11 eV. No experimental measurements on the 3Be(n. p) reaction are available below ~.5 keV, and the cross section was assumed to follow l/v up to 1.7 keV. The evaluation is compared with the available data below 10 keV in Fig. 1. For convenience, the inset- includes tabular values of the elastic. (n. p) and total cross sections at a few energies up to 1 keV. Up to 10 keV. the evaluation is a reasonable representation of the 1966 results of Gibbons and Macklin[3] and an average of their cross sections measured in 1963. These experiments which extend to 100 keV. are compared with ENDF/B-V in Fig. 2.

From 100 keV to 1 MeV. additional experiments are available. The evaluation is heavily weighted by the data of Refs. 3 and 4 and the cross sections of Perry et al. as given in Fig. 3. Note that these three measurements are in good agreement among themselves but are higher than the measurements of Batchelor et al. and of Sayres et al.[7] On the other hand. Sayres et l. measure an elastic cross section much higher than reported by Seagrave et al..[8] (noted on the same figure) .

In 1970, Costello et. al. measured the (n, p) cross section from 300 keV to 1 MeV and obtained essentially a constant value of 900 mb over this energy range. Agreement of the Costello data with this evaluation above 500 keV is excellent. although from 300 to 400 keV, their measurements are
more than 10% lower than ENDF/B-V.

Finally, Lopez et al. measured the relative ratio of the counting rates between ^{3}He and BF_3 proportional counters from 218 eV to 521 keV. To provide a comparison between these two standard cross sections, the Lopez ratios were normalized at 218 eV to the Version IV ratios. Then, by using the present evaluation for the ^{3}He(n, p) cross section to convert the Lopez ratio measurements to ^{10}B cross sections, reasonable agreement with Version V ^{10}B(n, a) is obtained. ,It should be noted, however, that the energy points are too sparse above a few keV to reproduce the structure observed in GB.

Although the thermal (n. p) cross section is known to better than 1%, the energy at which this cross section deviates from l/V is not well established . It should also be emphasized that experiments have not been carried out from 11 eV to a few keV, thereby placing severe restrictions upon the accuracy accompanying the use of the ^{3}He(n, p)T cross-section standard. The 10% error estimates on the ORNL experimental data are directly related to the uncertainties in the analysis of the target samples employed. Certainly, further absolute measurements are needed on this cross-section standard, especially above ~ 100 eV.

III. ENDF/!B-V FILES

File 1. General Information

MT = 451. Descriptive data.

File 2. Resonance Parameters

MT = l51. Scattering length -0.282~-12 cm.

File 3. Neutron Cross Sections

MT = 1. Total Cross Sections

From 0.00001 e\1 to 10.8 keV MT1 taken as sum MT2 + MT103. .From 10.8 keV to 20 MeV MT1 evaluated using experimental from Ref. 11.

MT-2. Elastic Scattering Cross Sections

From 0.00001 eV to 10.8 keV MT2 taken as constant -1.0 b. From 10.8 keV to 20.0 MeV MT2 = MT1 – MT103 - MTl04 with experimental data from Refs. 7 and 8 as checks. Note that two reactions are missing from the evaluation, namely, (n, n' p) and (n, 2n2p). Experimental data at 15 MeV indicate non-zero cross sections for these reactions. In the present evaluation, these reactions are simply absorbed in MT = 2.

MT = 3 (n, p) Cross Section

Standards reaction -see Sec. II above.

MT = 104. (n, d) Cross Sections

Threshold = 4.3614 MeV, Q = -3.2684 MeV. Evaluation from a detailed balance calcu1ation (Ref. 2) and experimental data (Ref. 7).

MT = 251. Average Value of Cosine Of Elastic Scattering Angle. Laboratory System.
Obtained from data MF = 4, MT = 2.

MT = 252. Values Of Average Logarithmic Energy Decrement
Obtained from data MF = 4, MT = 2.

MT = 253. Values Of Gamma
Obtained from data MF = 4, MT = 2.

File 4. Neutron Angular Distributions

MT = 2. Angular Distribution Of Secondary Neutrons From Elastic Scattering.
Evaluated from experimental data from Refs. 7,8. 11-14 covering incident energies as follows:

INCIDENT ENERGY	REFERENCES
l.E.-5 eV	(Isotropi.c)
0.5 MeV	(Isocropic)
1.0 MeV	8
2.0 MeV	8
2.6 MeV	11
3.5 MeV	8
5.0 MeV	11
6.0 MeV	8, 12 (from p+ t elastic scattering)
8.0 MeV	7, 12 (from p+ t elastic scattering)
14.5 MeV	12,13 (from p+ t elastic scattering)
17.5 MeV	7
20.0 MeV	11 (from p+ t elastic scattering)

REFERENCES

1. This evaluation was translated by R. J. LaBauve into the ENDF /B format for Version III.
2. J. Als-Nielsen and 0. Dietrich. "Slow Neutron Cross Sections for He^3, B, and Au." Phys. Rev. **133**. B 925 (1964).
3. J. B.. Gibbons and R. L. Macklin , "Total Neutron Yields from Light E1ements under Proton and Alpha Bombardment", Phys. Rev. **114**, 571 (1959).
4. R. L. Macklin and J. H. Gibbons. Proceedings of the Internaciona1 Conference on the Study of Nuclear Structure with Neutrons. Antwerp. 19-23 July 1965 (North-Holland Publishing Co., 1966). p. 498.
5. J. E. Perry, Jr.. E. Haddad, R. L. Henkel, G. A. Jarvis and R. K. Smith, private communication 1960.

6. R. Batchelor. R. Aves. and T. H. R. Skyrme. "Helium-3 Filled Proportional Counter for Neutron Spectroscopy." Rev. Sci. Instr. **26,** 1037 (1955).
7. A. R. Sayres. K. W. Jones. and C. S. Wu. "Interaction of Neutrons with He^3." Phys. Rev. **122**. 1853 (1961).
8.. J. D. Seagrave. L. Cranberg. and J. E. Simmons. "Elastic Scattering of Fast Neutrons by Tritium and He^3." Phys. Rev. **119**, 1981 (1960).
9. D. G. Costello. S. J. Friesenhahn. and W. H. Lopez. '^{3}He(n, p)T Cross Section from 0.3 to 1.16 MeV, "Nucl. Sci. Eng. **39**, 409 (1970).
10. W. H. Lopez. H. P. Fricke. D. G. Costello, and S. J. Friesenhahn,. "Neutron Capture Cross Sections of Tungsten and Rhenium,'t Gulf General Atomic, Inc. report GA-8835.
11. Los Alamos Physics and Cryogenics Groups, Nucl. Phys. **12**, 291 (1959).
12. J. E. Brolley. Jr.. T. H. Putnam, L. Rosen, and L. Stewart, Phys. Rev. **159**, 777 (1967).
13. B. Antolkovic, G. Paic, P. Tomas. and R. Rendic, Phys. Rev.**159**, .777 (1967).
14. L. Rosen and W. Leland, Private communication (1967).

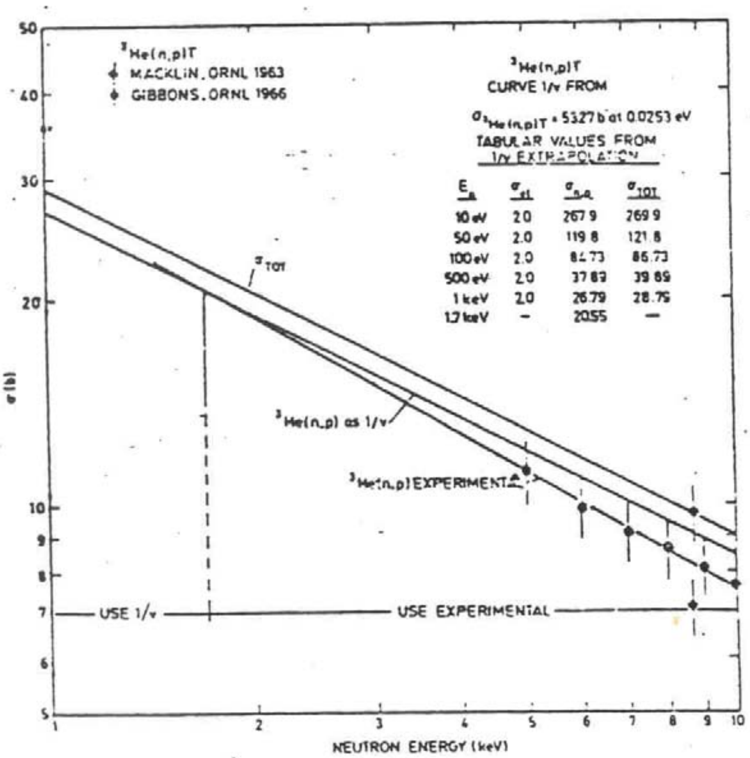

Fig. 1.

The (n,p) and total cross sections for ^{3}He from 1 to 10 keV. The curve drawn through the experimental points deviates from 1/V at 1.7 keV.

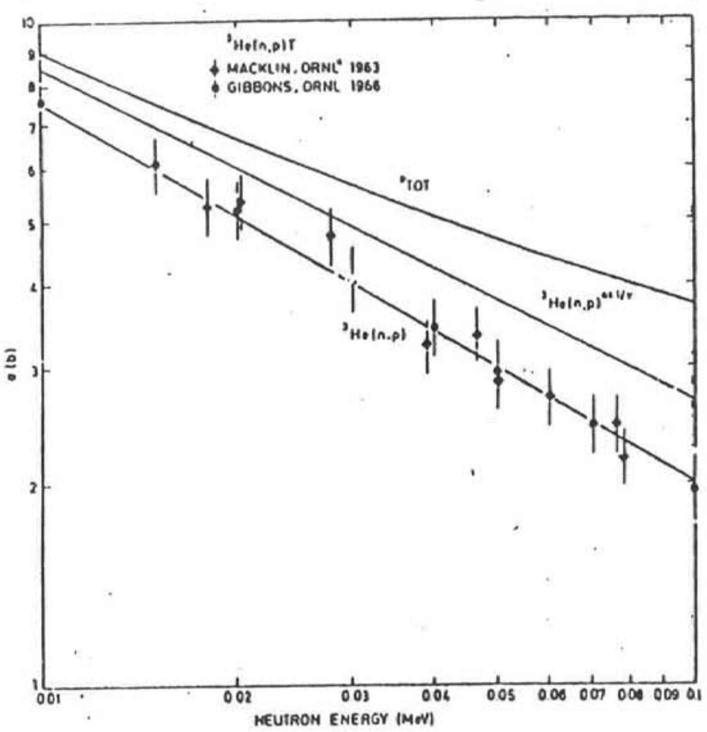

Fig. 2.
The (n,p) and total cross sections for ^{3}He from 10 to 100 keV.

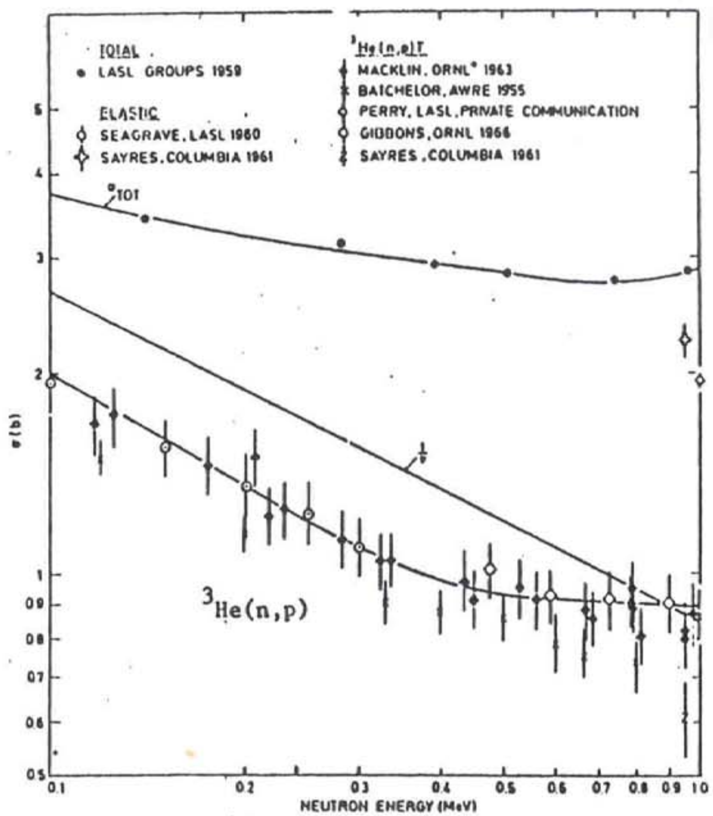

Fig. 3.
The (n,p), elastic, and total cross sections for ^{3}He from 100 keV to 1 MeV. The Costello data[9] have been omitted for the sake of clarity.

SUMMARY DOCUMENTATION FOR ^{6}Li

By

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I. SUMMARY

The previous evaluation for 'Li was extensively revised for Version V of ENDF/B (MAT 1303). 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. In the new representation, the (n, n' d) cross section is grouped into ^{6}Li excitation energy bins, which preserves the kinematic energy-angle relationships in the emitted neutron spectra. Finally, correlated error data were added up to a neutron energy of 1 MeV, triton-angular distributions from the ^{6}Li(n, t)^{4}He reaction were included below 1 MeV, and radioactive decay data were added to Files 8 and 9. Except for the covariance and (n, t.) angular distribution files, the eva1uation covers the neutron energy range of 10^{-5} eV to 20 MeV:

.II STANDARDS DATA

The ^{6}Li(n, a.) cross section is regarded as a standard below En=100 keV. The Version V cross sections for ^{6}Li below 1MeV were obtained from multichannel multilevel R-matrix analyses of reactions in the ^{6}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, a) cross section was determined mainly by fitting the Harwell tota1 cross section (reference 3 below), since this was presumably the most accurately known data included in the analysis. However, in addition to .he Harwell tota1, .he 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.-Q 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 σT	Harvey, ORNL	0.5-1%
^{6}Li(n. a) 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(t, t)^{4}He analyzing power	Bardekopf, LASL[36]	1%

Fits to the (n, α) data included in ~he Version V analysis are shown in Figs. 1 and 2. In Fig. 1, the data are plotted as $\sigma.\sqrt{E_n}$; in both figures, the Version IV evaluation is represented by the dashed curves. The good agreements~ with Lamaze's new '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 Li(n, α) cross section significantly (to the order of 3%) over that of previous evaluations in the region of the resonance.

III. ENDF/B-V-FILES

File 1: General Information
MT-451. Descriptive data.

File 2. Resonance Parameters
MT-l51. Effective scattering radius -0.23778 x 10-^{12} cm.
Resonance parameters not given.

File 3. Neutron Cross Sections

The 2200 m/s cross sections are as follows:

MT = 1 Sigma -936.64 b
MT = 2 Sigma -0.71046 b
MT = 102 Sigma -0.03850 b
MT = 105 Sigma -935.89 b

MT = 1. Total Cross Section

Below 1 MeV, the values are taken from an R-ma~r1x analysis- by Bale, Dodder.Witte (described in Ref. 2) which takes into account data from all reactions possible in 'Li up to 3 MeV neutron energy. Total cross section data considered in this analysis were those of Refs. 3 and 4. Between 1 and 5 MeV, the total was taken to be the sum of MT=2. 4. 24. 102.103, and 105, which generally follows the measurements of Refs. 5 and 6. Between 5 and 20 MeV. the total was determined by an average of the data of Refs. 6 and 7 which agrees with Ref. 8

except at the lowest energy. In this region, the total exceeds the sum of the measured partial cross sections by as much as 200-300 mb. This difference was distributed between the elastic and total (n ,n')d cross sections.

MT = 2. Elastic Cross Section

Below 3 MeV. the values are taken from the R-matrix analysis cited or MI-l. which includes the elastic measurements of Refs. 9 and 10. These calculations were matched smoothly in the 3-5 MeV region to a curve which lies about 50 mb above Batche1or (Ref. 26) between 5 and 7.5 MeV, and about 13% above the data of Refs. 14, 27. 28. and 29 at 10 ~o 14 MeV.

MT = 4. Inelastic Cross Section

Sum of MT = 51 through MT = 81.

MT-24. (n, 2n) α Cross Section

Passes through the point of Mather and Pain (Ref. 11) ac 14 MeV, taking into account the measurements of Ref. 12.

MT-51. 52, 54-56,58-81. (n, n')d Continuum Cross Sections

Represented by continuum-leve1 contributions in 6Li, binned in 0.5-MeV intervals. The energy-angle spectra are determined by -a 3-body phase-space calculation, assuming isotropic center-of-mass distributions. At each energy, the sum of the continuum level contributions is normalized to an assumed energy-angle integrated continuum cross section which approximates the difference of Hopkins measurement (Ref.13) and the contribution from the first and second levels in 6Li. The steep rise 6f the pseudo-level cross sections from their-thresholds and the use of fixed bin widths over finite angles produces anomalous structure in the individual cross sections which is especially apparent near the thresholds. Some effort has been made to smooth out these effects, but they remain to some extent.

MT = 53. $(n.n_1)d$ Discrete Level Cross Sections

Cross section-has p-wave penetrability energy dependence from threshold to 3.2 MeV. Matched at higher energies to a curve which lies 15-20% above Hopkins (Ref. 13) and passes through the l0-MeV point of Cookson (Ref. 14).

MT = 57. (n,n2)γ Cross Section

Rises rapidly from threshold, peaks at 5 mb .and' falls off gradually to 20 MeV. No data available except upper limits.

MT = 102. (n, γ) Cross Sections

Unchanged from Version IV, which was based on the thermal measurement of Jurney (Ref. 15) and the Pendlebury evaluation (Ref. 16) at higher energies.

MT = 103. (n, p) Cross Sections

Threshold to 9 MeV based on the data of Ref. 17. Extended to 20 MeV through the 14-MeV data of Refs. 18 and 19.

MT = 105. (n, t) Cross Sections Below 3 MeV. values are taken from the R-matrix analysis of Ref. 2., which includes (n, t) .measurements from Refs. 20-24. Between 3 and 5 MeV, the values are based on Bartle's measurements (Ref. 24). At higher energies. the cross sections are taken from the evaluation of Ref. 16, extended to 20 MeV considering the data of Kern (Ref. 25).

File 4~ Neutron Secondary Angular Distributions

MT-2. Elastic Angular Distributions

Legendre coefficients determined as follows :

Below 2 MeV, coefficients up to L=2 were taken from the R-matrix analysis of Ref. 2, which takes into account elastic angular distribution measurements from Refs. 9 and 10 above 2 MeV. The coefficients represent fits to the measurements of Refs. 13 and 26 in the 3.5-7.5 MeV range, that of Ref. 14 at 1 MeV, and those of Refs. 27-29 at 14 MeV. Exrapolat1on of the coefficients to 20 MeV was aided by optical model calculations.

MT = 24. (n. 2n) Angular Distributions

Laboratory distributions obtained by integrating over energy the 4-body phase-space spectra that result from transforming isotropic center-of-mass distributions to the laboratory system.

MT = 51 -81. (n, n') Angular Distributions

Obtained by transforming distributions that are isotropic in the 3-body center-of-mass system to equivalent 2-body distributions in the laboratory system. m-53 and 57 are treated as .real levels and assumed to be isotropic in the two-body reference system. Data available indicate departure from isotropy for the first real level (MT = 53) and this anisotropy will be included in a later update.

MT = 105. (n, t) Angular Distributions

Legendre coefficients obtained from the R-matrix analysis of Ref. 2 are supplied at energies below 1 MeV. The analysis takes into account (n, t) angular distribution measurements from Refs. 23 and 30.

Fi1e 5. Neutron Secondary Energy Distributions

MT = 24. (n,2n) Energy Distributions

Laboratory distributions obtained by integrating over angle the 4-body phase-space spectra that result from transforming isotropic center-of-mass distributions to the laboratory system.

File 8. Radioactive Nuclide Production

MT = 103. (n, p) ^{6}He

^{6}He beta decays, with-a half-1ife of 808 ms, back to ^{6}Li with a probability of unity.

MT = 105. (n , t) ^{6}He

Tritium, which is the only radioactive product of this reaction, beta decays to ^{3}He with a probability of unity and with a life-time of 12.33 years.

File 9. Radioactive Nuclide Multiplicities

MT = 103. (n, p) Multiplicity

A multiplicity-of one is given for the production of ^{6}He.

MT = l05. (n, t) Multiplicity

A multiplicity of one is given for the production of tritium.

File 12. Gamma-Ray Multiplicities

MT = 57. (n, n_2) Multiplicity

Multiplicity of one assumed for the 3.562-MeV gamma ray. Energy taken from reference 31.

MT = 102. (n, γ) Multiplicity

Energies and transition arrays for radiative capture taken from Ref. 15, as reported in Ref. 31. The LP. flag was used to describe the MT = 102 photons.

File 14. Gamma-Ray Angular Distributions

MT = 57. (n, n_2) γ Angular Distributions.

The gamma is assumed isotropic.

MT = 102. (n, γ) Angular Distributions

The two high-energy gammas are assumed isotropic. Data on the 477-keV gamma indicate isotropy.

File 33. Cross Section Covariances

The relative covariances for MI-l. 2. and 105 below 1 MeV are given in File 33. They are based on calculations using the covariances of the R-matrix parameters in first-order error propagation.

MT = l. Total

Relative covariances are entered as NC-type sub-subsections, implying that they are to be constructed from those for MT = 2 and 105. They are not intended for use at energies above 1.05 MeV.

MT = 2, 105. Elastic and (n, t)

Relative covariances among these two cross sections are entered explicitly as NI-type sub-subsections in the LB-5. (direct) representation. Although values for the 0.95-1.05 MeV bin are repeated in a 1.05-20 MeV bin, the covariances are not intended for use at energies above 1.05 MeV.

REFERENCES

1. G. M. Hale, L. Stewart, and P. G. Young, LA-6518-MS (1976).
2. G. M. Hale, proc. Internat. Spec1alists Symposium on Neutron Standards and Applications. Gaithersburg (1977).
3. K. H. Diment and C. A. Uttley. AERF-PR/NP & 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, Vol. 1,244 (1975).
5. H. H. Knitter, C. Budtz-Jorgensen, M. Mailly, and R. Vogt, CB~VG (1976).
6. C. A. Goulding and P. Stoler., EANDC(US)-**176U**, 161 (1972) .

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

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. 0. Lane, Ann. Phys. **12**. 135 (1961).
10. H. E. Knitter and A. M. Coppola, FANDC(E)-**57U** (1967). Also Ref. 5 above.

11. D. S. Mather and L. F. Pain, AWRE-0-47/69 (1969). .
12. V. J. Ashby et al., Phys. Rev. **129**, 1771 (1963):
13. J. C. Hopkins, D. M. Drake, and H. Conde, Nuc1. Phys. **A107**, 139 (1968), and J. C. Hopkins, D. M. Drake, and H. Conde, LA-3765 (1967).
14. J. A. Cookson and D. Dandy, Nucl. Phys. **A91**, 273 (1967).
l5. E. T. Jurney, LASL, private communication (1973).
16. E. D. Pend1ebury. AWRE-0-60/64 (1964).
17. R. Bass, C. Bindhardt, and K. Kruger, EANDC(E)-57U (1965).
18. G. M. Frye, Phys. Rev. **93**, 1086 (1954).
19. M. E. Battat and F. L. Ribe, Phys. Rev. **89**, 8 (1953).
20. M. G. Sowerby, B. B. Patrick C. A. Uttley, and K. M. Diment, J. Nucl. Energy **24**, 323 (19 70) . ^{6}Li/^{10}B Ratio Converted Using ENDF/B-IV ^{10}B(n, α) Cross Section.
21 G. P. Lamaze, 0. A. Wasson, R. A. Schrack, and A. D. Carlsont Proc. .Internat. Con£. on the Interactions of Neutrons w1th Nuclei, Vol. **2**, 1341 (1976).
22. W. P. Poenitz, Z. Phys. **268,** 359 (1974).
23. J. C. Overley, R. M. Sea1ock, and D. B. Ehlers, Nucl. Phys. **A221**, 573 (1974).
24. C. M.. Bartle, Proc. Con£. on Nuclear Cross $ections and Technology, Vo1. 2, 688 (1975), and private communication (1976).
25. R. D. Kern and W. E. Kreger, Phys. Rev. **112**, 926 (1958).
26. R. Batchelor and J. H. Towle, Nucl. Phys.**47**, 385 (1963).
27. A. B. Armstrong, J. Gammel, L. Rosen. and G. M. Frye, Nucl. Phys. **52**. 505 (1964).
28. C. Wong. J. D. Anderson, and J. W. McClure. Nucl. Phys. **33**, 680 (1962).
29. F. Merchez. N. V. Sen, v. Regis, and R. Bouchez, Compt. Rend. **260**, 3922 (1965).
30. I. G. Schroder, E. D. McGarry. G. DeLeeuw-Gierts, and S. DeLeeuw, Proc. Conf. on Nuclear Cross Sections and Technology, Vol. 1, 240 (1975).
31. F. Ajzenberg-Selove, and T. Lauritsen, Nucl. Phys. **A227**, 55 (1974).
32. M. S. Coates et a1, Neutron Standards Reference Data, IAEA, Vienna, p. 105 (1974).
33. S. J. Friesenhahn et al., INTEL-RT-7011-001 (1974).
34. W. Fort and J. P. Marquette, Proceedings of a Panel on Neutron Standard Reference Data, Nov. 20-24 (1972) , IAEA, Vienna.
35. N. Jarmie et al.. BAPS **20**, 596 (1975).
36. R. A. Bardekopf et a1, LA-6188 (1977).

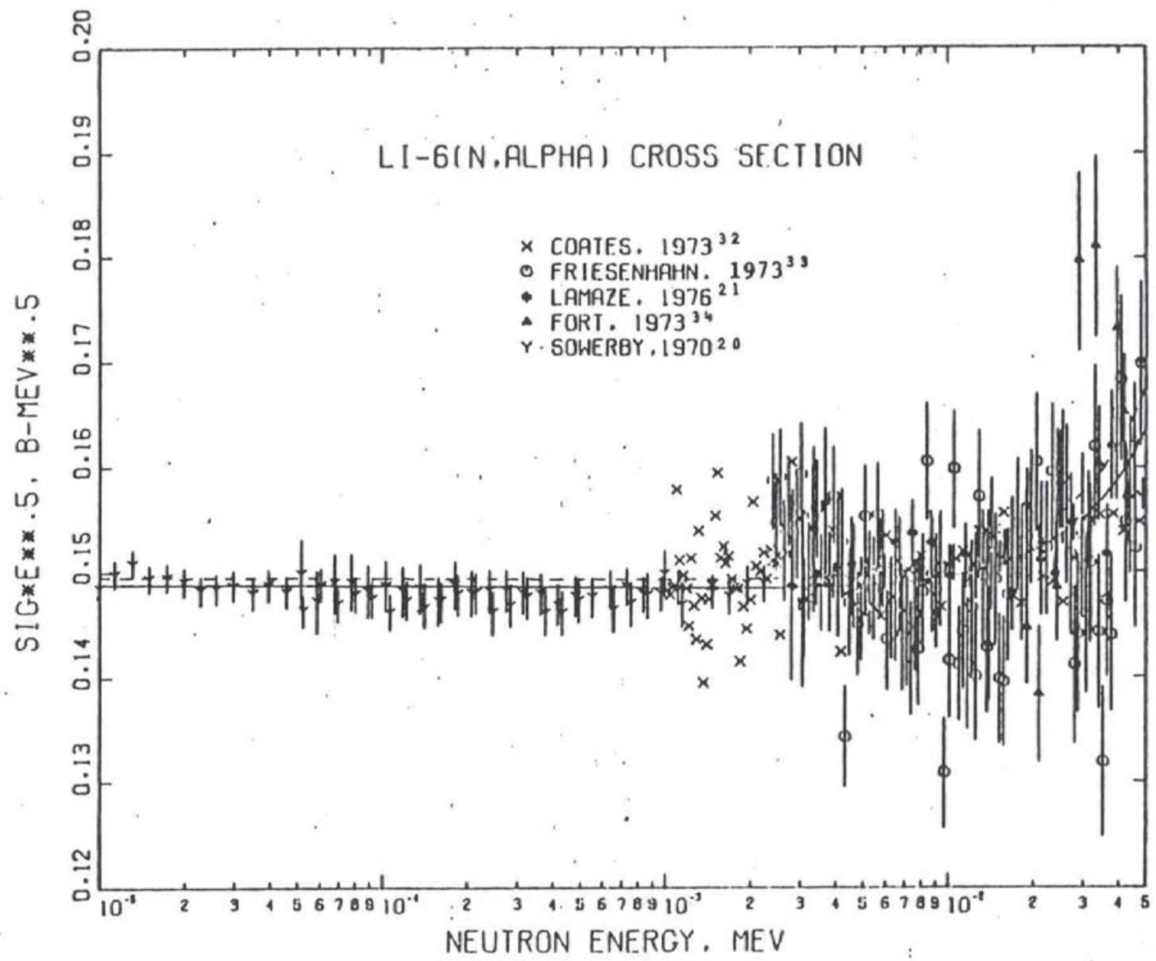

Fig. 1.
The Version V $^{6}Li(n,t)^{4}He$ cross section times $\sqrt{E_n}$ plotted versus E_n for neutron energies between 10 eV and 50 keV. The dashed curve is ENDF/B-IV; the experimental data are from references 20, 21, 32-34.

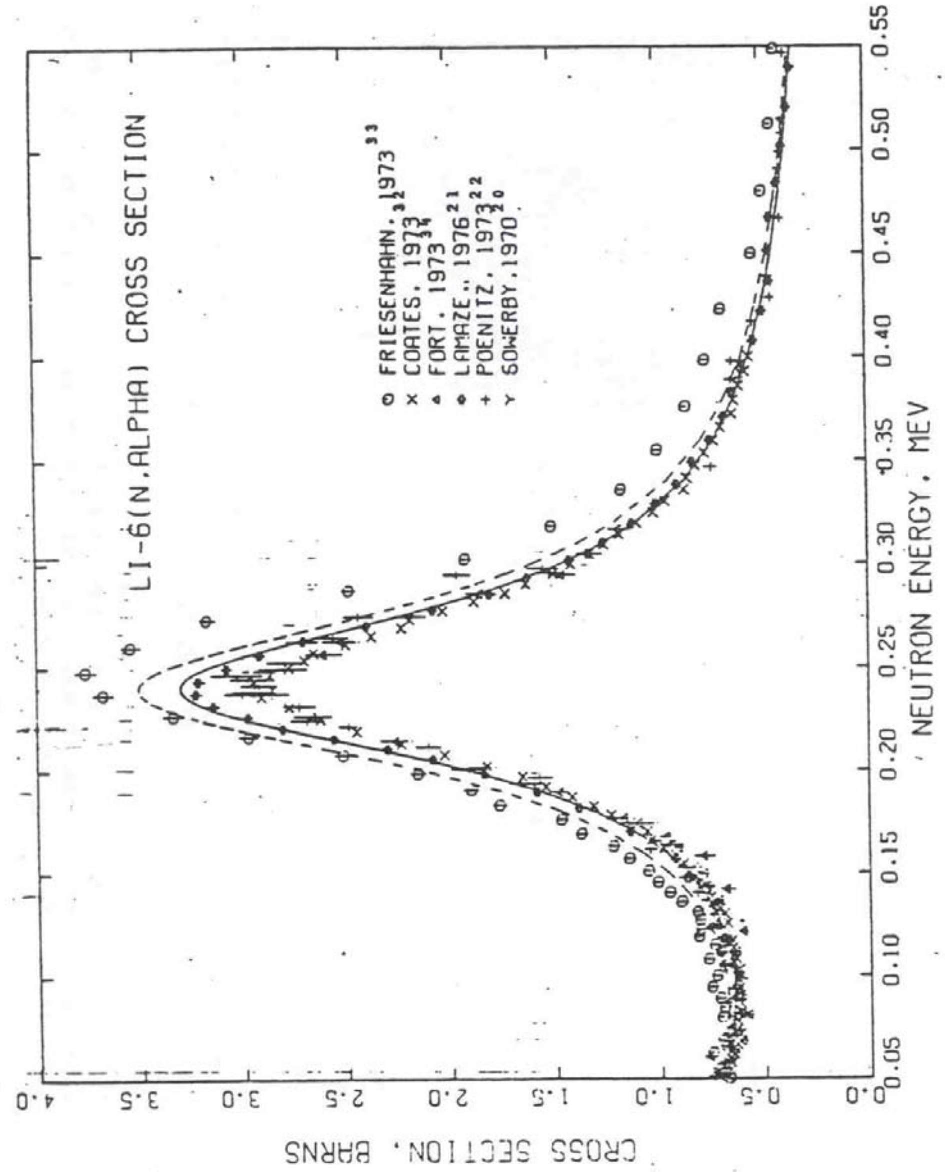

Fig. 2.

The Version V $^{6}Li(n,t)^{4}He$ cross section from 50 to 550 keV. The dashed curve is ENDF/B-IV; the experimental data are from references 20-22, 32-34.

SUMMARY DOCUMENTATION FOR ^{10}B

By

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I. SUMMARY.

All cross sections below a neutron energy of 1.5 MeV except the (n, p) and (n, t) reactions were revised for the Version V evaluation of ^{10}B (MAT 1305). The data above 1.5 MeV were carried over from ENDF!B-IV. Other changes to the file include the addition of evaluated cross sections and secondary gamma-ray spectra from the $^{10}B(n, \gamma)^{11}B$ reaction, as well as covariance data for cross sections below 1.5 MeV. Except for the covariance file, the evaluated data cover the energy range from 10^{-5} eV to 20 MeV. Partial documentation is provided in LA-6472-PR (1976) and LA-6518-MS (1976).

II .STANDARDS DATA

The $^{10}B(n, \alpha)^7Li$ and $^{10}B(n, \alpha_1\gamma)^7Li$ reactions are neutron standards at energies below 100 keV. The major reactions below 1 MeV were obtained for the version V evaluation from multichannel, multilevel, R-matrix analyses of reactions in-the ^{11}B 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 present analyses.

We have added Spencer's measurements of σ_τ (Sp73) and Sealock's $^{10}B(n,\alpha_1)$ angular distributions (Se76) to the data set that was analyzed for Version IV. In addition., we have replaced Friesenhahn's integrated (n, ,α_1) cross section with the recent measurements of Schrack et al. (both with GeLi and NaI detectors) at NBS (Sc76), and have deleted Friesenhahn's total (n, α) cross section from the data set. The resulting fit to the (n, α) and (n, α γ) data is shown in Figs. 1 and 2, respectively. The integrated $^{10}B(n, \alpha)$ cross section has changed negligibly from the Version IV results at energies below 200 keV. At higher energies, however, the {n, α) cross section has dropped significantly in response to the new NBS data. Unfortunately, the rest of the data in the analysis do not seem particularly sensitive Co such changes in the (n, α) cross section with the result that our calculated cross section must be considered quite uncertain at energies above -300 keV.

III. ENDF/B-V FILES

File I. General Information
MT-451. Descriptive data.

File 2. Resonance Parameters
MT-45l. Effective scattering radius -0.40238 x 10-12 cm.
Resonance parameters not included.

File 3. Neutron Cross Sections
the 2200 m/s cross sections are as follows:

MT = 1	Sigma = 3839.1	b
MT = 2	Sigma = 2.0344	b
MI = 102	Sigma = 0.5	b
MT = 103	Sigma = 0.000566	b
MT = 107	Sigma = 3836.6	b
MT = 113	Sigma = 0.000566	b
MT = 700	Sigma = 0.000566	b
MT = 780	Sigma = 44.25	b
MT = 781	Sigma = 3592.3	b

MT = l. Total Cross Section
0 to 1 MeV, calculated from R-matrix parameters obtained by fitting simultaneously data from the reactions $^{10}B(n, n)$, $^{10}B(n, \alpha_0)$, and $10B(n, \alpha_l)$. Total neutron cross-section measurements included in the fit are those of Bo52, Di67, and Sp73.

1 to 20 MeV, smooth curve through measurements of Di67, Bo52, Ts62, Fo6l, Co52, and Co54, constrained to match R-matrix fit at 1 MeV.

MT = 2. Elastic scattering Cross Section
0 to 1 MeV, calculated from the R-matrix parameters described for MT=1. Experimental elastic scattering data included in the fit are those of As70 and La71.

1 to-7 MeV, smooth curve through measurements of La71, Po70, and Ho69, constrained to be consistent with total and reaction cross section measurements.

7 to 14 MeV, smooth curve through measurements of Ho69, Co69, Te62, Va70, and Va65.

14 to 20 MeV, optical model extrapolation from 14-MeV data.

MT = 4. Inelastic Cross Section
Threshold to 20 MeV, sum of MT-51-85.

MT = 51-61. Inelastic Cross Sections To Discrete States

MT = 51	Q=-0.717 MeV	MT = 55	Q=-4.774 MeV	MT = 59	Q=-5.923 MeV
52	-1.740	56	-5.114	60	-6.029
53	.-2.154	57	-5.166	61	-6.133
54.	-3.585	58	-5.183		

Threshold to 20 MeV. based on (n. n') measurements of Po70, Co69, Bo69. and Va70. and the (n, xγ) measurements of Da56. Da60, and Ne70 using a gamma-ray decay scheme deduced from La66, A166, Se66A, and Se66B. Hauser-Feshbach calculations ere used to estimate shapes and relative magnitudes where experimental data were lacking.

MT = 62-85. Inelastic Cross Sec~1ons to Groups of Levels

These .sections were used to group (n. n') cross sections into 0.5- MeV wide excitation energy bins between Ex-6..5 and 18.0 MeV. This representation was used in lieu of MF=5. MT=91 to more accurately represent kinematic effects.

Threshold to 20 MeV. integrated cross section obtained by subtracting the sum of MT=2, 51-61. 103. 104, 107, and 112 from MT=l. Cross section distributed among the bands with an evaporation model using a nuclear temperature given by T= 0.9728 $\sqrt{E_n}$ (units MeV) taken from Ir67.

MT = 102. (n, γ) Cross Section

0 to 1 MeV, assumed l/V dependence with thermal value of 0.5 barn.
1 to 20 MeV, assumed negligible, set equal to zero.

MT = 103. (n. p) Cross Section

Threshold to 20 MeV. sum of MT =700-703.

MT = 104. (n. d) Cross Section

Threshold to 20 MeV. based on ^{9}Be{d, n)^{10}B measurements of Si65 and Ba60. and the {n, d) measurement of Va65.

MT = 107. (n, α) Cross Section

0 to 20 MeV. sum of MT=780 and 781.

MT = 113. (n, t2α) Cross Section

0 to 2.3 MeV, based on a single-1evel fit to the resonance measured at 2 MeV by Da61, assuming L=0 incoming neutrons and L=2 outgoing tritons.

1.3 to 20 MeV, smooth curve through measurements of Fr56 and Wy58, following general shape of Da61 measurement from 4 to 9 MeV.

MT = 700-703. (n, p) Cross Section to Discrete Levels

0 to 20 MeV. crudely estimated from the calculations of Po70 and the (n, xγ) measurements of Ne70. Cross section for MT=700 assumed identical to MT=113 below 1 MeV. Gamma-ray decay scheme for ^{10}B from La66.

MT = 780. (n, α_0) Cross Section

0 to 1 MeV calculated from the R-matrix parameters described for MT = l. Experimental (n, α_0) data input to the fit were those of Ma68 and Da61. In addition the angular distributions of Va72 for the inverse reaction were included in the analysis.

1 to 20 MeV based on Da61 measurements, with smooth extrapolation from 8 co 20 MeV. Da6l measurement above approximately 2 MeV was renormalized by factor of 1.4.

MT = 78l. (n, α_1) Cross Section

0 to 1 MeV. calculated from the R-matrix parameters described for MT = l. Experimental
(n, α_1) data included in the fit are those of Sc76. In addition the absolute differential cross-section measurements of Se76 were included in the analysis.

1 to 20 MeV. smooth curve through measurements of Da61 and Ne70, with smooth extrapolation from l5 to 20 MeV. The Da61 data above approximately 2 MeV were renormalized by a factor of 1.4.

File 4. Neutron Angular Distributions

MT-2. Elastic Angular Distributions

0 to 1 MeV. calculated from the R-matrix parameters described for MF=3, MT-l. Experimental angular distributions input to the fit for both the elastic scattering cross section and polarization were obtained from the measurements of La71. Assignments for resonances above the neutron threshold are based on La71.

1 to 14 MeV, smoothed representation of Legendre coefficients derived from the measurements of La71, Ha7J. Po70t Ho69. Co69. Va69, and Va6S. constrained to match the R-matrix calculations at E_n = l MeV.

14 to 20 MeV, optical model extrapolation of 14-MeV data.

MT-51-85. Inelastic Angular Distributions

Threshold to 20 MeV, assumed isotropic in center-of-mass.

File 12. Gamma Ray Multiplicities

MT = 102. Capture Gamma Rays

0 to 20 MeV. capture spectra and transition probabilities derived from the data of Th67. after slight changes in the probabilities and renormalization to the energy levels of Aj75. The LP flag is used ~o conserve energy and to reduce significantly the amount of data required in the file. Except for the modification due to the LP flag, the thermal spectrum is used over the entire energy range.

MT = 78l. 0.4776-MeV Photon from the (n, α_1) Reaction

0 to 20 MeV; multiplicity of 1.0 at all energies.

File 13. Gamma-Ray Production Cross Sections

MT = 4. (n, nγ) Cross Sections

Threshold to 20 MeV. obtained from MT = 5l-6l using ^{10}B decay scheme deduced from La66. Al66. Se66A. and Se66B.

MT = 103. (n, pγ) Cross Sections

Threshold to 20 MeV, obtained from MT-701-703 using ^{10}B decay Scheme deduced from La66.

File 14. Gamma Ray angular Distributions

MT = 4. (n, nγ) Angular Distributions

Threshold to 20 MeV. assumed isotropic.

MT = 102. (n, γ) Angular Distributions

0 to 20 MeV. assumed isotropic.

MT = 103. (n, pγ) Angular Distributions

Threshold to 20 MeV, assumed isotropic.

MT = 78l. (n, $\alpha_1\gamma$) Angular Distribution

0 to 20 MeV, assumed isotropic.

File 33. Cross-Section Covariances

The relative covariances for the most important reactions open below 1 MeV are given in File 33. These are calculated directly from the covariances of the R-matrix parameters, using first-order error propagation.

MT = 2, 780. 781. (n, n) (n, α_o), and (n, α_l) Covariances.

0 to 1 MeV, relative covariances among these three reactions are entered explicitly using NI-type sub-subsections in the LB-5 (direct) representation.

1 to 20 MeV. all covariances set equal to zero. Not intended for use in this energy range.

MT = 1, 107. Total and (n, α) Covariances.

0 to 1 MeV. for compactness, these covariances are constructed from those described above, using NC-type sub-subsections. The constructed covariances for the total cross section therefore neglect contributions from the (n, γ), (n, p), (n, t). and (n, n_l)reactions Which are all presumed to be smal1 in magnitude below 1 MeV. Note that although the total cross-section covariances are entered in the NC-type (derived) format, total cross-section data were included in the fit, and they influenced all the calculated covariances.

1 to 20 MeV, set equal to zero. Not intended for use in this energy range .

REFERENCES

Aj75 F. Ajzenberg-Se1ove. Nuc1. Phys. A248. 6 (1975).

A166 D. E. Alburger et al., Phys. Rev.**143**, 692 (1966). .;

As70 A. Asami and M. C. Moxon. J. Nucl. Energy **24**. 85 (1970).

Ba60 R. Bardes and G. E. Owen. Phys. Rev. **120**, 1369 (1960).

Be5.6 R. L. Becker and H. H. Barschall. Phys. Rev. 102, 1384 (1956).

Bo51 C. K. Bocke1man et a1.. Phys. Rev. **84**, 69 (1951).

B069 D. Bogart and L. L. l;icho1s. Nuc1. Phys. **A125**, 463 (1969).

Co52 J. H. Coon et a1., Phys. Rev. **88,** 562 (1952).

Co54 C. F. Cook and"T. w. Bonner. Phys. Rev. **94,** 651 (1954).

Co67 S. A. Cox-and F. R. Ponter. J. Nucl. Energy **21**. 271 (196n.

Co69 J. A. Cookson and J. G. Locke. Nucl. Phys. **A146,** 417 (1970).

Co73 M. S. Coaces et a1. , private communication to L. Stewart (1973).

Da56 R. B. Day. Phys. Rev. **102**, 767 (1956).

Da60 R. B. Day and M. Walc. Phys. Rev. **117**, 1330 (1960).

Da61 E. A. Davis et a1.. Nucl. Phys. **27**, 448 (1961). .

Di67 K. M. Dimen~. AERE-R-5224 (1967).

Fo61 D. M. Fossan et al., Phys. Rev. **123**, 209 (1961).

Fr56 G. .M. Frye and J. H. Gamme1, Phys. Rev. **103**, 328 (1956).

Ha73 S. L. Hausladen, Thesis. Ohio Univ, COO-1717-5 (1973).

Ho69 J. C. Hopkins. private communication to LASL (1969).

Ir67 D. C. Irving, ORNL-TM-1872 (1967) .
La66 T. Lauritsen and F. Ajzenberg-Selove. Nucl. Phys. **78**, 1 (1966).
La77 R. 0. Lane et al., Phys. Rev. **C4**, 380 (1971). --
Ma68 R. L. Macklin and J. H. Gibbons, Phys. Rev. **165**.1147 (1968).
Mo66 F. P. Mooring et al., Nucl. Phvs. 82. 16 (1966).
Ne54 N. G. Nereson. LA-l655 (1954).
Ne70 D. 0. Ne11is et al., Phys. Rev. **C1**, 847 (1970).
Po70 D. Porter et al.. AWRE **O**, 45/70 (l970).
Sc76 R. A. Schrack et.a1., Proc. ICINN (ERDA-CONF-760715-P2), 1345 (1976).
Se76 R. M. Sea1ock and J. C. Overley, Phys. Rev.**C13**. 2149 (1976).
Se66 A R. E. Segel and R. H. Siemssen. Pbys. lett. **20**, 295 (1966).
Se66 B R. E. Sege1 et a1., Phys. Rev. **145**, 736 (1966).
S165 R. H. Siemssen et a1. , Nucl. Phys. **69**, 209 (1965).
Sp73 R. R. Spencer et al., EANDC(E) **147**, Al (1973).
Te62 K. Tesch, Nucl. Phys. **37**, 412 (1962). .
Th67 G. E. Thomas et al. , Nucl. Instr. Meth. **56**, 325 (1967) .
Ts63 K. Tsukada and 0. Tanaka, J. Phys. Soc. Japan **18**, 610 (1963).
Va63 V. Valkovic et al., Phys. Rev. **139**, 331 (1965).
Va70 B. Vaucher et al., Helv. Phys. Acta, **43**, 237 (1970).
Va72 L. Van der Zwan and K. W. Geiger, Nucl. Phys, **A180**, 615 (1972) .
W155 H. B. Willard et al.. Phys. Rev. **98**, 669 (1955).
Wy58 .K. E..Wyman et al., Phys. Rev. **112**. l264 (1958).

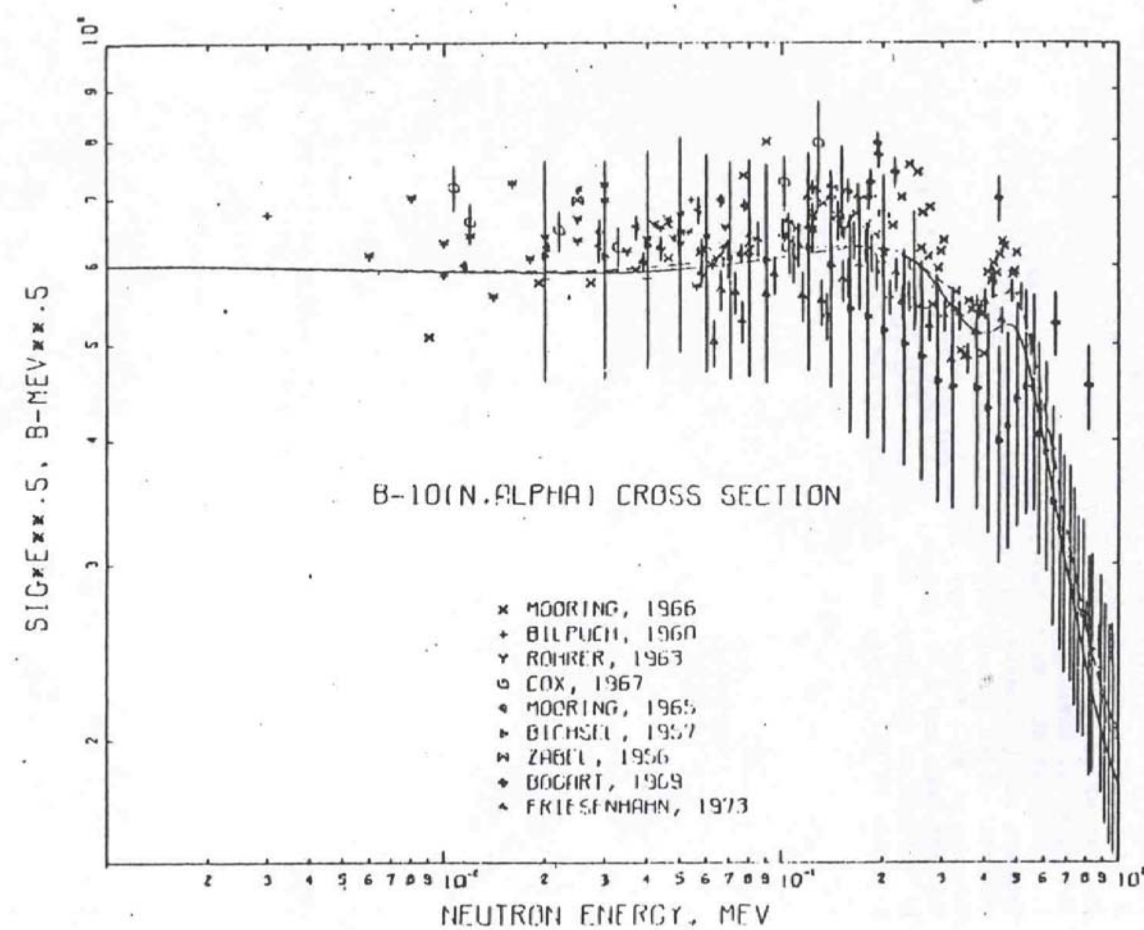

Fig. 1.
Experimental and evaluated data for the $^{10}B(n,\alpha)^{7}Li$ reaction from 1 keV to 1 MeV. The solid curve is ENDF/B-V and the dashed curve is ENDF/B-IV. References for experimental data are given in LA-6518-MS.

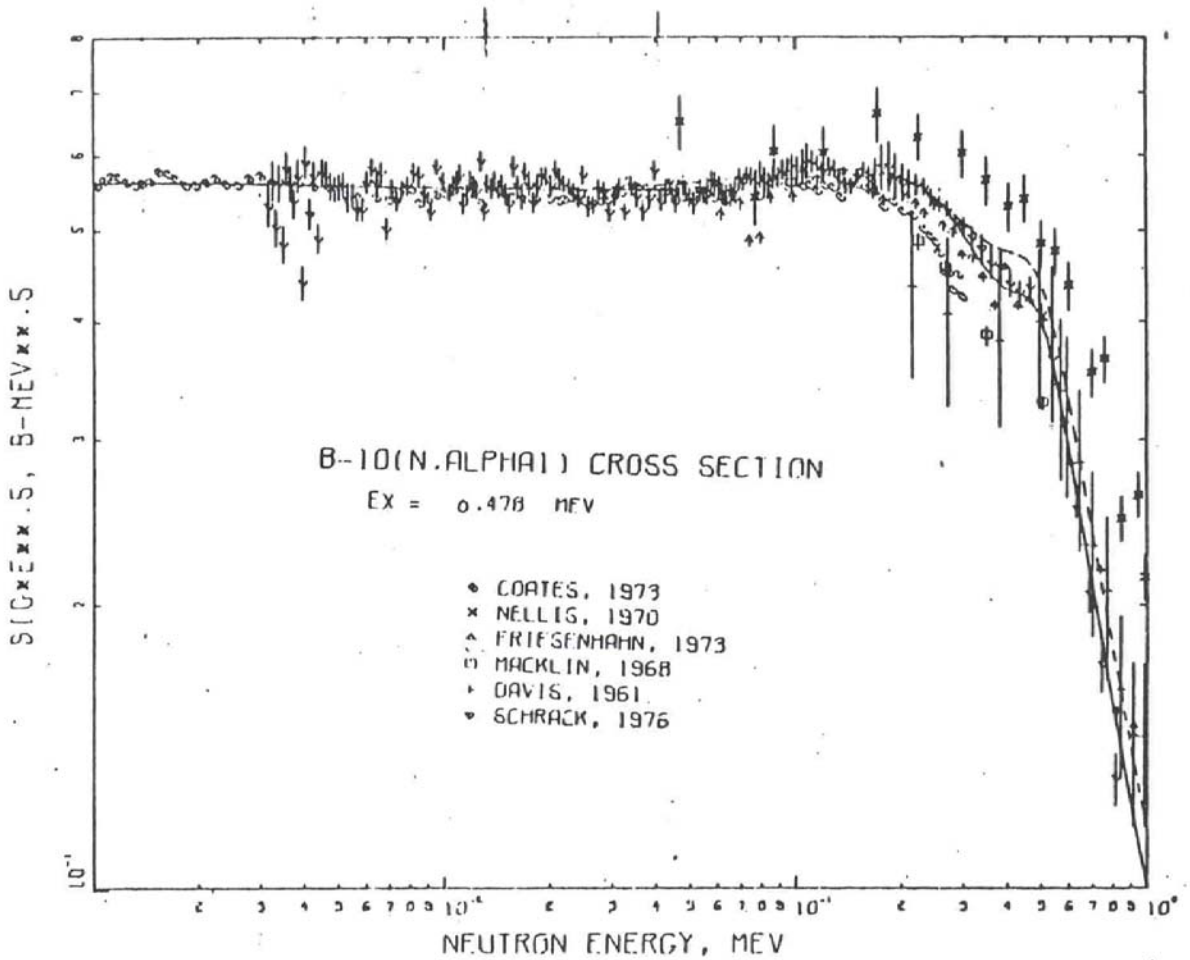

Fig. 2.
Experimental and evaluated data for the $^{10}B(n,\alpha_1\gamma)^7Li$ reaction from 1 keV to 1 MeV. The solid curve is ENDF/B-V and the dashed curve is ENDF/B-IV. References for experimental data are Co73, Da61, Ma68, Ne70, Sc76, and those included in LA-6518-MS.

Summary Documentation
Carbon Evaluation
ENDF/B-V MAT 1306

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August 1978

New Evaluation for Version V:

1. Total and elastic scattering from thermal to 4.81 MeV.
2. Elastic angular distribution: thermal to 4.81 MeV.
3. New representation for (n, n3α) to yield correct energy angle kinematics.
4. Activation file for (n, p).
5. Gas production file.
6. Uncertainty file.

Adopted from ENDF / B- I\' (by F. G. Perey and C. Y. Fu):

1. (n. α) below 15 MeV and (n, γ) below 1 MeV.
2. Angular distributions of secondary neutrons 4-51.
3. Multiplicity of capture gamma rays 12-102.
4. All other cross sections and distributions below 8.5 MeV except (n, γ). (n, α). and (n, t).

Adopted from French evaluation. which is an extensive revision of ENDF/B-IV:

1. (n, γ) above 1 MeV, (n, α), and (n, t).
2. Angular distribution of secondary neutrons 4-52 and 4-53 and gamma rays 14-51.
3. All other cross sections above 8.5 MeV except (n. α).

Data and evaluation techniques used in the new evaluation, the ENDF/B-IV evaluation, and the French evaluation, as adopted here, are summarized below:

File 3, MT=l. Total
1.E-S eV to 4.81 MeV - sum of File 3 MT = Z and File 3 MT = 1O2.
4.81 MeV to 20 MeV. [2-4]

File 3, MT=2. Elastic Scattering

1.E-5 eV to 4.81 MeV - R-matrix analysis with data.[2-27]
Bayes theorem (or nonlinear least-squares) used for energies less than 2 MeV. Resulting weights were then used in the R-matrix analysis. A thermal total cross section of 4.746 + 0.25% evaluated by Lubitz28 was also used in ~he R-matrix fit.
4.81 MeV to 8 MeV.[26,27,29]
8 MeV to 14 MeV. [29-31]
14 MeV to 20 MeV. [32]

File 3, MT=3. Nonelastic

I.E-5 eV to 4.81 MeV. Same as File 3 MT = 102.
4.81 MeV to 20 MeV - File 3 MT = l minus File 3 MT = 2.

File 3, MT=51. Inelastic Scattering to 4.439-MeV Level

4.81 MeV to 6.32 MeV - File 3 MT = 3 minus File 3 MT = 102.
6.32 MeV to 8.796 MeV - File 3 MT=3 minus File 3 MT = 102 minus File 3 MT = 107.
8.796 MeV to 20 MeV - Same references as in File 3 Mt = 2 and gamma-ray data of Morgan et al. [33].

File 3, MT=52-9l. (n ,n') and (n, n'3α) Lumped Together

Mt = 52 to 55: real levels with physical widths given in File 4.
MT=56 to 58: pseudo levels with 0.25-MeV half width of rectangular distribution given in File 4.
MT=9l: a small evaporation component with T=0.3 to reproduce threshold effect and the decay of ~he 2.43-MeV level of ^{9}Be.
Distribution of secondary neutrons agrees with Refs. 34 and .35.
The sum of File 3 MT=52 to File .3 MT=9l is derived from File .3 MT=3 and all other reaction cross sections, and agrees with Refs. 35-37.

File 3, MT=102. Capture

1. E-5 eV to 1 MeV – I/V with 3..36 mb at thermal.
1 MeV to 20 MeV - derived from (γ, n) cross section of Ref. 38.

File 3, MT=l03. (n. p)
See Ref. 39.

File 3. MT=I04. (n. d]
Derived from (d. n) of Ref. 40.

File 3, MT=l07. (n, α)
See Refs. 41-46.

File 3, MT=203 Proton Production
Same as File 3, MT=103

File 3, MT = 204. Deuteron Production
Same ~s File 3, MT=l04.

File 3, MT=207. Alpha Production
Sum of File 3. MT=52 to File 3, MT=9l, multiplied by 3 and added to File 3. MT=l07.

File 3, MT=251. Mu Bar
Derived from File 4, MT=2 with code SAD.

File 3, MT=252. Chi
See File 3, MT=25l.

File 3, MT=253. Gamma
See File 3. MT=25l.

File 4, MT=2. Angular Distribution of Elastically Scattered Neutrons
Same data and analysis as in File 3, MT=2. Legendre coefficients in center-of-mass with transformation matrix given.

File 4, MT=5l. Inelastic Scattering to 4. 439-MeV Level
Same data sources as in File 4, MT=2.

File 4 MT=52. Inelastic Scattering to 7.653-MeV Level
See Ref. 47.

File 4, MT=53. Inelastic Scattering to 9.638 MeV Level
See Ref. 47.

File 4, MT=54 to 91. Isotropic in Center-of-Mass

File 5, MT=9l. Evaporation Spectrum with T=0.3 MeV.
This is a small component of (n, n' 3α) and is used mainly for the decay of the 2.43 MeV level of ^{9}Be (Ref. 34) and for reproducing the correct threshold effect. [35]

File 8, MT=103. Activation Data Following (n, p) Reaction.[48]

File =10, MT=I03. (n, p) Cross Section Leading to Activation
Same as File 3, MT=l03.

File 12, MT=l02. Multiplicity of (n, γ) gamma rays. [49]

File 13, MT=51. Production of 4.439 MeV gamma rays.
Same as File 3, MT=5l.

File 14, MT=51. Angular Distribution of 4.439 MeV gamma rays.[33,50-56]

File 14, MT=l02. Angular Distribution of Capture gamma rays.
Isotropic in center-of-mass.

File 33, MT=l to 107. Uncertainty Files for File 3 Data.

References

1. J. Lashkar **et al**., INDC(F/R)-7/L (1965).

2. R. B. Schwartz. H. T. Heaton. and R. A. Schrack. Bull. Am. Phys.Soc. **15**. 567 (1967).

3. S. Cierjacks .et al.. KFK 1000 and private communication (1969) .

4. F. G. Perey. T. A. Love. and W. E. Kinney. ORNL-4823 (1972).

5. H. Ahmed **et al**.. Nucl. Data for Reactors. Helsinki. paper CN-26/23 (1970)

6. R. C. Block **et al**., J. Nucl. Sci.. and Tech. **12**. 1 (1975).

7. K. M. Diment and C. A. Uttley. EANDC(UK)94AL (1968).

8. N. C. Francis **et al**.. Neutron Standards and Flux Norm. Symp. Argonne. p. 21(1970).

9. H. T. Heaton **et al**., Nucl. Sci. Eng. 56, 27 (1975).

10. A. Langsdorf, Jr. **et al**., Phys. Rev.**107**, 1077 (1957).

11. R. 0. Lane.**et al**., Ann. Phys. 12, 135 (1961).

12. R. 0. Lane.**et al**., Phys. Rev. **186**. 1618 (1969).

13. J. W. Meadows and J. F. Whalen. Nucl. Sci. Eng. **41**. 351 (1970).

.

14. W. E. Kinney. ORNL. private communication (1976).

15. R. J. Holt. Phys. Rev. Lett. **28**, l34. (1972).

16. R. J. Holt, Nuclear Cross Sections and Technology, NBS-42S, Vol. I. p. 246 (1975) .

17. P. Stoler et al.. Bull. Am. Phys. Soc. **15**, 1668 (1970).

18. R. W. Meier **et al**., Helv. Phys. Acta **27**, 577 (1954).

19. J. E. Wills **et al**., Phys. Rev. **109**. 891 (1958).

20. H. D. Knox .**et al**.. .Nucl. Phys. **A213**, 611 (1973).

21. F. 0. Purser **et al.**, WASH-1048 (1964).

22. A. J. Elwyn and R. 0. Lane, Nucl. Phys. **31**, 78 (1962).

23. P. E. Wenzel **et al.**. , Phys. Rev. **137**, B80 (1965).

24. C. A. Kelsey et al., Nuc1. Phys. **68**, 413 (1965).

25. G. V. Gor1ov **et a!.**, Doklady Akad. Nauk. **158**, 574 (1964).

26. W. Galati **et al**., Phys. Rev. C **5**, 1508 (1972).

27. F. G. Perey and W. E. Kinney, ORNL-4441 (1969).

28. C. R. Lubitz, KAPL, private communication (1976).

29. D.. E. Velk1ey **et al**., Phys. Rev. C **7**, 1736 (1973).

30. G. Haouat **et al**., CEA-R 4641 (1975).

31. F. 0. Purser. TUNL. private communication (1976) .

32. F. Bore1i **et al**., Phys. Rev. **174**, 1174 (1968).

33. G. L. Morgan **et al**. , ORNL-TM-3702 (1972) .

34.. B. Antolkovic and Z. Dolenec, Nucl. Phys. **A237**, 235 (197S) .

35. G. M. Frye **et al**., Phys. Rev; **99** , 1375 (1955).

36. L. L. Green and W. Gibson, Prov. Phys. Soc. **A26**, 296 (1949).

37. S. S. Vasilev **et al**. , J. E. T. P. **6**, 1016 (1958) .

38. B. C. Cook, Phys. Rev. **106**, 300 (1957).

39. E. M. Rimmer and P. S. Fisher, Nuc1. Phys. **A108**,.561 (1968).

40. 0. Ames **et al**., Phys. Rev. **106**., 775.(1957).

41. E. A. Davis **et al**., Nucl. Phys: **48**. 169 (1963).

42. V. V. Verginsky **et al**., Phys. Rev. **170**, 916 (1968).

43. T. Retz **et al.**, Bull. Am. Phys. Soc.**5**, 110 (1968).

44. E. R. Graves and R. W. Davis, Phys. Rev. **97**, 1205 (1955).

45. A. W. Obst **et al**., Phys. Rev. C **5**, 738 (1972).

46. L. Van der Zwan and K. W. Geiger, Nucl. Phys.**A152**, 481 (1970).

47. G. A. Grin **et al**., Helv. Phys. Acta **42**, 990 (1969).

48. F. Ajsenberg-Selove, Nuc1. Phys. **A248** I (1975).

49. F. Ajsenberg-Selove. Nuc1. Phys. **A152**, 1 (1970).

50. D. M. Drake et al., Nuc1. Sci. Eng. **40**, :294 (1969).

51. H. E. Hall and T. W. Bonner, Nucl. Phys. **14**, 295 (1959).

52. J. T. Prudhomme **et al**., AFSWC-TR-30 (1960).

53. D. 0. Nellis and I. L. Morgan **et al**., Texas Nucl. Corp (1964).

54. J. D. Anderson **et al**., Phys. Rev. **111**, 572 (1958).

55. T. Koslowski **et al**., INR/661/IA/PL (1965).

56. F. C. Engesser, W. E. Thompson, and J. M. Ferguson, USNRDL-TR-791 (1964).

Covariance File for Carbon MAT 306

Covariance data are given for MF=33. MT=l, 2,3,51-68, 91, 102, 103, 104, and 107. Derived sections (NC subsections) reflect exactly the way the cross-section files were generated.

For MT=l, MT=2 above 2 MeV, MT=5l. and MT=107, covariances were determined for ±2α error bands. The error bands were extended and enlarged to cover energy regions lacking experimental data:. In general, long range covariances reflect systematic errors common to all data sets. Medium range covarinaces reflect differences in energy coverage by different data sets and differences in the experimental methods within ~he same data set. Short range covariances- reflect structures in the cross sections and/or threshold effects. Statistical errors are. in principle, nonexistent in the evaluated cross sections.

For MT=2 below 2 MeV. covariances were evaluated individually for each of six data sets. These six data sets and their covariances were averaged by least squares (Bayes theorem). The resulting covariances were further modified by considering the effects of the R-matrix fit which included thermal data. data above 2 MeV, and polarization data. Uncertainties (not covariances) in the. angular distributions were also evaluated and are reported in Atomic Data and Nuclear Data Tables (in press).

MT=52-68 are either discrete levels or bands of continuum levels to represent the secondary neutron distributions in (n.n3α) reactions with correct energy-angle kinematics. A 20% fully correlated uncertainty is given to each level or band of levels. This may require improvement in the next round of evaluation.

79-Au-197
MAT 1379

SUMMARY DOCUMENTATION
of
^{197}Au

S.F. Mughabghab

1. INTRODUCTION

Because of its monoisotopic nature, its chemical purity , its large thermal neutron capture cross section and absorption resonance integral [1] and the simple decay scheme of the product nucleus formed by neutron capture , the capture cross section of gold has become one of the primary basic standards . The evaluation of the capture cross section of gold in the energy region 200 keV-3.5 MeV, subject to the requirement for a consistent set of primary standards on (n, p) , ^{6}Li(n, α) , ^{10}B(n, α) and ^{235}U(n, f) for ENDF/B-V, was carried out in Conjunction with the Standards and Normalization Subcommittee of CSEWG and its Task Force. (a)

II THERMAL CROSS SECTIONS AND RESONANCE PARAMETERS

The recommended resonance parameters in the energy range 4.9 eV-2 keV, which appeared in BNL-32S, Third Edition [1] were adopted with minor changes and additions. The spin assignments of Lottin and Jain (2] were incorporated, and the parameters of a bound level with spin J=2 were derived in order to fit the experimental capture and total cross section at low neutron energies. This spin value of the bound level was deduced by Wasson et al [3] from interference analysis of neutron capture γ-rays.

Because of the presence of structure in the gold capture cross section up to 100 keV [4] , it was decided by the Standards and Normalization Subcommittee of CSEWG to extend the resolved energy region from 2.0 to 4.8 keV. Unfortunately, individual resonance parameters (r $_n$, r_γ , J values) were not available as yet. The $g\tau_n\tau_\gamma/\tau$ values of Macklin et AL [41 were combined with the renormalized $g\tau^2_n/\tau$ values of Hoffman et al [5J to obtain J, $\tau_{n,}$ r_γ values for the individual resonances. The renormalization factors were estimated by a comparison of the $g\tau^2_n$ values of Hoffman et al [5] with those derived frau BNL-32S [1] in the overlap region. This procedure indicated that the values of these authors are underestimated by about a factor of 3.5 for the strong resonances.

(a) The Au Capture Task Force members are: B.R. Leonard, Jr. (BNL) , Chairman, M.R. Bhat (BNL) , A.D. Carlson (NBS) , M.S. Moore (LASL) , S.F. Mughabghab (BNL) , R.W. Peelle (ORNL), W.F. Poenitz. (ANL) , L. Stewart (LASL).

79-Au-197
MAT 1379

The thermal cross sections at .0~53 eV are:
capture -98.71 b

scattering -6.84 b
total -105.55 b

The absorption resonance integral with a 0.5 eV cutoff is 1559 b.

III FAST NEUTRON CAPTURE CR.OSS SECTIONS

A. Total Cross Section

As pointed out previously, the total cross section from 10 eV to 4.8 keV is represented by the resonance parameters. The total cross section from 4.8-10 keV was derived from the average resonance parameters from -1.0 kev-2.3 MeV; it is based on data of Ref. [6-10] , from 2.3-15.0 MeV on data of Foster et al [11] .In the high energy region, 15.0 to 20.0 MeV, the evaluation is based on data of Peterson [12].

B. Elastic Cross Section

The elastic cross section from 4.8 kev to 20 MeV is obtained by subtracting the sum of all the nonelastic cross sections from the total cross section.

C. Total elastic Cross Section

This is obtained by the sum of all the discrete level excitation (77 keV-l.24 MeV) cross sections and the continuum cross section. The latter is derived by nuclear model calculations.

D. (n, particle) Cross Section

(n, 2n) cross section is based on the experimental data: contained in References [13-16). The (n, 3n) evaluation is based on the experimental data of Veeser et al. [16] .The (n, p) and (n, c) evaluation is based on data of Prestwood and Bayhurst [14].

E. Inelastic Cross Sections

The inelastic scattering cross section data. of Devilliers et al. [17] , Barnard et a1 [18] and Nelson et al. [19] were considered. In the neutron energy region where experimental information is not available, i.e. near threshold and above E_n = 1.6 MeV, the evaluation is based on a properly normalized statistical model calculation following the formalism of Hauser and Feshbach. Nuclear modal. calculations were carried out with the aid of the code Nuclear Data Group (vintage 1973) ,. and Barnard et al. [18] . Inelastic scattering cross section to the continuum of levels , specified by a low energy cut off of 1.25 MeV, is obtained by using COMNUC-l. The derived values are normalized to the difference between non-elastic and the sum of discrete inelastic and (n , particle) reaction cross sections .

F. Capture cross Section

The capture cross section of gold in the energy region from 10^{-5} ev to 4.8 keV is represented by the resolved resonance parameters . In the energy region from 4.8 keV to 200 keV, the evaluation is based on Macklin et al's data [4].

In the energy. region from 200-3500 keV r a great deal of effort was placed on the evaluation. The following procedure was adhered to. At first, the totality of the old and recent data were divided into two groups, depending on whether the measurement is designated as absolute or relative. Subsequently, the relative gold capture cross sections were separated into four groups corresponding to one of the adopted standards (n, p) , ^{6}Li.(n, α) , ^{10}B(n, α) or ^{135}U(n, f). In those cases where the ratio values were not reported by the authors, these were reconstructed

whenever enough information was provided by the authors. As an example, the ^{6}Li(n, α} cross section adopted by Macklin, et al. [4] in his flux measurements was derived here from the reported prescription and the ratio values of the gold capture cross section to ^{6}Li(n, α} cross section were obtained. Then various ratio values corresponding to each standard were placed saparate1y and were initially compared with the ratio values derived from ENDF/B-V. Such a procedure is helpful in discerning any systematic trends in the data as may be indicated by high or low values or possible changes in the shape of the relative cross sections. Ratio values which deviated by more than two standard deviations from ENDF /B-V or the average of the experimental values were rejected.

The following observations could be made regarding these data.:

1. Data of Macklin et al. , [4], Lindner, et al, [21] and Fort and Le Rigolaur [221 are generally in very good agreement.
2. As show by Fort and Le Rigo1eur [22] the activation and nonactivation measurements are in reasonable agreement with each other particular1y in the energy region 400-500 keV where the deviation is only about 2%.
3. Data of Paulsen, et al., [23] Fricke, et al. [24] and Barry .et al. [25] measured relati- ve to the (n, p) cross section are consistently high with respect to the ENDF./B-IV evaluation and with the data of Macklin, et al. , [4], Lindner. et al. , [21], Poenitz [26] and Fort and Le Rigoleur [22] .
4. In the energy range l000-3500 keV, the data of Paulsen, et al., [23] appear to Converge, particularly at the high energy and with that of Peonitz [26] and Lindner, et al., [21].
5. The Robertson. et al. , [27] cross section value at 966 keV is about 12% high , with respect to Poenitz [26], Lindner et al. , [21] and ENDF/B-IV evaluation , but somehow in agreement with the data point of Paulsen, et al., [23] .Since it is believed that there is no structure in the gold capture cross section at this energy , the result of Robertson, et al. , [27] was down-graded.
6. The data. of Czirr and Stalts [28] is high when compared with other data, and with the.ENDF/B-IV evaluations. It is to be noted that. the data points at 319, .412 and 532. keV were withdrawn by the authors

.

On the basis of these observations, it was decided to base the ENDF/B-V evaluation on the data. sets of Macklin, et al., [4] , Fort and Le Rigo1eur [22], Poenitz [26], and Lindner, et. a1.,[21] in the. Energy range 100-1000 keV. Above l00 keV, the ENDF/B-IV evaluation is based on Poenitz [26] , Lindner's et al.' s [21] and Paulsen et al. ' s [23 data. The result of this is essentially to decrease the capture cross section of gold by not more than about 4%. This is about the magnitude of the uncertainty of the gold capture cross section in this energy range.

In the energy region 3.5-2.0 MeV, experimental data is sparse. These include the data of Johnsrud et al [29] and Miskel et al., [30], both of which used the activation technique and measured the flux with a fission chamber. Between 4 MeV and 20 MeV, only 14 MeV data by Drake et al., [31] and Schwerer et al., [32] are available, which indicate that the capture cross section of gold at 14 MeV is about 1 mb. As a result, the ENDF/B-V evaluation between 3.5-

20 MeV is based on COMNUC calculations which are normalized to a value of 14 mb at 14 mb at 4.4 Mev (renormalized Johnsrud et al., [29] data point) and 1 mb at 14 MeV.

It is of interest to calculate the fission spectrum average of the capture cross section and compare it with experimental measurements. Absolute capture cross section measurements for ^{197}Au for ^{252}Cf spontaneous fission neutrons were carried out recently by Green [33] and Mannhart [34] who reported values of 79.9 ± 2.9 and 76.2 ± 1.8 mb respectively .In addition, Fabry, et a.l., [35] reported an integral cross section ratio .measurement of 197Au(n, γ) relative to ^{238}u(n, f) for a thermal-induced ^{235}U fission neutron spectrum. Adopting a value of 295.4 mb for ^{238}u(n, f) fission spectrum average from the ENDF/B-V dosimetry file. [36], (ENDF/B-V file as yet unavailable}, one obtains a value of 85 + 4 mb for ^{198}Au(N, γ)^{199}Au.

A maxwellian fission spectrum of characteristic temperature T and represented by:

$$\Phi(E) = C\sqrt{E}\, e^{-\frac{E}{T}} \qquad (1)$$

was employed (C is a normalizing constant). Values for T of 1.32 MeV (ENDF/B-IV) and 1.39 MeV were used in the calculations for ^{235}U and ^{232}Cf fission. spectra respectively.

The ^{235}U and ^{252}Cf fission spectrum averages of the ENDF/B-V gold capture cross section are calculated with the aid of Eq. 1, and are shown in Table 1. The evaluated values are compared with experimental numbers [33-35,37].

TABLE I

Compari.son with Integral Measurements

Fission Spectrum	Experimental Values (mb}	Present Evaluation (mb)	Reference	
^{235}U(T=1.32 MeV)	84.8 + 4.1	81.3	Fabry	[34]
^{252}Cf (T=1.39 MeV)	79.9 + 2.9	78.1	Green	[33]
	76.2 + 1.8		Mannhart	[34]
	95.5 + 2.3		Pauw	[36]

IV ANGULAR DISTRIBUTION OF SECONDARY NEUTRONS

The elastic scattering Angular distribution in the energy range up to 8.05 MeV are based on experimental data. With the aid of the optical model parameters derived by Holmquist and Wiedlinq [38] , optical model calculations were carried out bv using ABACUS-2. The

calculations were compared with measurements at the following neutron energies: 0.5, 1.0, 2.0, 2.5, 5.0, and 8.05 MeV. The agreement between calculations and measurements is reasonably good enough to warrant extrapolating them above 8.1. MeV where experimental data are not available. In addition, the graphic display code Tiger [39] was used to fit the experimental data with a least-squares spline procedure, check Wick's 1imi t , and then extract Leqendre coefficients of various orders for the angular distribution of scattered neutrons. Because of the absence of experimental data., the angular distributions for the (n, particle) reactions have been specified as isotropic

V. ENERGY DISTRIBUTION OF SECONDARY. NEUTRONS

The energy distribution of secondary neutrons for the (n,2 n) , (n, n') reactions have been calculated as a nuclear temperature energy in MeV using code THETA [40] .For more detail, see documentation on Gd isotopes by B.A. Magurno.

79-Au-t97
MAT 1379

REFERENCES

l. S.F..Mughabghab and D.I. Garber, BNL-325, Third Edition, Volume 1 (1973) .

2. A. Lottin and A. Jain, Journal de Physique, 34, l23, (1973) .
3. O.A. Wasson et al, Phys. Rev. l73, 1170 (l968).
4. R .L. Mack1in, J. Halperin, and R.R. Winters, Phys. Rev/C, 11, l270 (1975) .
S. M.M. Hoffman , et al, Neutron cross Sections and Technology Vol. 2, p868 (1971), Knoxville, Tenn.
6. K.K. Seth, Phys. Letters, 16, 306 (1965).
7. W. Bilpuch, private communication (1959).
8. J.F. Whalen, ANL-7210, 16 (1966).
9. M. Wait and R.L. Becker, Phys. Rev. .89, 1271 (1953).
10. R.B. Day, private communication (1965).
11 D.G. Foster, Jr., private communication (1967} .See also Phys. Rev/C 3, 576 (1971) .
l2. J.M. Peterson, Phys. Rev. 110, 927 (1958); ibid, l20, 521 (1960).
13. H. Tewes, et al, private communication (1960).
14. R.J. Prestwood and B.D. Bayhurst, Phys. Rev. l21(1438, (1961).
15. K. Liskin, et al, Atomkernenergie 26, 24 (1978).
16. E.R. Veeser, E.D. Arthur and P.G. YOUNG Phys. Rev/C, l6, 1792 (1977)
17. J.A.M. DeVilliers, et al. , Zeit. Physik l63, 323. .(1965) .
l8. E. Barnard, et al., .Nucl. Phys., A107, 612 (l968).
19 J.A. Nelson et al., Phys. Rev. C3, 307 (197l) .
20. C.L. Dunford, AI-AEC-l2931. (1970) -
21. M. Lindner, R.J. Naqle, and J.H. Landrum, Nuc1. Sci. Eng- 59, 38l (l976).
22. E. Fort and C. Le Rigoleur , NBS Special Publication 425, Vol. 2, 957, (1975). This represents two data. sets, one by .Fort using the activation technique, the other by Le Rigoleur using prompt gamma rays.
23. A. Paulsen, R. Widera, and H. Liskien, Atomkernergie 26, 80 (1975)-
24. M.P. Fricke, et a1, Nuclear Data for Reactors,. Helsinki, Vol- 2, 281 (1970).
25. J .F .Barrv, J- Nuc1- Energy l8. 491. (l964) -
26. W. Poenitz. Nuc1. Sci. Enq. 57, 300 (1975).
27. J.C. Robertson et al., Jour. Nucl. Energy 23, 205 (1969) -
28. J.B. Czirr and M.L. Stelts, Nucl- Sci. Eng. 52, 299 (1973).
29. A. E. Johnsrud, M. G. Silbert, and H.B. Barshall, Phys. Rev. 116, 927 (l959).
30. J.A. Miskel, et al., Phys. Rev. l28, 27l7 (1962).
31. D. Drake, I. Berqvist and .D.X. McDaniels, Phys. Letters 36B, 557 (197l).
32. 0. .Schwerer , et al , Nucl. Phys. A264, l05 (1976).
33. L. Green, Nucl. Sci. Enq. 58, 361 (l975).
34. W. Mannhart, Proceedinqs of the IAEA Consultants Meeting on Integral Cross Section Measurements in Standard Neutron Fields , Vienna., November 15-l8, 1976.

35. A. Fabry, J .A. Grundl and C. Eisenhauer, NBS special publication 425, Vol. 1, 254 (l975) , Nuclear Cross Sections and Technology.

36. ENDF/B-IV Dosimetry file BNL-NCS-50446 (1975) Ed. B.A. Magurno.

37. B. Pauw and A.H.W. Aten, Nucl. Energy 25, 457 (l971).

38. B. Ho1mqvist and T. Wied1ing, Nucl. Phys. Al88, 24 (1971) , AE-403 (l971) .

39. R.F. Kinsey, DUMMY-5, private communication.

40. C. Dunford, private communication.

92-U –235

MAT 1395

Summary Documentation for ^{235}U.

(MAT-1395)

M. R. Bhat

1. Introduction

The present evaluation of ^{235}U for ENDF/B-V is based on the ENDF/B-IV evaluation by L. Stewart (LASL), R. Alter (A. I.) and R. Hunter (LASL) [1] except for changes and updates in the fol1owng sections discussed below. These changes represent the work of many people either as individuals or as .a group such as The Normalization and Standards Subcommittee of CSEWG. Some of these contributions have been discussed in separate reports by the authors. These w1l1 be referred to here and their contents wil1 not be discussed in detail.

2. File 1

(i) Nu-bar Total (MT=452)

These values were changed to reflect changes made in the $\bar{\nu}_{prompt}$ and $\bar{\nu}_{delayed}$.

(11) Nu-bar Delayed (MT=455)

The delayed neutron yields were evaluated by Kaiser and Carpenter [2 where the details of the evaluation are discussed.

(iii) Nu-bar Prompt (MT=456)

The data sets [3-19] were used. They were first normalized to

$^{252}Cf\ \bar{\nu}_{prompt} = 3.757 \pm .015$ and $^{235}U\bar{\nu}_{prompt}$ (0.0253 eV) =2.420 ± .012 as recommended by the Normalization and Standards Subcommittee [20]. Data were fitted with straight lines in the energy region 0-2 MeV, 2-5.5 MeV, 6-20 MeV with a join from 5.5 to 6.0

MeV. A plot. of the renormalized data indicates that there is a step in the $\bar{\nu}_p$ 5.5 to 6 MeV. and this was included in the calculation. The details of the evaluation and data plots are in Ref. 21.

(iv) Energy Released in Fission (MT=458)

The energy released in fission and its partition into the different modes of decay was evaluated by R. Sher et al., [22].

92-U-235

MAT 1395

3. File 2

(i) The Resolved Resonance Region (MT=151) (1,0-82.0 eV).

The resolved resonance parameters are the same as those evaluated by Smith and Young [23] for ENDF/B-III.

(ii) The Unresolved Resonance Region MT=151) (82.0-2.5E+04 eV)

Evaluation of the bin averaged fission and capture cross-sections is described in Ref. [21,23]. The fine structure in fission cross-section was a consensus structure arrived at by energy shifting the data of Blons [24], ORNL-RPI [25] , Gwin [26] with respect to the Lemley [27] data. Similarly, the fine structure as well as the bin average of the capture cross-section were determined. Results of the analysis of Moore [281 were used and the unresolved resonance region parameters were extracted using the code UR by Pennington [29].

4. <u>File 3</u>

(i) <u>The Thermal Energy Region (1.0E-05 -1.0 eV)</u>

.The total scattering capture and fission cross-sections in this energy region were obtained by Leonard [30]. This evaluation as modified between 0.85 and 1 eV to join smoothly with the resolved resonance region at 1 eV. The 0.0253 eV values for capture and fission are 98.38 ± 0.760 and 583.54 ± 1.70b respectively.

(ii) <u>Fission Cross-Section (25 keV-100 keV) .</u>

The structure in the fission cross-section as given in ENDF/B-IV and based on. Gwin data was preserved by multiplying theENDF/B-IV cross-section by 0.9781 to give the average cross-section evaluated in Ref. 23.

(iii) Fission Cross-Section (100 kev-20 MeV)

This evaluation is by Poenitz [31].

(iv) <u>Capture Cross-Section (25 keV-20 MeV).</u>

This was obtained by multiplying the evaluated ENDF/3-V fission cross-section by the capture-to-fission ratio of ENDF/B-IV.

5. <u>File 4</u>

The angular distributions are the same as in ENDF/B-IV [1] .

6. <u>File 5</u>

(i) <u>Fission Neutron Spectra</u>

The energy dependent Watt spectrum representation is used for fission neutrons. The procedure used was to take the a and b parameters for an energy dependent Watt spectrum as given by Kujawski and Stewart for their Pu-239 evaluation (for the fission part of file 1399/5/19) calculate the mean energy $\bar{E}$ and divide it by 1.04, the value obtained by Adams [32] for the $\bar{E}_{Pu-239}/\bar{E}_{U-235}$ to give $\bar{E}$ for U-235 as a function of energy. From these values, and assuming a=0.988 MeV as given by Adams at lower energies, b is calculated. These are assumed to be constant for $E_n = 1.0E^{-5}$ eV to $1.5x10^6$ eV and a sma11 energy dependence is built into a and b to give the correct E. The pre-fission part of sections 5/20 and 5/21 are given as an evaporation spectrum with a temperature obtained from section 5/91, i.e., at a particular energy E_n one finds (E_n – $E_{thresh.2nd}$) chance fission or (E_n - $E_{thresh.3rd}$) chance fission and the corresponding temperature above the 5/91 threshold is given. Having fixed these parameters, the mean energy corresponding to section 5/18 could be calculated knowing $\sigma_{f\,Total}$, $\sigma_{nn'f}$, σ_{n2nf}, and.$\bar{v}_p$ and the energy dependent parameters a and b calculated.

(ii) Delayed neutron Spectra
The evaluation is by Kaiser and Carpenter [2].

7. File 8
(i) Fission Product Yield Data (MT=454 and 459)
The fission product yield data were reviewed and recommended by the Fission Products Yields Subcommittee and the data files prepared by T.R. England [33].

(ii) Radioactive Decay Data (MT=457)
Radioactive decay data were evaluated by C.W. Reich. The Q (alpha)-values are from [34] and the half-life data are from Jaffey et al., [35], and also Vaninbroukx [36] .Alpha energies and intensities are from Ref. [31,38] , and the gamma-ray and L x-ray data are from Ref. [31] .

8. File 13
(i) Gamma-ray Production Cross-Section from E_n = 1.09 - 20 MeV (MT=3)
This was re-evaluated to include the new data of Drake et al., [39,40]. These were compared with the earlier data of Nellis and Morgan [41] and Buchanan et al., [42] above E_γ 0.5 MeV and are found to be in good agreement. The Drake data in Ref. [39] have a

low-energy cut-off of $E_\gamma = 0.25$ MeV and for their 14.2 data [40] it is $E_\gamma = 0.3$ MeV. The low- energy part of the spectrum vas obtained by a simple extrapo1ation of the data.

9. File 15

(1) Energy Distribution of the Gamma-rays $E_n = 1.09 - 20$ MeV (MT=3)

These are based on the Drake data [39,40].

10. Files 31 & 33

(i) Data Variance -Covariance Files (MT=452, l8, 102)

The evaluation of these files for $\bar{\nu}_{Total}$, σ_f and $\sigma_{n\gamma}$ is by R.W. Pee1le [43].

References

1. L. Stewart, H. Alter and R. Hunter.ENDF-201 (1976).
2. R.E. Kaiser and S.G. Carpenter (ANL-West) Priv. Comm. (1978).
3. J.Y. Meadows, WASH-1053. 9 (1964).
4. J.W. Meadows and J.F. Whalen, Jour. Nuc. Energy **21**. 157 (1967).
5. D.W. Calvin and M.G. Sowerby 65 Salzburg Conf., 31 (1965).
6. B. Conde. Arkiv for Fysik. **29**. 293 (1965).
7. B.C. Diven et al.. Phys. Rev. **101,** 1012 (1956).
8. J.W. Meadows and J.F. Whalen. Phys. Rev. **126**, 197 (1962).
9. J.W. Boldeman et al.. Nuc. Sci. and Eng. **63**, 430 (1977).
10. M. Solei1hac. Priv. Comm. to L. Stewart (1976).
11. V.G. Nesterov. '70 Helsinki. CN-26/74 (1970).
12. J.C. Hopkins and B.C. Diven. Nuc. Phys. **48**, 433 (1963).
l3. D.S. Mather et al., Phys. Rev. **B133**, 1403.(1964).
14. L.I. Prokhorova et al., Sovt. Nuc. Phys. **7**, 579, (1968).
l5. A. Moat et al., Jour. Nuc. Energy **15**. 102 (1961).
16. J. Frehaut, Priv. Comm. to L. Stewart (1976).

17. J. Frehaut et al., see Ref. 9.
18. A. De Volpi et al., '66 Paris Conf. Vol. I, p297 (1966).
19. D.W. Colvin and M.G. Sowerby '65 Salzburg Conf.
20. B.R. Leonard, Jr. , Priv. Communication (1978) .
2l. M.R. Bhat, U-235 Evaluation for ENDF/B-V (ENDF-248) to be published.
22. R. Sher, S. Fiarman and C. Beck. Private Communication (1977).
23. M.R. Bhat, ANL-76-90 (ERDA-NDC-5/L) p307 (1976).

24. J. Blons, Nuc. Sci. and Eng. **51**, 130 (1973).
25. G. de Saussure.et al., ORNL-TM-1804 (1967).
26. R. Gwin et a1., Nuc. Sci. and Eng., **59**. 79 (1976).
27. J.R. Lemley et al., Nuc. Sci. and Eng. **43**, 281 (1971).
28. M.S. Moore et al., Phys. Rev. **C18** 1328 (1978)
29. E. Pennington, Private Communication (1973).
30. B.R. Leonar-d. Jr., et al.. EPRI NP-167 (1976j.
31. W.P. Poenitz, ANL/NDN-45 (1978) to be published.
32. J. M. Adams, AERE-R-8636 (1977).
33. T.R. England, Private Communication (1978).
34. 1974 Version of Wapstra – Bos - Gove Mass Tables.
35. A.H. Jaffey et a1., Phys~ Rev. **C8** lS8S (1971).
36. R. Vaninbroukx, Euratom Report EUR-5194E (1974).
37. E. Vano et al., Nuc. Phys. **A251**, 225 (1975).
38. A. Artna-Cohen, Nuclear Data , **B6** 287 (1971).
39. D.M. Drake, Nuc. Sci. and Eng. **55**, 427 (1974).
40. D.M. Drake, E.D. Arthur and M.G. Silbert, Nuc. Sci. and Eng. **65**, 49 (l978).
41. D.O. Nellis and I.L. Morgan ORO-2791-17 (1966).
42. P.S. Buchanan, D.O. Nellis and W.E. Tucker, ORO-279l-32 (197l).
43. R.W. Peelle (Appendix B) of EPRI Proj 612 Report by E.T. Tomlinson et al. EPRI NP-346, Project 612, ENDF-252 (1977).