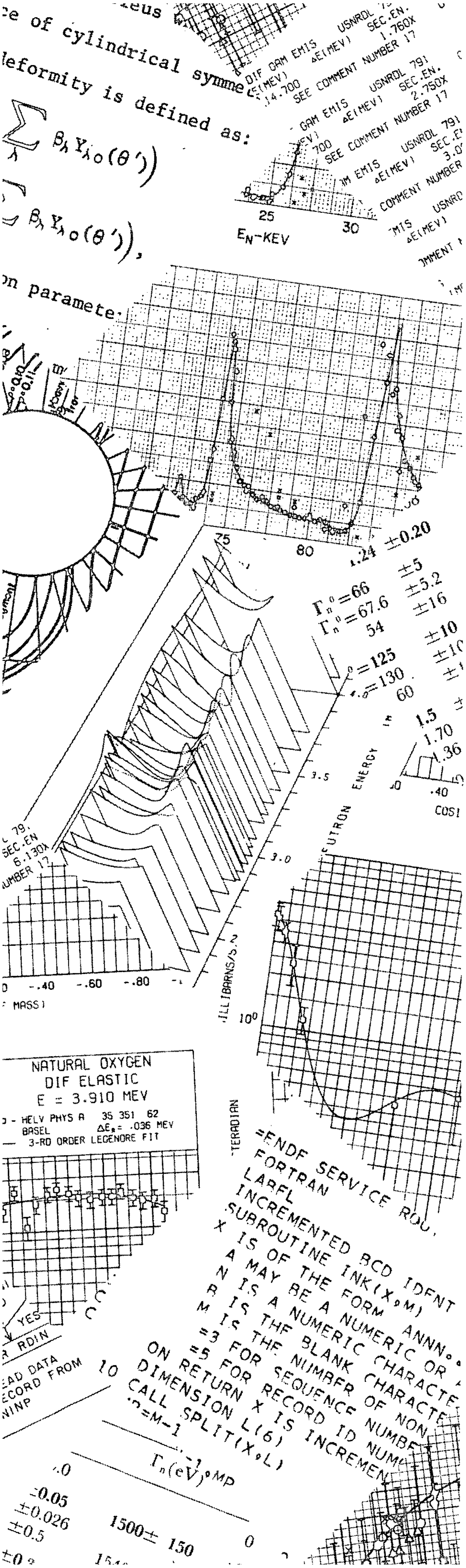

BNL-NCS-51619
ENDF-301
NEACRP-L-261
NEANDC(US)-213/L
INDC(US)-89/L

ENDF/B-V CROSS SECTION MEASUREMENT STANDARDS

Edited by:
A.D. Carlson and M.R. Bhat

with Contributions by
C.Y. Fu, G.M. Hale, R.J. LaBauve, S.F. Mughabghab,
F.G. Perey, W.P. Poenitz, L. Stewart, and P.G. Young

October 1982

INFORMATION ANALYSIS CENTER REPORT

NATIONAL NUCLEAR DATA CENTER
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

national nuclear data Center

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes:
Printed Copy: A05; Microfiche Copy: A01

Table Of Contents

	Page
Introduction	1
The Hydrogen (^{1}H) Scattering Cross Section L. Stewart, R. J. LaBauve and P. G. Young Los Alamos National Laboratory.	3
^{3}He (n,p)T Cross Section L. Stewart Los Alamos National Laboratory	19
The ^{6}Li (n,t)^{4}He Cross Section G. M. Hale, L. Stewart and P. G. Young Los Alamos National Laboratory	25
The ^{10}B $(n,\alpha)^{7}Li$ and ^{10}B $(n,\alpha_1\gamma)^{7}Li^{*}$ Reactions G. M. Hale, L. Stewart and P. G. Young Los Alamos National Laboratory	31
Neutron Scattering Cross Sections of Carbon Below 2 MeV for ENDF/B-V C. Y. Fu and F. G. Perey Oak Ridge National Laboratory	35
Evaluation of the Capture Cross Section of ^{197}Au S. F. Mughabghab Brookhaven National Laboratory	47
Evaluation of ^{235}U (n,f) Between 100 keV and 20 MeV W. P. Poenitz Argonne National Laboratory	59
Appendix: Numerical Tabulation of Cross Sections and Their Uncertainties	73
H (n,n)	75
^{3}He (n,p)T	78
^{6}Li (n,t)^{4}He	79
^{10}B $(n,\alpha)^{7}Li$	81
^{10}B $(n,\alpha_1\gamma)^{7}Li^{*}$	82
C (n,n)	83

Table of Contents (cont.)

	Page
$^{197}Au\ (n,\gamma)$	91
$^{235}U\ (n,f)$	93

Introduction

The Subcommittee on Normalization and Standards of the Cross Section Evaluation Working Group (CSEWG) coordinates, oversees and approves evaluations of cross section measurement standards for the Evaluated Nuclear Data Files (ENDF/B). This report is a collection of brief summaries describing the eight cross section standards approved for ENDF/B-V. It is hoped that this document will form a handy reference to the ENDF/B-V standards and serve as an introduction to the more detailed reports published by individual evaluators. This report may be considered to be the latest in a series of similar reports on ENDF/B standards. The report on ENDF/B-III was edited by Drake (BNL-17188, ENDF-179, 1972) and the one for ENDF/B-IV was edited by Magurno (BNL-NCS-50464, ENDF-225, 1975). We have also included in an Appendix numerical tables of the standard cross sections and their uncertainties selected from the International Nuclear Data Committee Standards Report INDC-36/LN published by the IAEA Nuclear Data Section, Vienna. Our grateful thanks are due to Alan B. Smith for providing us with a tape containing these tables.

A. D. Carlson M. R. Bhat

THE HYDROGEN (^1H) SCATTERING CROSS SECTION

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

I. SUMMARY

The ^1H evaluation for ENDF/B-V is basically the same as the Version IV evaluation. Changes include the addition of correlated error data and different interpolation rules. 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. STANDARDS DATA

The $^1H(n,n)^1H$ elastic scattering cross section and angular distribution 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 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 20.442b derived by Davis and Barschall.[5] Therefore, for the present evaluation, the free-atom scattering cross section is assumed to be constant below

---

* For E_n = 30 MeV, the difference in the 180° cross section is ∼1% as calculated from the Legendre coefficients[3] compared to that calculated from the phase shifts.

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 from 0.5 to 20 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.

The Wisconsin data[8] are compared from 1.5 to 20 MeV with ENDF/B-V in Fig. 4 along with the very precise value[9] at 2.533 $\pm$ 0.003 MeV of 2.536 $\pm$0.0015 barns. Data from KFK and Harwell which are not shown in these figures also tend to support the ENDF curve reasonably well. At the same time, it would be useful to have a few points measured with excellent precision as further checks on the phase-shift analysis.

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[10] at 3.1 MeV is not atypical of the earlier distributions which, as shown in Fig. 5, 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. 6. 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[11] 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 7 shows the measurements of Galonsky[12] 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. 1 as Lengendre expansion coefficients. Using the Hopkins-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 1-MeV intervals from 1 to 20 MeV.

Certainly the Hopkins-Breit phase 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 ~1% and the angular distribution to ~2-3%. At lower energies where the angular distributions approach isotropy, the error estimate on the angular distribution is less than 1%.

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 $\sigma(\Theta)$ 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 $\sigma(\Theta)$ 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 much 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 2.5%. 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.

Several years have passed since the Hopkins-Breit phase-shift analysis was performed. Recent phase-shift analyses carried out by Bohannon, et al.,[53] in 1976 and by Arndt, et al.,[54] in 1977 agree reasonably well with each other and with the Hopkins-Breit and the LLNL constrained set. These analyses emphasize the need for precise angular distribution measurements which cover a wide angular range in order to improve the precision obtainable for the value of $\delta(^1P_1)$.

It is very doubtful whether a new phase-shift analysis using the existing relative angular distribution measurements would provide data with better accuracy than already quoted for the Yale phase-shift analysis. It may be worthwhile, however, to perform a simultaneous charge-independent analysis of the n-p and p-p systems since p-p experimental data cover a wide energy range and the charged-particle measurements have very small associated errors.

ENDF/B-V contains the covariance matrices for the integral elastic scattering cross sections. The associated errors on the angular distributions were not allowed in the ENDF/B-V formats.

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 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. Seamon, K. A. Friedman, G. Breit, R. D. Haracz, J. M. Holt, 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 Singlet 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. A 183, 51 (1972).

8. J. C. Davis and H. H. Barschall, "Fast-Neutron Total Cross Section of Deuterium," Phys. Rev. C3, 1978 (1971).

9. J. C. Davis, K. A. Weaver, D. Hilscher, H. H. Barschall, and A. B. Smith, "Total Cross Section of Protons for 2.5 MeV Neutrons," Phys. Rev. C4, 1061 (1971).

10. Y. Oda, J. Sanada, and S. Yamabe, "On the Angular Distribution of 3.1-MeV Neutrons Scattered by Protons," Phys. Rev. 80, 469 (1950).

11. F. Cambou, "Amelioratin des Methods de Spectrometrie des Neutrons Rapids," Thesis - U. of Paris, CEA-N-2002 (1961).

12. A. Galonsky and J. P. Judish, "Angular Distribution of n-p Scattering at 17.9 MeV," Phys. Rev. 100, 121 (1955).

13. "ENDF/B Summary Documentation," ENDF-201, Compiled by D. Garber, (October 1975).

14. E. Melkonian, "Slow Neutron Velocity Spectrometer Studies of O_2, N_2, A, H_2, H_2O, and Seven Hydrocarbons," Phys. Rev. 76, 1950 (1949).

15. 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).

16. 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).

17. E. Bretscher and E. B. Martin, "Determination of the Collision Cross-Section of H, Deuterium, C and O for Fast Neutrons," Helv. Phys. Acta 23, 15 (1950).

18. C. E. Engleke, R. E. Benenson, E. Melkonian, and J. M. Lebowitz, "Precision Measurements of the n-p Total Cross Section at 0.4926 and 3.205 MeV," Phys. Rev. 129, 324 (1963).

19. C. L. Bailey, W. E. Bennett, T. Bergstralh, R. G. Nuckolls, H. T. Richards, and J. H. Williams, "Neutron-Proton and Neutron-Carbon Scattering Cross Sections for Fast Neutrons," Phys. Rev. 70, 583 (1946).

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

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

22. S. Bashkin, B. Petree, F. P. Mooring, and R. E. Peterson, "Dependence of Neutron Cross Sections on Mass Number," Phys. Rev. 77, 748 (1950).

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

24. C. L. Storrs and D. H. Frisch, "Scattering of 1.32 MeV Neutrons by Protons," Phys. Rev. 95, 1252 (1954).

25. D. G. Foster, Jr. and D. W. Glasgow, "Neutron Total Cross Sections, 2.5-15 MeV, Part 1 (Experimental)," Nucl. Instr. and Methods, 36, 1 (1967).

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

27. G. Ambrosino and A. Sorriaux, "Total Cross Section Efficiency for Carbon, Fluorine and Vanadium," Comptes Rendus 260, 3045 (1965).

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

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

30. 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).

31. W. Sleator, Jr., "Collision Cross Sections of Carbon and Hydrogen for Fast Neutrons," Phys. Rev. 72, 207 (1947).

32. A. Bratenahl, J. M. Peterson, and J. P. Stoering, "Neutron Total Cross Sections in the 7- to 14-MeV Region," UCRL-4980 (1957).

33. A. H. Lasday, "Total Neutron Cross Sections of Several Nuclei at 14 MeV," Phys. Rev. 81, 139 (1951).

34. L. S. Goodman, "Total Cross Sections for 14-MeV Neutrons," Phys. Rev. 88, 686 (1952).

35. H. L. Poss, E. O. Salant, and L. C. L. Yuan, "Total Cross Sections of Carbon and Hydrogen for 14-MeV Neutrons," Phys. Rev. 85, 703 (1951).

36. M. Tanaka, N. Koori, and S. Shirato, "Differential Cross Sections for Neutron-Proton Scattering at 14.1 MeV," J. Phys. Soc. (Japan) 28, 11 (1970).

37. M. E. Battat, R. O. Bondelid, J. H. Coon, L. Cranberg, R. B. Day, F. Edeskuty, A. H. Frentrop, R. L. Henkel,R. L. Mills, R. A. Nobles, J. E. Perry, D. D. Phillips, T. R. Roberts, and S. G. Sydoriak, "Total Neutron Cross Sections of the Hydrogen and Helium Isotopes," Nucl. Phys. 12, 291 (1959).

38. J. C. Allred, A. H. Armstrong, and L. Rosen, "The Interaction of 14-MeV Neutrons with Protons and Deuterons," Phys. Rev. 91, 90 (1953).

39. C. F. Cook and T. W. Bonner, "Scattering of Fast Neutrons in Light Nuclei," Phys. Rev. 94, 651 (1954).

40. H. L. Poss, E. O. Salant, G. A. Snow, and L. C. L. Yuan, "Total Cross Sections for 14-MeV Neutrons," Phys. Rev. 87, 11 (1952).

41. P. H. Bowen, J. P. Scanlon, G. H. Stafford, and J. J. Thresher, "Neutron Total Cross Sections in the Energy Range 15 to 120 MeV," Nucl. Phys. 22, 640 (1961).

42. J. M. Peterson, A. Bratenahl, and J. P. Stoering, "Neutron Total Cross Sections in the 17- to 29-MeV Range," Phys. Rev. 120, 521 (1960).

43. D. E. Groce and B. D. Sowerby, "Neutron-Proton Total Cross Sections Near 20, 24, and 28 MeV," Nucl. Phys. 83, 199 (1966).

44. 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).

45. 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).

46. R. B. Day and R. L. Henkel, "Neutron Total Cross Sections at 20 MeV," Phys. Rev. 92, 358 (1953).

47. M. E. Remley, W. K. Jentschke, and P. G. Kruger, "Neutron-Proton Scattering Using Organic Crystal Scintillation Detectors," Phys. Rev. 89, 1194 (1953).

48. J. D. Seagrave, "Recoil Deuterons and Disintegration Protons from the n-d Interaction, and n-p Scattering at E_n = 14.1 MeV," Phys. Rev. 97, 757 (1955).

49. S. Shirato and K. Saitoh, "On The Differential Cross Section for Neutron-Proton Scattering at 14.1 MeV," J. Phys. Soc. (Japan) 36, 331 (1974).

50. T. Nakamura, "Angular Distribution of n-p Scattering at 14.1 MeV," J. Phys. Soc. (Japan) 15, 1359 (1960).

51. A. Suhami and R. Fox, "Neutron-Proton Small Angle Scattering at 14.1 MeV," Phys. Lett. 24, 173 (1967).

52. I. Basar, "Elastic Scattering of 14.4 MeV Neutrons on Hydrogen Isotopes," Few Body Problems Light Nuclei/Nucl. Interactions, Brela, 867 (1967).

53. G. E. Bohannon, T. Burt, and P. Signell, "Phase-Shift Analysis of the 20-30-MeV pp and np Scattering Data, Including New High-Precision np P(θ) Measurements," Phys. Rev. C13, 1816 (1976).

54. R. A. Arndt, R. H. Hackman, and L. D. Roper, "Nucleon-Nucleon Scattering Analyses, II. Neutron-Proton Scattering From 0 to 425 MeV and Proton-Proton Scattering From 1 to 500 Mev," Phys. Rev. C15, 1002 (1977).

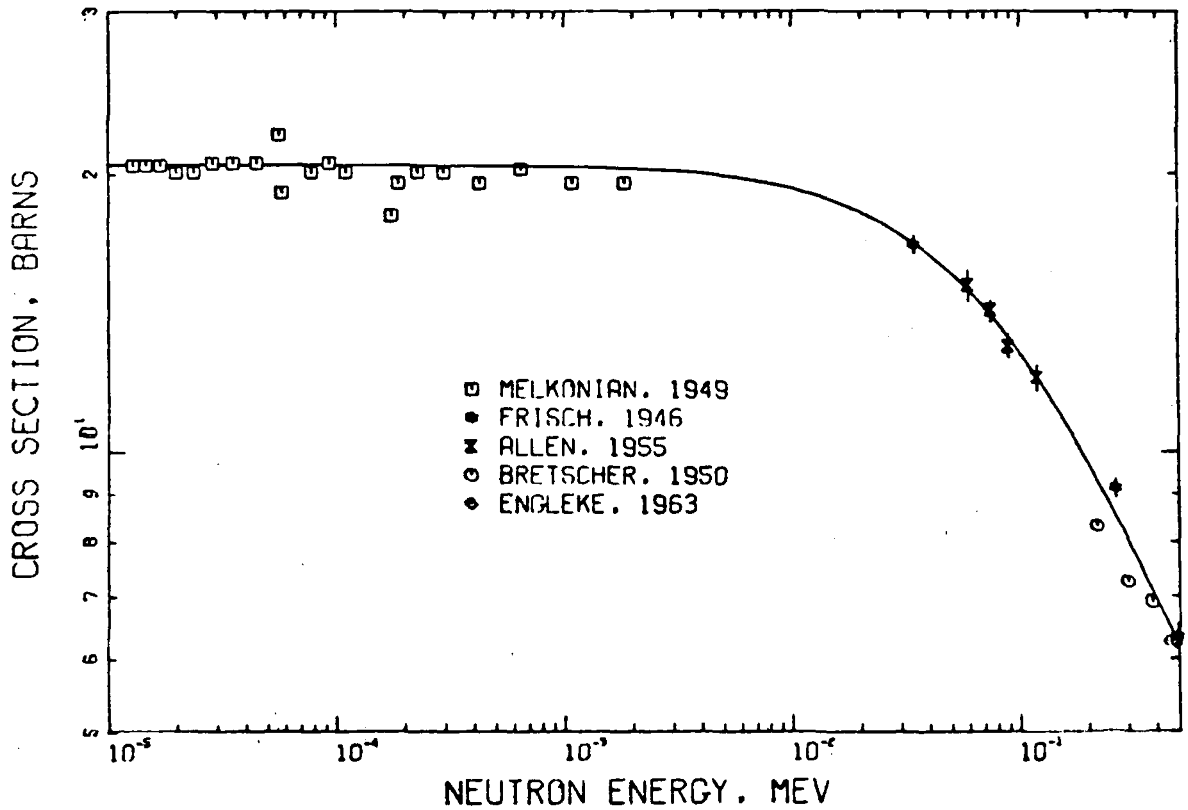

Fig. 1. Total cross section of hydrogen from 10 eV to 0.5 MeV. The ENDF/B-V evaluation is compared to the measurements of Refs. 14-18.

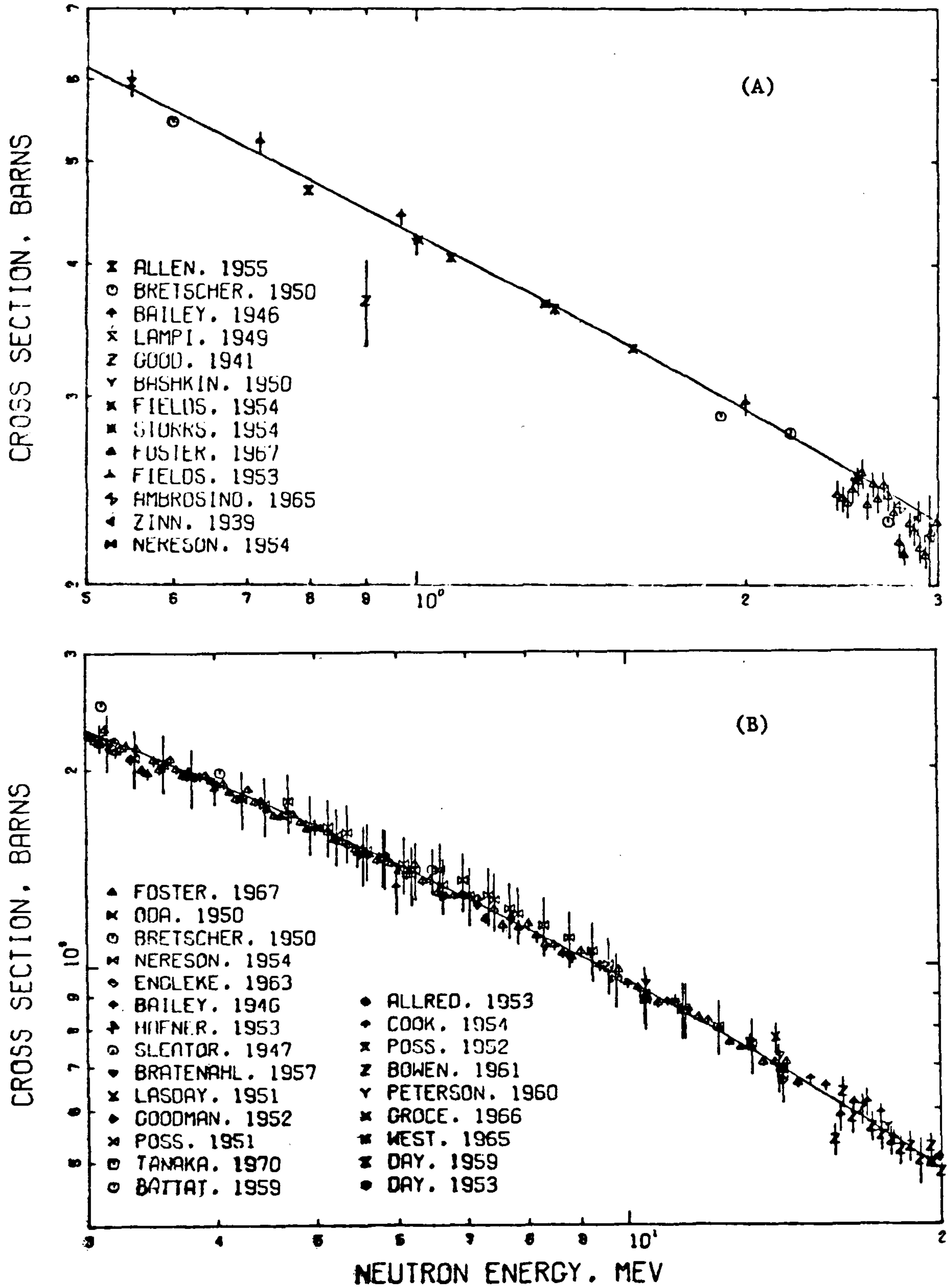

Fig. 2. Total cross section for hydrogen from 0.5 to 20 MeV. The ENDF/B-V evaluation is compared to measurements reported in Refs. 10, 16-46.

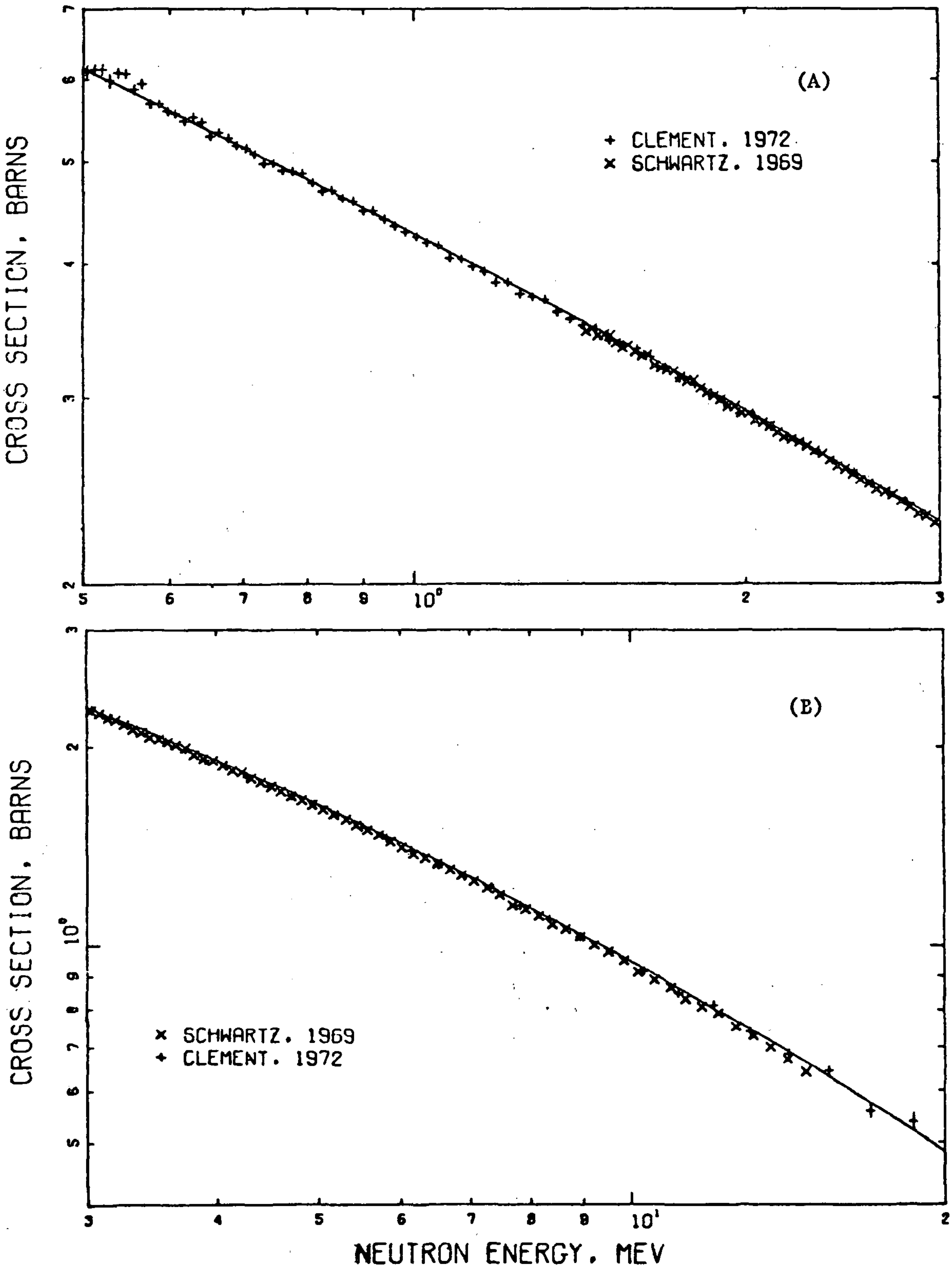

Fig. 3. Total cross section for hydrogen from 0.5 to 20 MeV. The ENDF/B-V evaluation is compared to measurements reported in Refs. 6 and 7.

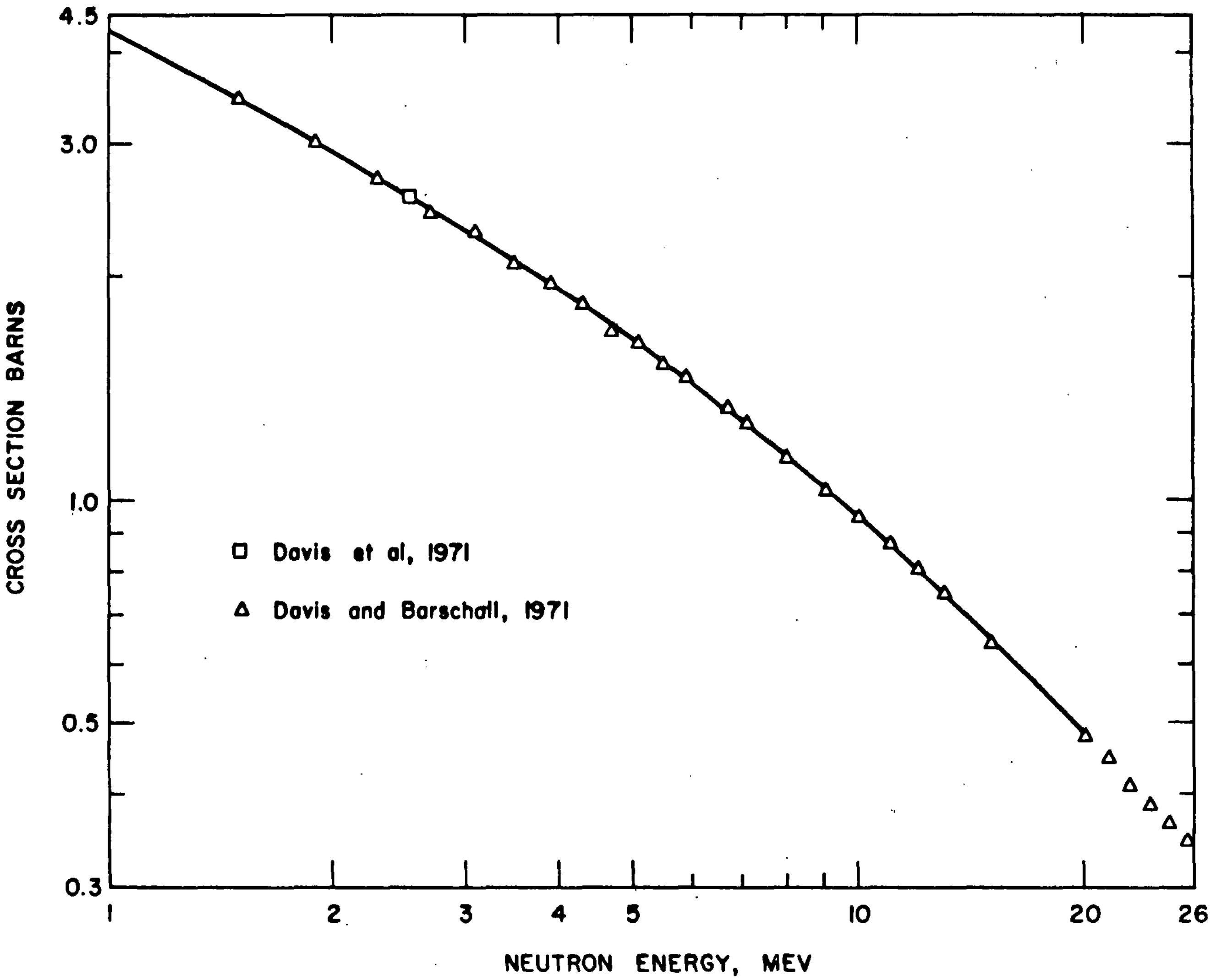

Fig. 4. Total cross section for hydrogen from 1 to 26 MeV. The ENDF/B-V evaluation is compared to the Wisconsin measurements of Refs. 8 and 9. Note that the symbols are larger than the experimental errors on these very precise measurements.

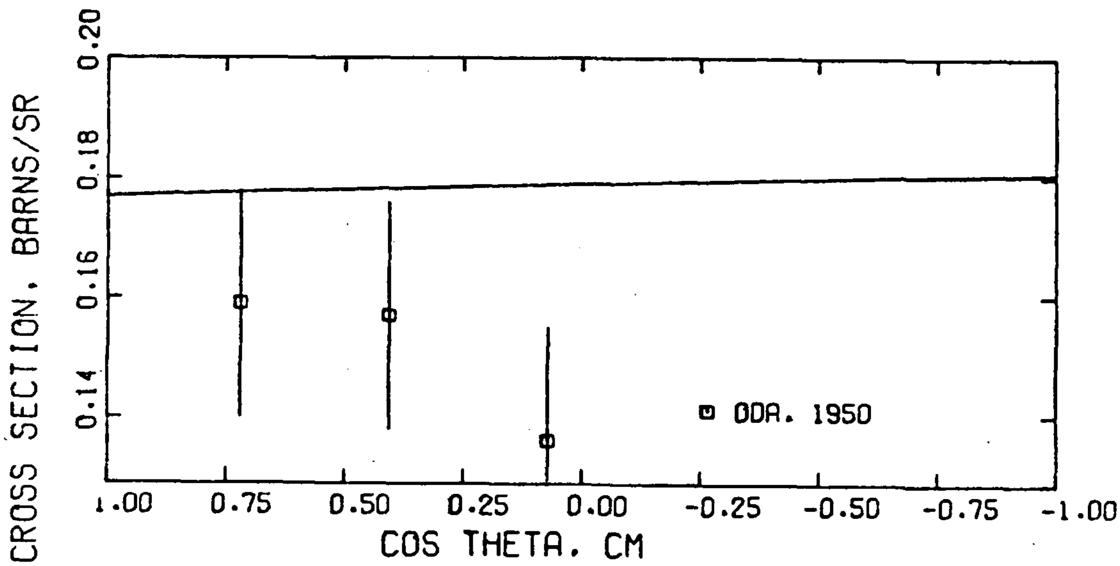

Fig. 5. Angular distribution of the neutrons elastically scattered from hydrogen at 3.1 MeV. ENDF/B-V is compared with the experimental values of Oda (Ref. 10).

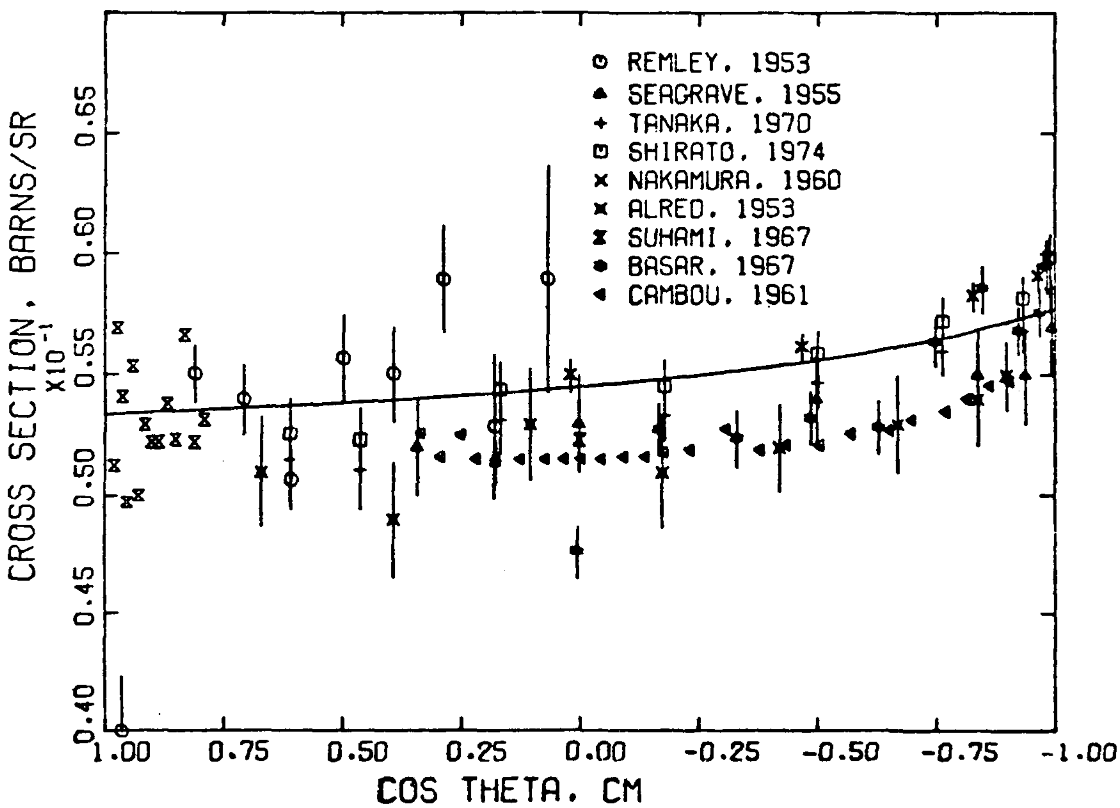

Fig. 6. Angular distribution of the neutrons elastically scattered from hydrogen at energies near 14 MeV. The experimental data shown were reported in Refs. 11, 36, 38 and 47-52.

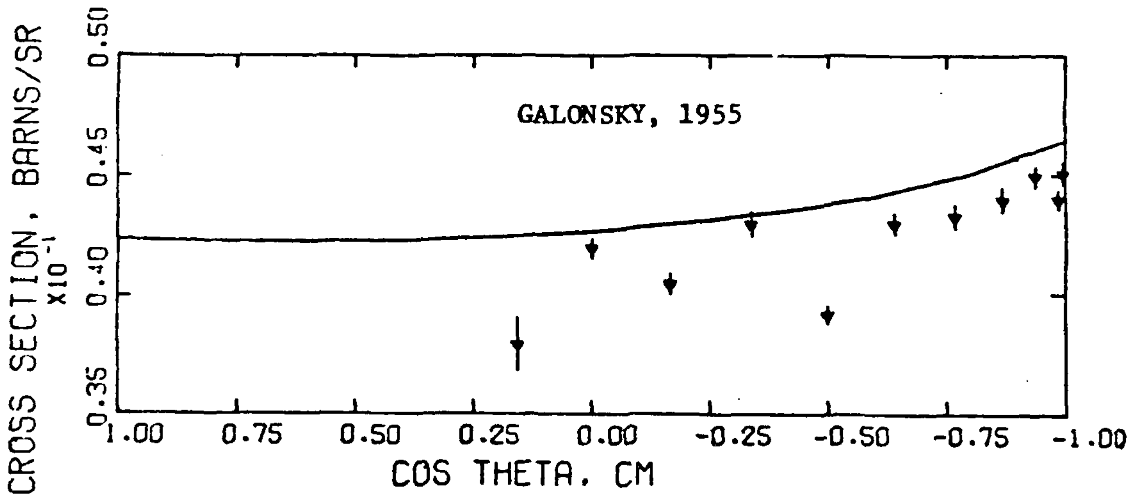

Fig. 7. Angular distribution of the neutrons elastically scattered from hydrogen at energies near 17.8 MeV. The experimental data shown were reported in Ref. 12.

$^3He(n,p)T$ CROSS SECTION

L. Stewart

I. SUMMARY

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

II. STANDARDS DATA

The ^3He (n,p)T cross section is recognized as a standard in the neutron energy range from thermal to 50 keV. 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 was derived from precise measurements by Als-Nielsen and Dietrich[2] of the total cross section up to an energy of 11 eV. At the time of the evaluation no experimental measurements on the $^3He(n,p)$ reaction were available below ~ 5 keV, and the cross section was assumed to follow 1/v up to 1.7 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.[4] These data which extend to 100 keV, are compared with ENDF/B-V in the upper part of Fig. 1. The measurements of Lopez et al.[5] and Costello et al.[6] which were reported after this evaluation was performed are also shown in the figure. The Lopez et al. data are relative measurements of the ratio for the counting rates of ^3He and $^{10}BF_3$ proportional counters. The ENDF/B-V $^{10}B(n,\alpha)$ cross section was used with these measurements in order to obtain the ^{3}He (n,p) cross section. The ^{3}He data were normalized at 200 eV. The Costello _et al_. measurements employed the same ^{3}He proportional counter used by Lopez _et al_. These data are relative to the hydrogen scattering cross section through the use of a methane gas proportional counter.

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_.[7] as given in the lower part of Fig. 1. Note that these three measurements are in good agreement among themselves but are higher than the measurements of Batchelor _et al_.[8] and of Sayres _et al_.[9] On the other hand, Sayres _et al_. measure an elastic cross section much higher than reported by Seagrave _et al_.[10]

In 1970, Costello _et al_.[11] measured the (n,p) cross section from 300 keV to 1 MeV. The cross section was deduced from the pulse-height spectrum of a ^{3}He gas proportional counter and the ^{3}He neutron total cross section. As can be seen in Fig. 1 the 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.

Although the thermal (n,p) cross section is known to better than 1%, the energy at which this cross section deviates from 1/v is not well-established. New Measurements by Bowman[12] relative to ^{10}B(n,α) have improved this standard and should have a large impact on new ^{3}He evaluations. 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.

REFERENCES

1. This evaluation was translated by R. J. LaBauve into the ENDF/B format for Version III.

2. J. Als-Nielsen and O. Dietrich, "Slow Neutron Cross Sections for He^3, B, and Au," Phys. Rev. 133, B 925 (1964).

3. J. H. Gibbons and R. L. Macklin, "Total Neutron Yields from Light Elements under Proton and Alpha Bombardment," Phys. Rev. 114, 571 (1959).

4. R. L. Macklin and J. H. Gibbons, Proceedings of the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, 19-23 July 1965 (North-Holland Publishing Co., 1966), p. 498.

5. W. M. Lopez, M. P. Fricke, D. G. Costello, and S. J. Friesenhahn, "Neutron Capture Cross Sections of Tungsten and Rhenium," Gulf General Atomic, Inc. report GA-8835.

6. D. G. Costello, M. P. Fricke, A. D. Carlson, and S. J. Friesenhahn, Gulf General Atomic, Inc. (1970) unpublished.

7. J. E. Perry, Jr., E. Haddad, R. L. Henkel, G. A. Jarvis, and R. K. Smith, private communication 1960.

8. R. Batchelor, R. Aves, and T. H. R. Skyrme, "Helium-3 Filled Proportional Counter for Neutron Spectroscopy," Rev. Sci. Instrum. 26, 1037 (1955).

9. A. R. Sayres, K. W. Jones, and C. S. Wu, "Interaction of Neutrons with He^3," Phys. Rev. 122, 1853 (1961).

10. J. D. Seagrave, L. Cranberg, and J. E. Simmons, "Elastic Scattering of Fast Neutrons by Tritium and He^3," Phys. Rev. 119, 1981 (1960).

11. D. G. Costello, S. J. Friesenhahn, and W. M. Lopez, "$^3He(n,p)T$ Cross Section from 0.3 to 1.16 MeV," Nucl. Sci. Eng. 39, 409 (1970).

12. C. D. Bowman, et al., "The Ratio of the $^{10}BF_3$ and $^3He(n,p)$ Cross Sections Between 0.025 eV and 25000 eV," Proceedings of the International Conference on Nuclear Cross Sections for Technology, Univ. of Tennessee, Knoxville, Tennessee, USA, Oct. 1979, p. 97.

13. M. D. Goldberg, J. D. Anderson, J. P. Stoering, and C. Wong, "Angular Distributions of $T(p,n)He^3$ Neutrons for 3.4- to 12.4-MeV Protons," Phys. Rev. 122, 1510 (1961).

14. D. G. Costello, "Review of $^3He(n,p)T$ Reaction," Proc. Symp. Neutron Standards and Flux Normalization, CONF-701002, p. 74, U.S.A.E.C. (1971).

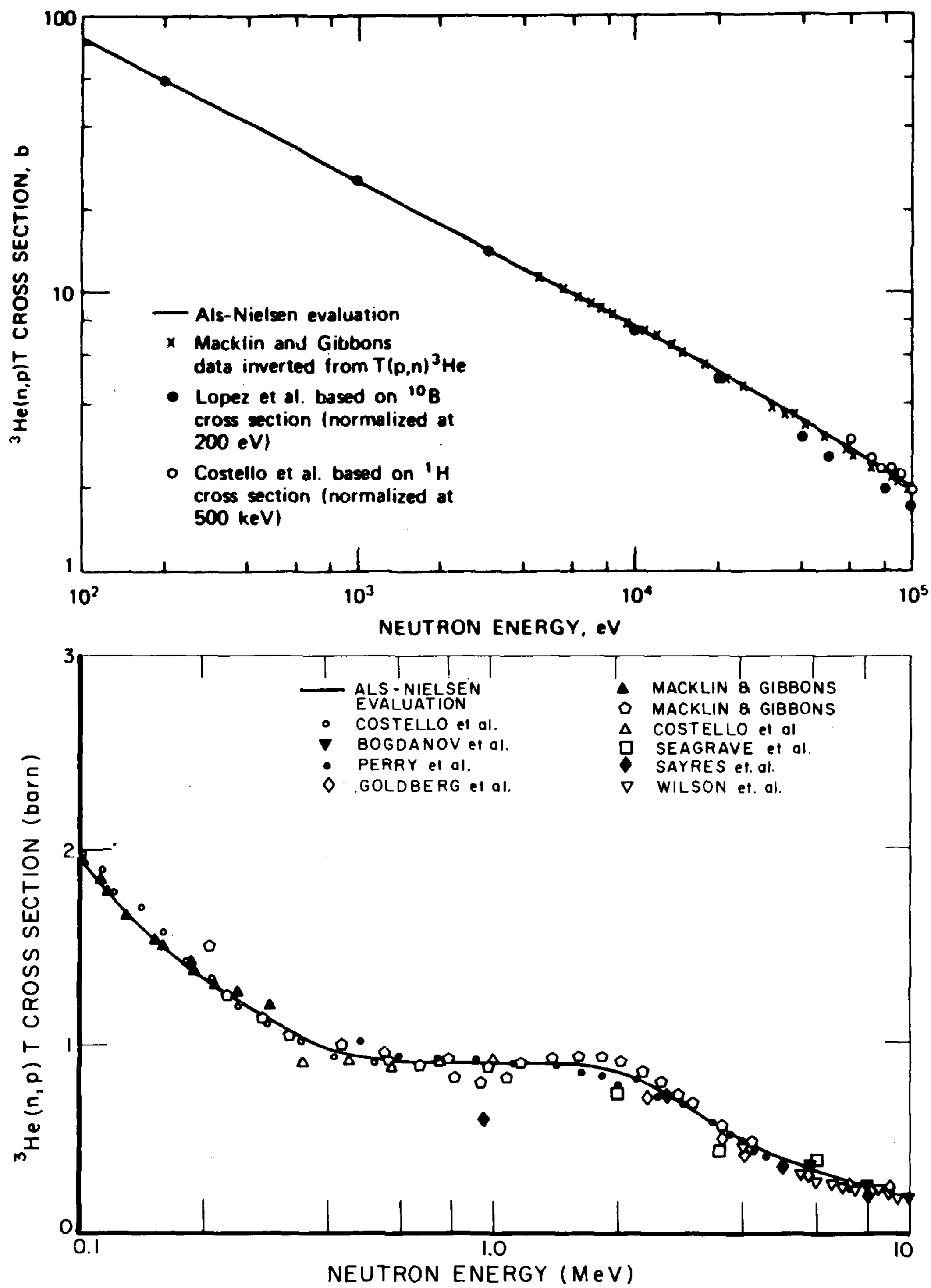

Figure 1. Measurements of the $^3He(n,p)T$ Cross-Section. The references to all the experimental work except Goldberg et al.[13], and Batchelor et al.[8] are contained in Ref.14.

THE ^{6}Li (n,t) ^{4}He CROSS SECTION

G. M. Hale, L. Stewart, and P. G. Young

The ^{6}Li (n,t) cross section is regarded as a standard over an energy range from thermal to 100 keV. The Version V cross sections for ^{6}Li below 1 MeV were obtained from multichannel, multilevel R-matrix analyses of reactions in the ^{7}Li system, similar to those from which the Version IV evaluation[1] 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.[2]

For Version IV, the $^{6}Li(n,t)$ cross section was determined mainly by fitting the Harwell total cross section (Ref. 3 below), since this was presumably the most accurately known data included in the analysis. However, in addition to the Harwell total, the data base for the analysis included the shapes of the n-^{6}Li elastic angular distributions and polarizations, $^{6}Li(n,t)^{4}He$ angular distributions and integrated cross sections (normalized), and t-α elastic angular distributions.

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

Measurement	References	Approximate Precision
n-^{6}Li σ_T	Harvey, ORNL[4]	0.5-1%
$^{6}Li(n,t)$ integrated cross section	Lamaze, NBS[5]	1-2% (relative)
$^{4}He(t,t)^{4}He$ differential cross section	Jarmie, LASL[6]	0.4-1%
$^{4}He(\vec{t},t)^{4}He$ analyzing power	Hardekopf, LASL[7]	1%

Fits to the (n,t) data included in the 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 agreement with Lamaze's new $^6Li(n,t)$ integrated cross section measurement[5] is particularly encouraging, since these are close to the values most consistent with the accurate new t + α measurements.[6,7] On the other hand, a shape difference persists between the fit and measurements[4] 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 $^6Li(n,t)$ cross section significantly (to the order of 3%) over that of previous evaluations in the region of the resonance.

Relative covariances for the evaluated cross section, based on using the covariances of the R-matrix parameters in first-order error propagation, are provided in File 33 for use at energies below 1 MeV. Also, Legendre coefficients for the $^6Li(n,t)$ angular distribution are tabulated in File 4 at energies below 1 MeV.

REFERENCES

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

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

3. K. M. Diment and C. A. Uttley, AERE-PR/NP 15 and AERE-PR/NP 16 (1969).

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

5. G. P. Lamaze, et al., Nucl. Sci. Eng. 68, 183 (1978).

6. N. Jarmie, et al., BAPS 20, 596 (1975).

7. R. A. Hardekopf, et al., LA-6188 (1977).

8. M. S. Coates, et al., Neutron Standards Reference Data, IAEA, Vienna, p. 105 (1974).

9. S. J. Friesenhahn, et al., INTEL-RT-7011-001 (1974).

10. W. Fort and J. P. Marquette, Proceedings of a Panel on Neutron Standard Reference Data, Nov. 20-24 (1972), IAEA, Vienna

11. M. G. Sowerby, B. H. Patrick, C. A. Uttley, and K. M. Diment, J. Nucl. Energy 24, 323 (1970). ^{6}Li/^{10}B Ratio Converted Using ENDF/B-IV ^{10}B(n,α) Cross Section.

12. W. P. Poenitz, Z. Phys. 268, 359 (1974).

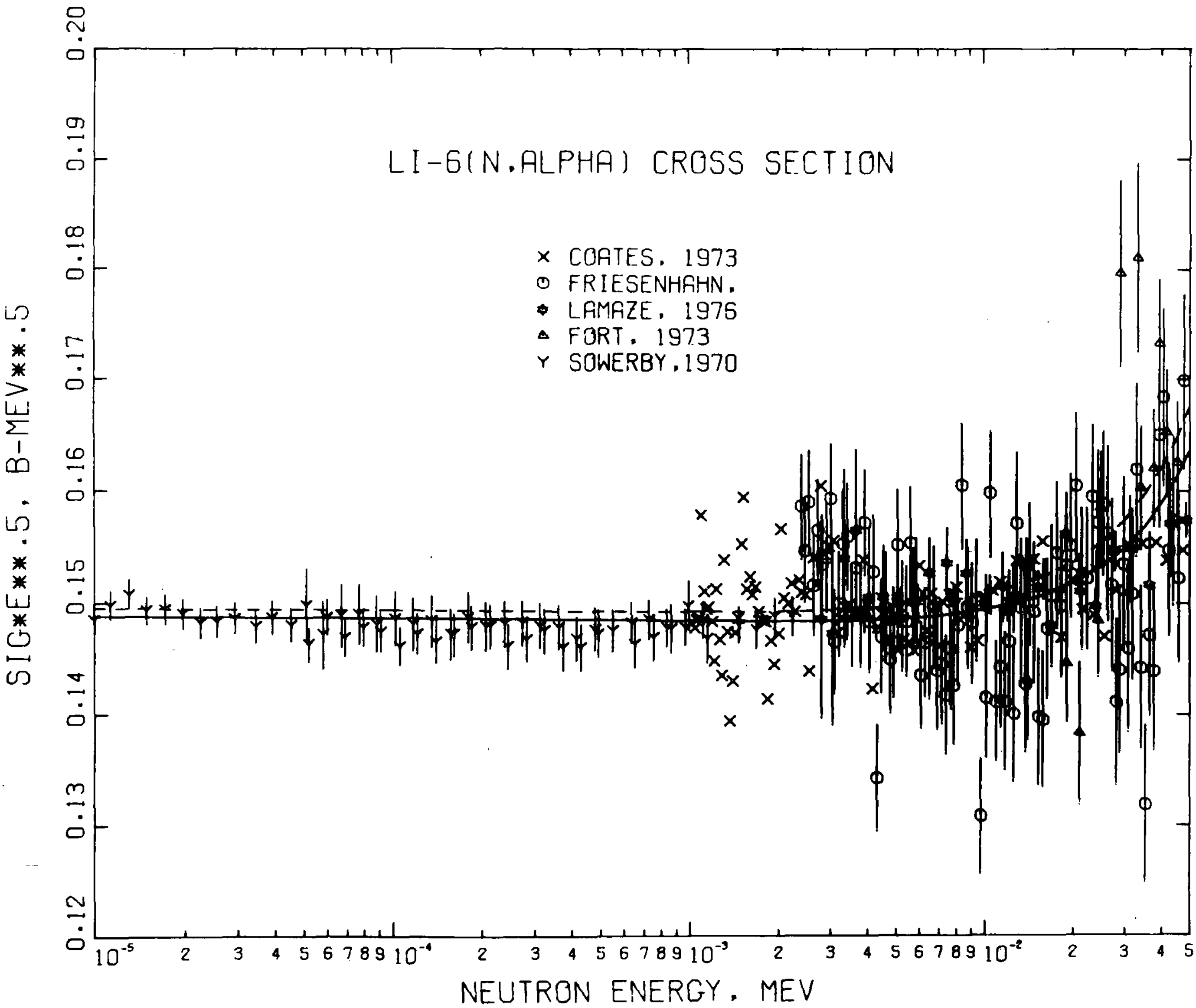

Fig. 1. The Version V $^{6}Li(n,t)^{4}He$ cross section times $\sqrt{E_n}$ plotted versus E_n for neutron energies between 10 eV and 50 keV. The dashed curve is ENDF/B-IV.

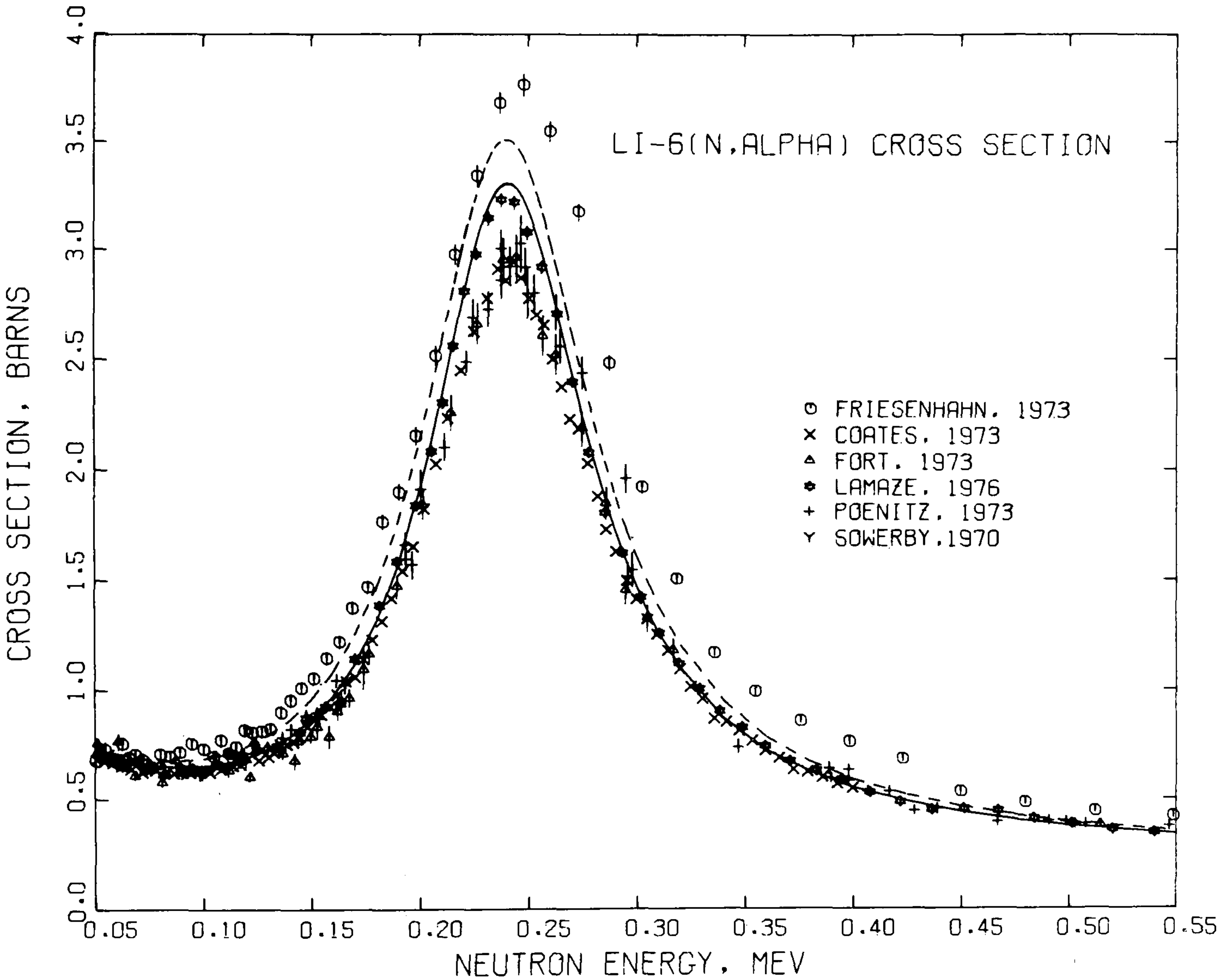

Fig. 2. The Version V $^{6}Li(n,t)^{4}He$ Cross Section from 50 to 550 keV. The dashed curve is ENDF/B-IV; the experimental data are from Ref. 5, 8-12.

THE $^{10}B(n,\alpha)^7Li$ AND $^{10}B(n,\alpha_1\gamma)^7Li^*$ REACTIONS

G. M. Hale, L. Stewart, and P. G. Young

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.

Experimental (n,α_0) data input to the fit were those of Macklin and Gibbons[1] and Davis *et al.*[2] In addition, the angular distributions of Van der Zwan and Geiger[3] for the inverse reaction were included in the analysis.

We have added Spencer's measurements[4] of σ_T and Sealock's $^{10}B(n,\alpha_1)$ angular distributions[5] to the data set that was analyzed for Version IV. In addition, we have replaced Friesenhahn's integrated (n,α_1) cross section[6] with the recent measurements of Schrack *et al.*[7] (both with GeLi and NaI detectors) at NBS, and have deleted Friesenhahn's total (n,α) cross section from the data set. The resulting fit to the (n,α) and $(n,\alpha_1\gamma)$ 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 to such changes in the (n,α) cross section, with the result that our calculated cross section must be considered quite uncertain at energies above $\sim$ 300 keV.

Relative covariances for the evaluated (n,α_0) and (n,α_1) cross sections, based on using the covariances of the R-matrix parameters in first-order error propagation, are provided in File 33 for use at energies below 1 MeV. The (n,α) covariances can be obtained as simple linear combinations of the (n,α_0) and (n,α_1) covariances, once they are converted to absolute quantities.

REFERENCES

1. R. L. Macklin and J. H. Gibbons, Phys. Rev. 165, 1147 (1968).
2. E. A. Davis *et al.*, Nucl. Phys. 27, 448 (1961).
3. L. Van der Zwan and K. W. Geiger, Nucl. Phys., A180, 615 (1972).
4. R. R. Spencer *et al.*, EANDC(E) 147, AL (1973).
5. R. M. Sealock and J. C. Overley, Phys. Rev. C13, 2149 (1976).
6. S. J. Friesenhahn *et al.*, "The (n,α) cross sections of ^{6}Li and ^{10}B between 1 and 1500 keV," Intelcom Rad Tech Report INTEL-RT 7011-001 (1974).
7. R. A. Schrack *et al.*, Nucl. Sci. Eng. 68 189 (1978).
8. F. P. Mooring *et al.*, Nucl. Phys. 82, 16 (1966).
9. E. G. Bilpuch *et al.*, J. Appl. Phys. 10, 455 (1960).
10. R. H. Rohrer, private communication 1963 via the NNCSC.
11. S. A. Cox and F. R. Pontet, J. Nucl. Energy 21, 271 (1967).
12. H. Bischel and T. W. Bonner, Phys. Rev. 108, 1025 (1957).
13. C. Zabel, private communication (1956).
14. D. Bogart and L. L. Nichols, Nucl. Phys. A125, 463 (1969).
15. M. S. Coates *et al.*, private communication to L. Stewart (1973).
16. D. O. Nellis *et al.*, Phys. Rev. C1, 847 (1970).

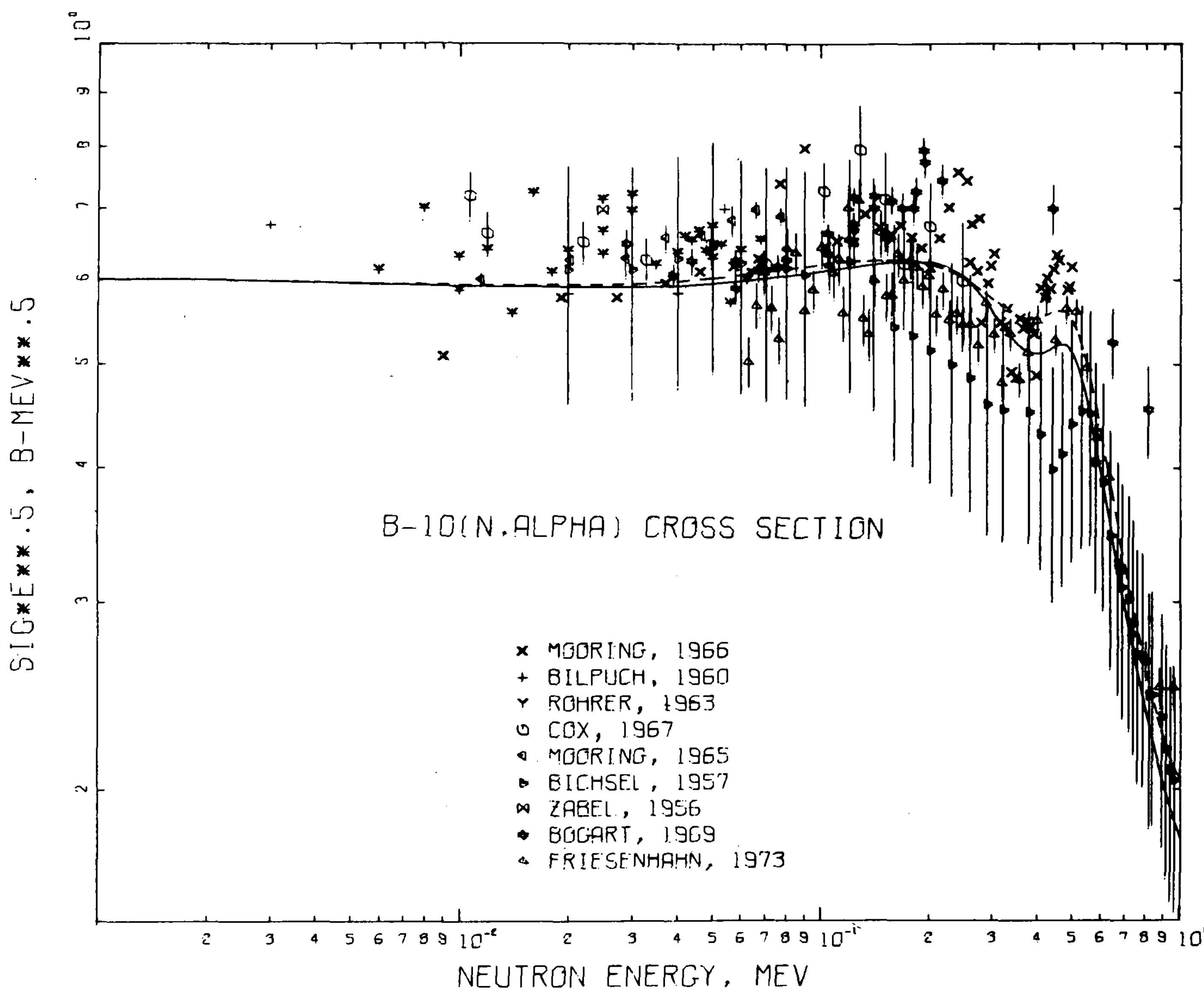

Fig. 1.

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. The experimental data are those of Refs. 6 and 8-14.

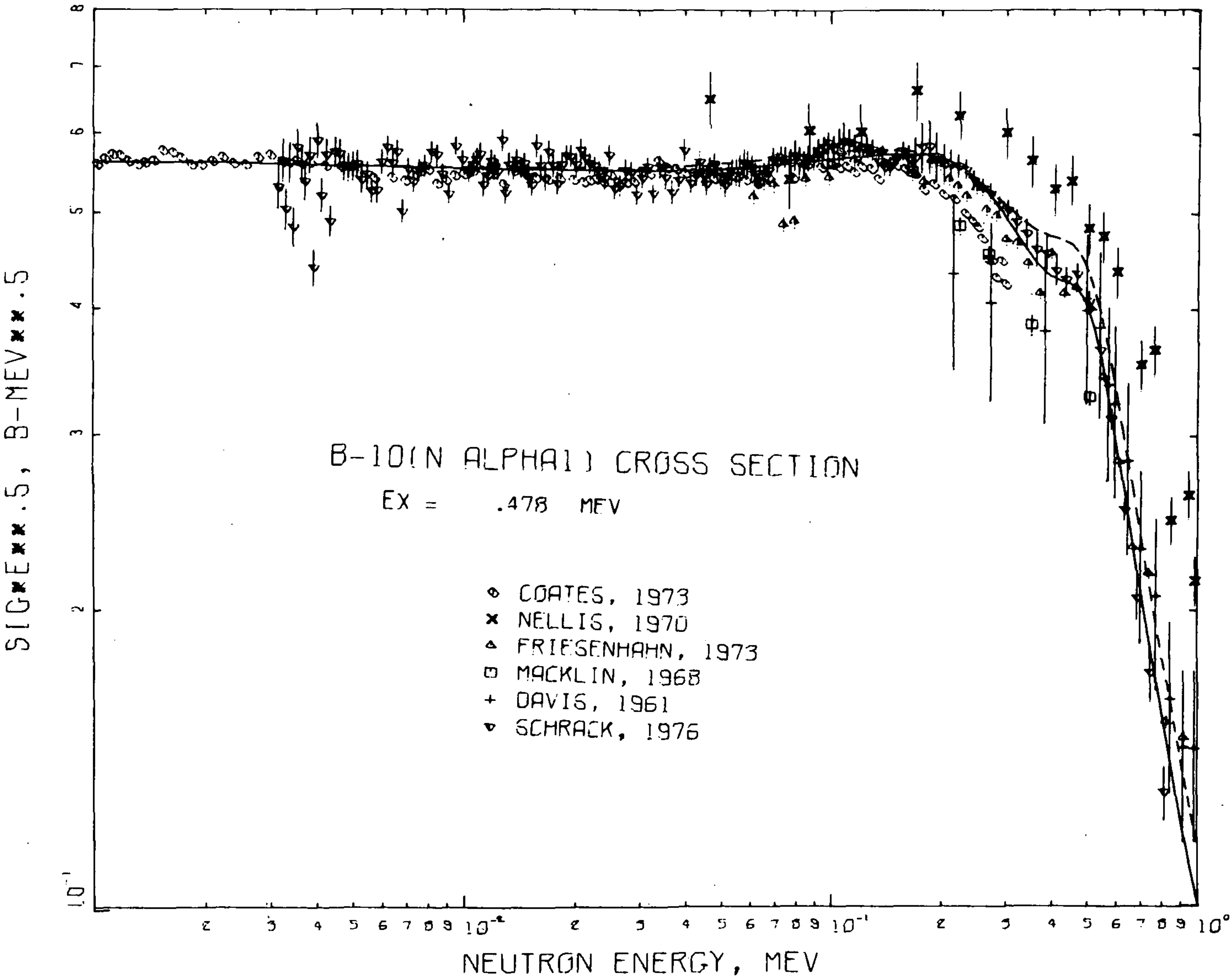

Fig. 2.

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 the experimental data are 15, 16, 6, 1, 2, and 7.

NEUTRON SCATTERING CROSS SECTIONS OF CARBON
BELOW 2 MeV FOR ENDF/B-V

C. Y. Fu and F. G. Perey

Cross-section and polarization data for neutron interactions with carbon below the inelastic threshold (4.81 MeV) were evaluated and analyzed by R-matrix theory. Six sets of total cross-section data below 2 MeV were partially smoothed and least-square fitted with non-diagonal weighting to obtain averages with estimated uncertainties for use in the R-matrix search program. The resulting differential scattering cross sections below 2 MeV are recommended as standards. The good quality of the fits well above 2 MeV and a high-precision (0.1%) thermal value enhance the confidence in the recommended values below 2 MeV.

INTRODUCTION

R-matrix-based differential scattering cross sections below 2 MeV presented here are recommended as standards with estimated standard deviations varying from 0.2% to 0.6% for the integrated cross sections and 0.2% to 4.0% for the differential scattering cross sections. The energy and angular ranges in which the differential cross sections are estimated to be known to better than 1% are identified. All recommended cross sections were generated from the R-matrix fit to evaluated data.

The recommended differential elastic scattering cross sections of this study have been incorporated into the ENDF/B-V standard files up to 2 MeV and general-purpose files below 4.81 MeV.

R-Matrix Fit

In the R-matrix search we had five types of input: (1) the total cross sections up to 6.3 MeV, (2) the differential scattering cross sections below

4.81 MeV, (3) the A_1 coefficients up to 2.3 MeV, (4) the differential polarizations below 4.81 MeV, and (5) the 120-degree polarizations up to 2.7 MeV. The chi-square sum of each type of input was minimized.

Although all the data above worked together in determining the R-function parameters listed in Table I, some data had particular influence on a given phase shift below 2 MeV and the related parameters:

1. All phase shifts contribute to the total cross section in terms of squared sine functions. Thus the total cross sections below 2 MeV impose strong limits to the sums of these functions up to $d_{5/2}$.

2. The $s_{1/2}$ phase shifts contribute more than 99.7% to the total cross sections below 0.5 MeV, which in turn determined essentially all the $s_{1/2}$ parameters.

3. The interference between the $p_{3/2}$ and the $d_{5/2}$ phase shifts produces the interference in the A_1 coefficients near the 2.08-MeV $d_{5/2}$ resonance. Since the $p_{3/2}$ phase shift is slowly varying over this resonance, its value at 2.08 MeV can be derived from the peak-to-bottom distance of this interference. If there is little room for variation in the shape of the $p_{3/2}$ phase shifts below 2 MeV, their values below 2 MeV are nailed down by determinations above 2 MeV.

4. The $d_{3/2}$ phase shifts below 2 MeV are nearly fixed by the shape of the total cross sections from 2.2 to 2.9 MeV--the giant tail of the two $d_{3/2}$ resonances.

5. The polarization data up to 1.8 MeV, particularly the more reliably measured 120-degree data, are sensitive to the differences between the $p_{1/2}$ and $p_{3/2}$ phase shifts. On the other hand, the A_1 coefficients below 1.8 MeV and the A_3 coefficients near 2.08 MeV are sensitive to the sums of these phase shifts.

6. The polarization data near 2.5 MeV, where the $p_{1/2}$ and $p_{3/2}$ phase shifts cross each other, are sensitive to the sums of the absolute values of the $d_{3/2}$ and $d_{5/2}$ phase shifts.

From the above, the power of the R-matrix fit in determining our recommendation can be seen clearly. The $d_{3/2}$ and $d_{5/2}$ resonances above 2 MeV worked to our advantage in helping determine the $d_{3/2}$ and $p_{3/2}$ phase shifts below 2 MeV. It is also clear that the data in the energy range from

2 to 3 MeV are almost as important to our evaluation as the data below 2 MeV.

Experimental Data Input

Data and techniques which we used for establishing the values for use in the R-matrix search are now discussed.

Thermal Cross Sections

A total cross section of 4.746±0.005 b at 0.0253 eV is recommended by Lubitz[1] on the basis of three measurements[2,3,4] overlapping within 0.1%. A thermal capture cross section of 3.36 mb, as recommended[5] previously, defines a scattering cross section of 4.743±0.005 b at 0.0253 eV for use in the R-matrix search.

23.5-keV Total Cross Section

Block *et al.*[6] reported a high-precision value of 4.684±0.009 b at 23.5 keV. This value and its quoted uncertainty, when used in the search, tended to pull the thermal cross section of the calculation up about 0.2% above the value of the data. This is clearly unacceptable. We then increased the error of the 23.5 keV cross section to 0.5%, which still represents a very precise measurement, for use in the subsequent search.

Total Cross Sections from 50 keV to 2 MeV

Total cross sections measured over the last ten years were considered. These are the measurements of Heaton (NBS),[7] Cierjacks (KFK),[8] Diment (HAR),[9] Meadows (ANL),[10] Stoler (RPI),[11] and Perey (ORNL).[12] The ANL measurement is with monoenergetic beams; the others are time-of-flight measurements with white neutron sources.

Total Cross Sections above 2 MeV

The total cross sections of Schwartz (NBS),[13] Cierjacks (KFK),[8] and Perey (ORNL)[12] above 2 MeV were used for the ENDF/B-IV evaluation.[14] Selected data points from the evaluation, with uncertainties assumed to be 1%, were used in the R-matrix search. These points as well as their uncertainties were adjusted during the search such that the average chi-square value per point was comparable to that below 2 MeV.

Three resonances above the inelastic threshold were also included in the search so that their tails below 4.81 MeV are included in the R-matrix.

Differential Scattering Cross Sections

Input to the R-matrix search was the weighted average of the available data (Refs. 15-25). The data of Ahmed *et al.*[18] below 1 MeV seemed to be in gross error and were given very low weight. The data of Holt *et al.*[19] have more than 40 angles per energy. We smoothed their data and plotted only the smoothed values for a few angles.

The Legendre coefficients were those fitted by Kinney,[26] instead of those fitted by the experimentalists themselves, to insure uniformity in the definition of these coefficients.

The assignment of the A_1 coefficients below 2.3 MeV can be made more reliably than that of the differential data because the A_1 coefficients are independent of the absolute normalizations and their fluctuations from energy to energy can be smoothed out. Therefore, we formed a separate chi-square sum for the A_1 coefficients.

Polarization Data

The same evaluation techniques as used for the differential scattering cross sections were used for the polarization data (Refs. 17, 21, 24, and 27-31). A separate chi-square sum was formed for the 120-degree data below 2.7 MeV, which have the largest polarizations, to reduce the need to examine the differential polarizations for a large number of energies.

Comparisons of the R-Matrix Fit with Data

Comparisons of the R-matrix fit with some experimental data at representative energies are shown in Figs. 1-3.

In Fig. 1 the six sets of smoothed total cross sections were compared in percent differences with the R-matrix fit. Here we can see the real fluctuations of the data within each set.

The differential scattering cross section and polarization data are shown in Figs. 2 and 3, respectively. There is generally good agreement between the more accurate measurements and the fit.

DISCUSSION

It should be noted that all data we considered are for natural carbon (containing 1.11% ^{13}C) while our analysis is for ^{12}C; the differences between the two are examined below.

There are two resonances in ^{13}C below 2 MeV--one at 0.153 MeV with a width of 3.7 keV[7] and the other at 1.75 MeV having a 20-keV width.[32] The peak cross sections and areas are 21 b and 122 b-keV for the 0.153-MeV resonance and 1.29 b and 40.6 b-keV for the one at 1.75 MeV. Even if the resonance area is smeared out over a 100-keV interval, each resonance will still contribute about 0.2% to the natural carbon cross sections. Therefore, the energy ranges from 0.13 to 0.18 MeV and from 1.72 to 1.78 MeV are not recommended as standards until sufficient evaluation is done for these resonances, particularly the angular distributions.

Due to the bulk of the file involved, the data set will not be shown, however, the recommended differential elastic scattering cross sections below 2 MeV are given by

$$\frac{d\sigma}{d\Omega}(E,\Omega) = \frac{\sigma_S(E)}{4\pi} \sum_{\ell=0}^{L} \frac{2\ell + 1}{2} A_\ell(E) P_\ell(\mu) \qquad (1)$$

where the integrated cross sections $\sigma_S(E)$ are listed in Table II. The Legendre coefficients $A_\ell(E)$ are given in Table III. Note that $A_0 = 1$. Linear interpolation between the tabulated entries is recommended for intermediate energies.

The estimated one-standard-deviation for the recommended $\sigma_S(E)$ varies linearly from 0.2% at 0 MeV to 0.45% at 0.5 MeV, then to 0.6% at 2 MeV. The estimated one standard deviation for the Legendre coefficients and the differential cross sections are respectively listed in Table IV and Table V. The energy regions from 0.13 to 0.18 MeV and from 1.72 to 1.78 MeV contain ^{13}C resonances and should be avoided.

Covariance matrices are provided for the integrated cross sections only since ENDF/B-V does not allow input errors on angular distributions.

REFERENCES

1. C. R. Lubitz, Knolls Atomic Power Laboratory, private communication (1976).
2. W. Dilg, Phys. Rev. C 11, 103 (1975).
3. T. L. Houk, Phys. Rev. C 3, 1886 (1971).
4. L. Koester and W. Nistler, Phys. Rev. Lett. 27, 956 (1971).
5. N. C. Francis, C. R. Lubitz, J. T. Reynolds, C. J. Slavik, and R. G. Stieglitz, Proc. Symp. on Neutron Standards and Flux Normalization, Argonne, 1970, ed. A. B. Smith (AEC Symposium Series 23, 1971), p. 166.
6. R. C. Block, Yoshiaki Fujita, Katsuhei Kobayashi, and Tohru Oosaki, J. Nucl. Sci. and Tech. 12, 1 (1975).
7. H. T. Heaton II, J. L. Menke, R. A. Schrack, and R. B. Schwartz, Nucl. Sci. Eng. 56, 27 (1975).
8. S. Cierjacks, P. Forti, D. Kopsch, L. Kropp, J. Nebe, and H. Unseld, Institute für Angewandte Kernphysik report KFK-1000 (1968) and private communication (1969).
9. K. M. Diment and C. A. Uttley, EANDC(UK)94AL (1968).
10. J. W. Meadows and J. F. Whalen, Nucl. Sci. Eng. 41, 351 (1970).
11. P. Stoler, J. C. Clement, S. G. Goulding, R. C. Block, and P. F. Yergin, Bull. Am. Phys. Soc. 15, 1668 (1970).
12. F. G. Perey, T. A. Love, and W. E. Kinney, Oak Ridge National Laboratory report ORNL-4823 (1972).
13. R. B. Schwartz, H. T. Heaton, R. A. Schrack, Bull. Am. Phys. Soc. 15, 567 (1967).
14. F. G. Perey and C. Y. Fu, "Evaluation of Neutron and Gamma-Ray-Production Cross Sections for Carbon for ENDF/B-IV," unpublished (1973).
15. A. Langsdorf, Jr., R. O. Lane, and J. E. Monahan, Phys. Rev. 107, 1077 (1957).
16. R. O. Lane, A. S. Langsdorf, Jr., J. E. Monahan, and A. J. Elwyn, Ann. Phys. 12, 135 (1961).
17. R. O. Lane, R. D. Koshel, and J. E. Monahan, Phys. Rev. 188, 1618 (1969).
18. H. Ahmed, M. Coppola, and H. -H. Knitter, Proc. Symp. on Neutron Standards and Flux Normalization, Argonne, 1970, ed. A. B. Smith (AEC Symposium Series 23, 1971), p. 208.

19. R. J. Holt, A. B. Smith, and J. F. Whalen, Proc. Conf. on Nuclear Cross Sections and Technology, Washington, D.C., 1975 eds. R. A. Schrack and C. D. Bowman (National Bureau of Standards Special Publication 425, 1975, p. 246.
20. R. W. Meier, P. Scherrer, and G. Trumpy, Helv. Phys. Acta 27, 577 (1954).
21. H. D. Knox, J. M. Cox, R. W. Finlay, and R. O. Lane, Nucl. Phys. A217, 611 (1973).
22. J. E. Wills, Jr., J. K. Bair, H. O. Cohn, and H. B. Willard, Phys. Rev. 109, 891 (1958).
23. W. Galati, J. D. Brandenberger, and J. L. Weil, Phys. Rev. C 5, 1508 (1972).
24. G. V. Gorlov, N. S. Lebedeva, and V. M. Morozov, Doklady Akad. Nauk. 158, 574 (1964). English transl.: Soviet Phys. Doklady 9, 806 (1965).
25. F. G. Perey and W. E. Kinney, Oak Ridge National Laboratory report ORNL-4441 (1969).
26. W. E. Kinney, Oak Ridge National Laboratory, private communication (1976).
27. R. J. Holt, Phys. Rev. Lett. 28, 134 (1972).
28. F. O. Purser, Jr., J. R. Sawers, W. D. Andress, G. L. Morgan, and R. L. Walter, WASH-1048 (1964).
29. A. J. Elwyn and R. O. Lane, Nucl. Phys. 31, 78 (1962).
30. B. E. Wenzel and M. F. Steuer, Phys. Rev. 137, B80 (1965).
31. C. A. Kelsey, S. Kobayashi, and A. S. Mahajan, Nucl. Phys. 68, 413 (1965).
32. S. F. Mughabghab and D. I. Garber, Brookhaven National Laboratory report BNL-325, Third Ed., Vol. I (1975).

TABLE I. R-Function Parameters $\quad A = 3.72$ F

Levels in ^{13}C				R-function parameters					
ℓJ	E_{ex} (keV)	E_{lab} (keV)	E_{cm} (keV)	E_λ (keV)	γ_λ^2 (keV)	$b_{\ell J}$	R_0	R_1 (MeV^{-1})	R_2 (MeV^{-2})
0 1/2	3090	--	-1860	-1860	4118.71	-1.0164	0.2994	-0.0497	0.0
1 1/2	0 8860	-- 4260	-4946 3910	-4946 3900.16	191.81 85.74	-0.2933	0.1108	0.00105	0.00302
1 3/2	3680 9520 9900	-- 4940 5380	-1270 4500 4950	-1270 4553.09 4941.75	94.72 1.72 11.83	-0.2475	0.2421	0.00539	0.00038
2 3/2	7680 8250	2950 3580	2730 3300	2716.68 3536.27	206.73 2265.92	-1.3673	0.5600	0.0	0.00551
2 5/2	3850 6860	-- 2076	-1093 1915	-1093 1949.29	1743.21 61.95	-2.2139	0.0490	0.0449	0.0
3 5/2	7550	2820	2600	2590.92	30.00	-2.41	-0.3626	0.0	0.0
3 7/2	10750	6280	5790	5869.64	184.33	-2.41	0.6924	0.0	0.0

Note:

The R function used is

$$R_{lJ}(E) = \sum_\lambda \left[\frac{\gamma_\lambda^2}{E_\lambda - E}\right]_{lJ} + R_{lJ}^\infty(E_L)$$

where γ_λ^2 and E_λ are the reduced width and characteristic energy, respectively, for the λth state of given J^π, and $R_{lJ}^\infty(E_L)$ is the corresponding background term given by

$$R_{lJ}^\infty(E_L) = R_0 + R_1 E_L + R_2 E_L^2$$

where E_L is the laboratory energy of the incident neutron in MeV. The corresponding phase shift is

$$\delta_{lJ}(E) = \tan^{-1}\left[\frac{P_l(\rho)R_{lJ}(E)}{1 - [S_l(\rho) - b_{lJ}]R_{lJ}(E)}\right] - \phi_l(\rho)$$

where $P_l(\rho)$ is the penetration factor, $(S_l - b_{lJ})$ is the shift factor for boundary value b_{lJ}, $\phi_l(\rho)$ is the hard-sphere phase, and $\rho = kA$ with k the wave number and A the interaction radius. The interaction radius A was taken to be 3.72 F as recommended by Lane. The boundary values b_{lJ} were chosen such that E_λ fall near the observed resonance energies. All other parameters were determined by fitting the recommended data without any physical constraints. The negative choice for R_1 for the s-wave improved the fit.

TABLE II. Recommended Elastic Scattering Cross Sections of Neutrons on Carbon

E(keV)‡	σ(barn)	E (keV)	σ(barn)	E (keV)	σ(barn)
1.0E-8	4.7392	2.53E-5	4.7392*	5†	4.7161
10	4.6991	15	4.6821	20	4.6653
25	4.6486	30	4.6319	35	4.6154
40	4.5989	45	4.5825	50	4.5662
75	4.4862	100	4.4084	125	4.3326
150	4.2589	175	4.1871	200	4.1172
225	4.0491	250	3.9828	275	3.9182
300	3.8551	325	3.7937	350	3.7338
375	3.6753	400	3.6182	425	3.5626
450	3.5082	475	3.4551	500	3.4033
525	3.3527	550	3.3032	575	3.2549
600	3.2076	625	3.1615	650	3.1163
675	3.0722	700	3.0290	725	2.9868
750	2.9454	775	2.9050	800	2.8654
825	2.8267	850	2.7888	875	2.7517
900	2.7154	925	2.6798	950	2.6450
975	2.6108	1000	2.5774	1025	2.5446
1050	2.5125	1075	2.4811	1100	2.4503
1125	2.4201	1150	2.3905	1175	2.3615
1200	2.3331	1225	2.3052	1250	2.2779
1275	2.2511	1300	2.2249	1325	2.1991
1350	2.1739	1375	2.1492	1400	2.1250
1425	2.1012	1450	2.0780	1475	2.0552
1500	2.0328	1525	2.0109	1550	1.9895
1575	1.9685	1600	1.9479	1625	1.9277
1650	1.9080	1675	1.8887	1700	1.8698
1725	1.8513	1750	1.8332	1775	1.8155
1800	1.7981	1825	1.7811	1850	1.7645
1875	1.7482	1900	1.7321	1925	1.7163
1950	1.7007	1975	1.6853	2000	1.6704

*Total cross section is 4.7426 barns.
†At and above this energy, total cross sections and elastic scattering cross sections are identical to the fifth significant figure.
‡$E = E_{lab}$.

TABLE III. Recommended Center-of-Mass Legendre Coefficients for Elastically Scattered Neutrons from Carbon [See Eq. (1)]

E(keV)	A_1	A_2	A_3	A_4	A_5
1.0E-8	0	0	0	0	0
1	1.4011E-4	0	0	0	0
5	6.9820E-4	0	0	0	0
10	1.3906E-3	0	0	0	0
50	6.7282E-3	7.4988E-5	0	0	0
100	1.2923E-2	2.7931E-4	0	0	0
200	2.3883E-2	9.7357E-4	0	0	0
300	3.3165E-2	1.9172E-3	6.3380E-5	0	0
400	4.0990E-2	2.9952E-3	1.2848E-4	0	0
500	4.7529E-2	4.1298E-3	2.2415E-4	0	0
600	5.2916E-2	5.2714E-3	3.4924E-4	0	0
700	5.7252E-2	6.3923E-3	4.9974E-4	-5.7108E-5	0
800	6.0616E-2	7.4832E-3	6.6841E-4	-1.0257E-4	0
900	6.3065E-2	8.5502E-3	8.4457E-4	-1.7208E-4	0
1000	6.4638E-2	9.6140E-3	1.0135E-3	-2.7366E-4	0
1100	6.5355E-2	1.0710E-2	1.1562E-3	-4.1675E-4	0
1200	6.5220E-2	1.1887E-2	1.2476E-3	-6.1223E-4	0
1300	6.4218E-2	1.3213E-2	1.2560E-3	-8.7217E-4	0
1400	6.2315E-2	1.4775E-2	1.1394E-3	-1.2092E-3	6.1831E-5
1500	5.9450E-2	1.6680E-2	8.4180E-4	-1.6345E-3	8.9279E-5
1600	5.5528E-2	1.9063E-2	2.8256E-4	-2.1536E-3	1.2619E-4
1700	5.0385E-2	2.2081E-2	-6.6742E-4	-2.7532E-3	1.7476E-4
1800	4.3701E-2	2.5897E-2	-2.2609E-3	-3.3576E-3	2.3674E-4
1850	3.9559E-2	2.8143E-2	-3.4747E-3	-3.5833E-3	2.7253E-4
1900	3.4589E-2	3.0612E-2	-5.2021E-3	-3.6296E-3	3.1000E-4
1925	3.1624E-2	3.1924E-2	-6.3914E-3	-3.5053E-3	3.2820E-4
1950	2.8147E-2	3.3294E-2	-7.9505E-3	-3.1843E-3	3.4451E-4
1960	2.6550E-2	3.3863E-2	-8.7269E-3	-2.9673E-3	3.4999E-4
1970	2.4790E-2	3.4453E-2	-9.6255E-3	-2.6751E-3	3.5449E-4
1980	2.2820E-2	3.5077E-2	-1.0682E-2	-2.2814E-3	3.5761E-4
1990	2.0574E-2	3.5757E-2	-1.1949E-2	-1.7464E-3	3.5876E-4
2000	1.7948E-2	3.6542E-2	-1.3506E-2	-1.0079E-3	3.5702E-4

TABLE IV. One-Standard-Deviations (percent) of the Recommended Legendre Coefficients

E (MeV)	A_1	A_2	A_3
0.5	20	45	60
1.0	20	40	60
1.5	25	35	60
2.0	30	30	60

TABLE V. One-Standard-Deviations (percent) of the Recommended Differential Cross Sections

E (MeV) \ deg-cm	0	20	40	70	135	180
0.5	1.15	1.07	0.87	0.58	0.82	1.15
1.0	1.69	1.53	1.16	0.74	1.06	1.69
1.5	2.15	1.92	1.38	0.89	1.24	2.15
2.0	4.02	3.04	1.85	1.14	1.14	4.02

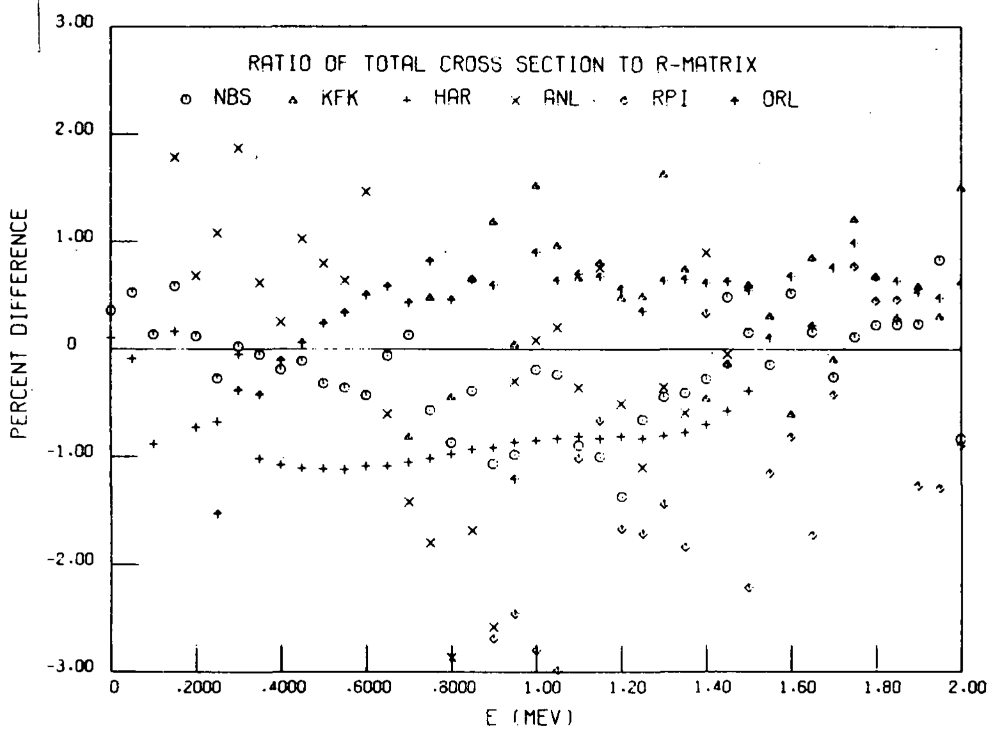

Fig. 1 Percent differences between partially smoothed experimental total cross sections and R-matrix values.
NBS[7] KFK[8] HAR[9] ANL[10] RPI[11] ORL[12]

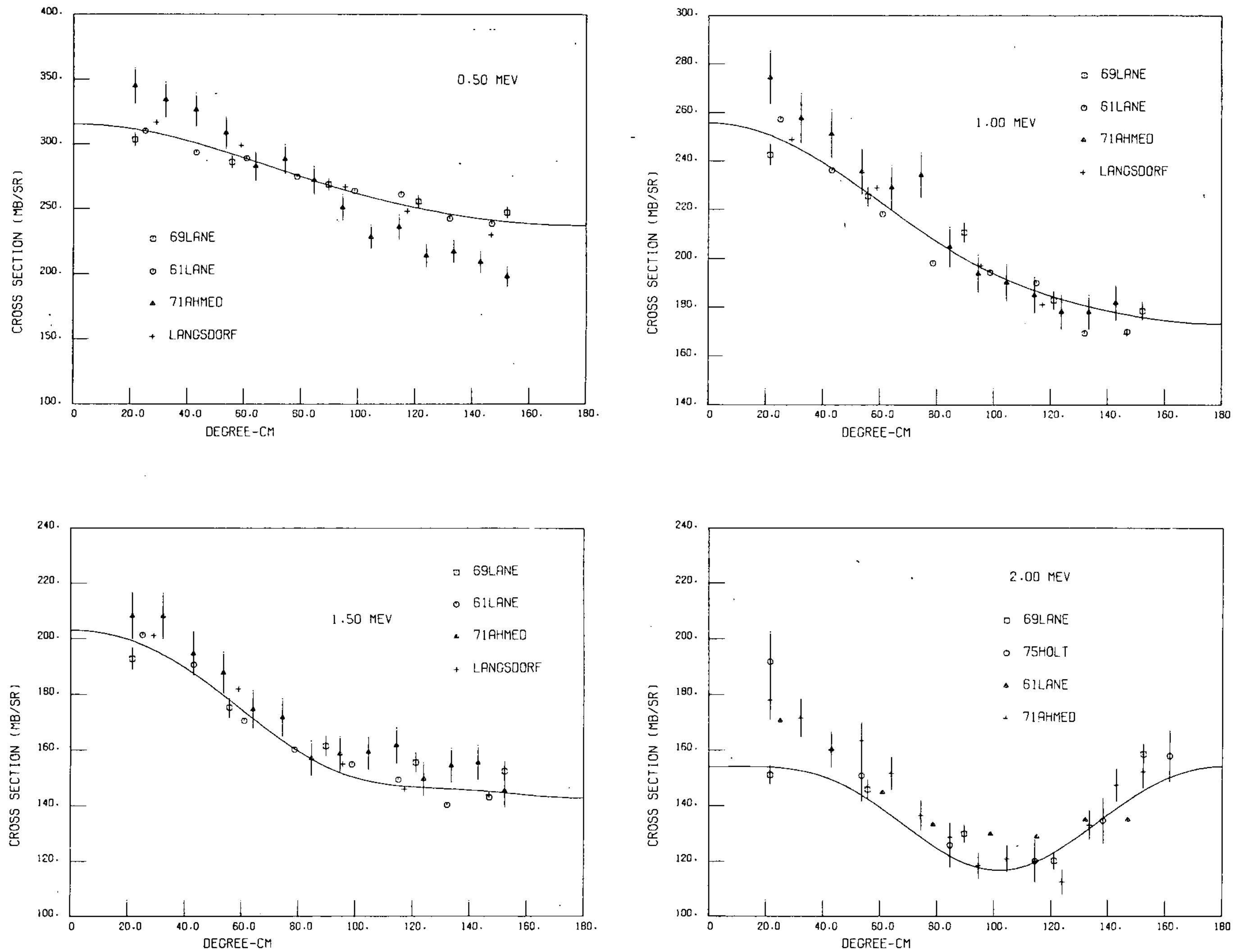

Fig. 2 Experimental differential scattering cross sections compared to R-matrix values. The experimental data can be found in Refs. 15-19.

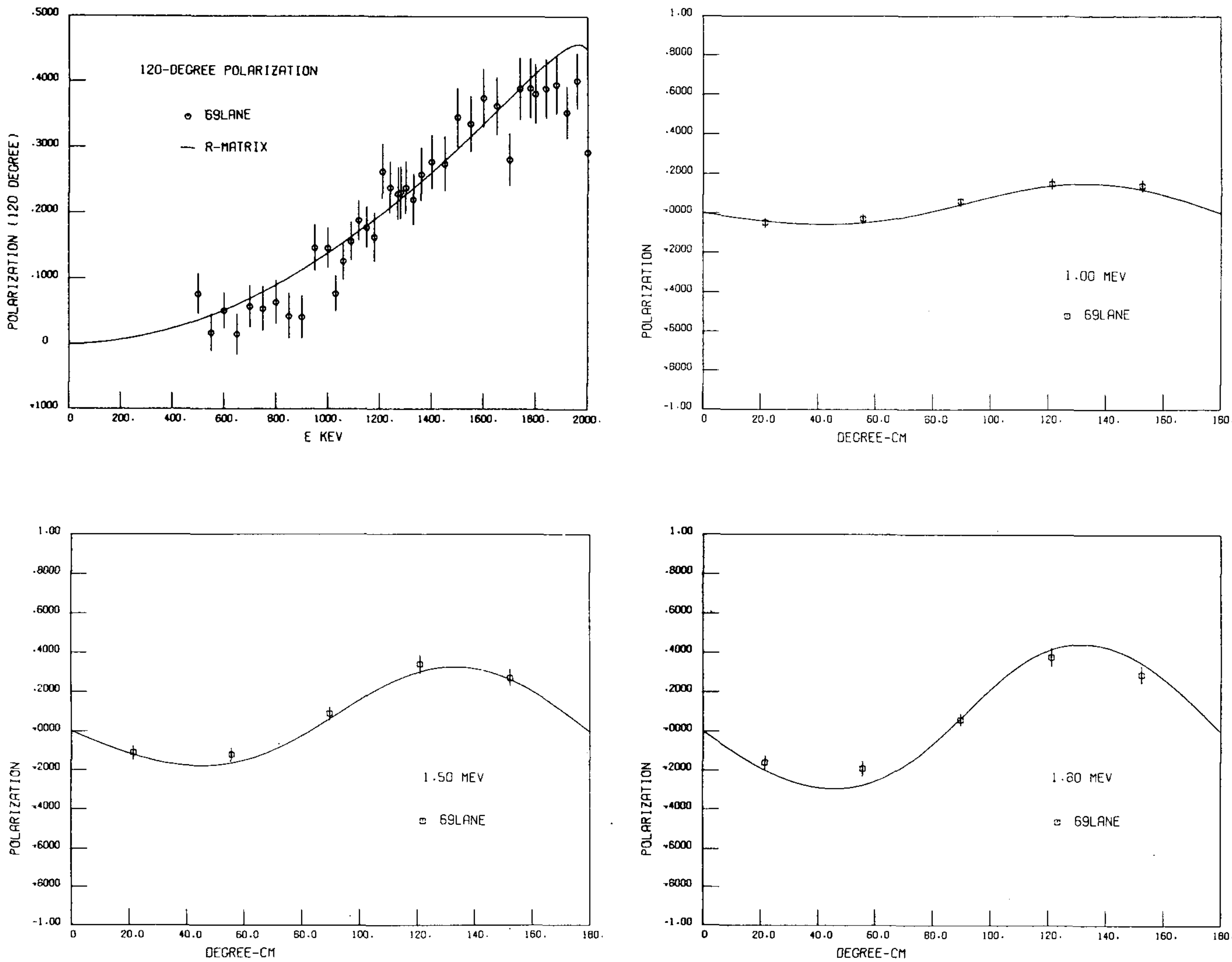

Fig. 3 Experimental differential polarizations compared to R-matrix values[17].

EVALUATION OF THE CAPTURE CROSS SECTION OF ^{197}AU

S.F. Mughabghab

Evaluation of the capture cross section of ^{197}Au is described with emphasis on its use as a standard in the energy region 200-3500 keV where the cross section appears to vary smoothly with energy. In this energy region, the capture cross section is presented in graphical and tabular forms.

I. 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 standards. For these reasons, and the fact that several recent measurements appeared in the literature and became available through private communications, it became evident and essential that a new evaluation of the capture cross section of gold be done. An additional reason is 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) cross sections for ENDF/B-V. This evaluation was carried out in conjunction with the Standards and Normalization Subcommittee of CSEWG and its Task Force.[a]

As indicated by the data of Macklin, et al.,[2] and Le Rigoleur[3] substantial structure, possibly attributable to doorway states, is observed in the gold capture across section up to about 200 keV. Above this energy, the capture cross section seems to vary smoothly with energy. Because of this situation, and with the exception of the thermal energy region, the point-wise

---

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

capture cross section of ^{197}Au below 200 keV is de-emphasized as a standard. In the present note, we primarily describe the ENDF/B-V evaluation of the gold capture cross section in the energy range from 200-3500 keV and outline the procedures followed in the high energy region (3.5 - 20.0 MeV). This evaluation differs from its predecessor[4] in that the input data measured relative to a standard cross section, were renormalized to the approved primary standards to give a consistent set of standard cross sections. Because of the various inter-relations between the primary standard cross sections, (n,p),$^{6}Li(n,\alpha)$, $^{10}B(n,\alpha)$, $^{197}Au(n,\gamma)$, and $^{235}U(n,f)$, an attempt was made by various evaluators to obtain a consistent set of standard cross sections. As a result, the evaluations of $^{6}Li(n,\alpha)$, $^{10}B(n,\alpha)$, and $^{235}U(n,f)$ cross sections by Hale and Dodder[5], Hale and Arthur[5] and Poenitz[6] were adopted here. In addition, the evaluation of the (n,p) cross section carried out by Stewart, et al.,[7], (approved for ENDF/B-V), which is essentially based on the analysis of Hopkins and Breit[8] was considered in this evaluation. For details of the $^{6}Li(n,\alpha)$ and $^{10}B(n,\alpha)$ cross section analysis in terms of an R-matrix fit the reader is referred to reference 9.

II. ^{197}AU CAPTURE CROSS SECTION BETWEEN 200-3500 keV

The first step in this evaluation was to assemble the input data from the NNDC data files, CSISRS (Cross Section Information Storage and Retrieval System), from the literature, and through private communications with the experimenters. A brief summary of the recent data since the last evaluation of the gold capture cross section (1972 vintage) is shown in Table I which represents the leading author, adopted standard, relative to which gold capture cross sections is measured, the neutron energy range, method (activation or prompt γ ray measurement), monitor and sample detectors, and reported accuracy. The data can be found in references 2,3 and 10-26 or in the NNDC data files, CSISRS. Data prior to 1972 can be found in reference 4. 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 ^{235}U(n,f). In those cases where the ratios 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.,[2] in his flux measurements, was derived here from the reported prescription and the ratios of the gold capture cross section to the ^{6}Li(n,α) cross section. Then various ratios corresponding to each standard were plotted separately and were initially compared with the ratios derived from ENDF/B-IV. 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. Ratios which deviated by more than two standard deviations from ENDF/B-IV or the average of the experimental values were rejected.

Figs 1 and 2 show the renormalized recent data in the energy ranges 100-1000 keV and 1.0-3.5 MeV respectively. For comparison, ENDF/B-IV and ENDF/B-V evaluations are shown. On the abscissa, thresholds of the inelastic channels and their spins are indicated by vertical lines.

The following observations could be made regarding these data:

(1) data of Macklin, et al.,[2] Lindner, et al.,[10] and Le Rigoleur[3] are generally in very good agreement.

(2) as shown by Fort and Le Rigoleur[3] the activation and non-activation measurements are in reasonable agreement with each other particularly in the energy region 400 - 500 keV where the deviation is only about 2%.

(3) data of Paulsen, et al.,[12] Fricke, et al.,[23] and Barry, et al.,[24] all of which are measured relative to the (n,p) cross section are consistently high with respect to the ENDF/B-IV evaluation and compared to the data of Macklin, et al.,[2] Lindner, et al.,[10], Poenitz[11], and Fort and Le Rigoleur[3]. This may have to do with the response of the hydrogen proportional counter.

(4) in the energy range 1000 - 3500 keV, the data of Paulsen, et al.,[12] appear to converge, particularly at the high energy end, with that of Poenitz[11] and Lindner, et al.,[10].

(5) the Robertson, et al.,[25] cross section value at 966 keV is about 12% high with respect to Poenitz[11], Lindner, et al.,[10]. and the ENDF/B-IV evaluation but somehow in agreement with the datum point of Paulsen, et al.,[12]. Since it is believed that there is no structure in the gold capture cross section at this energy, the result of Robertson, et al.,[25] was down-graded.

(6) the apparent structure in Macklin, et al.'s renormalized data at about 250 keV is partially due to a lack of a precise knowledge of the peak position of the resonance at about this energy.

(7) the data of Czirr and Stelts[17] are high when compared with other data, and with the ENDF/B-IV evaluation. 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.,[2] Fort and Le Rigoleur[3], Poenitz[11], and Lindner, et al,[10] in the energy range 100 - 1000 keV. Above 1000 keV, the ENDF/B-IV evaluation is based on Poenitz[11] and Lindner, et al.'s[10] 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 uncertainty of the gold capture cross section in this energy range. The ENDF/B-V capture cross section in the energy range 200 - 3500 keV is given in Table II.

III. ^{197}AU CAPTURE CROSS SECTION IN ENERGY RANGE 3.5-20 MeV

In this energy region, experimental data are sparse. These include the data of Johnsrud, et al.,[27] and Miskel, et al.,[28] both of these experiments used the activation technique and measured the flux with a fission counter.

Between 4 MeV and 20 MeV, only 14 MeV data by Drake, et al.,[20] and Schwerer, et al.,[21] 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 4.4 MeV (renormalized Johnsrud, et al.,[27] data point), and 1 mb at 14 MeV.

IV. CONCLUSION

Gold capture cross section in the energy region 200 - 3500 keV is emphasized as a primary standard. The uncertainty in the evaluated curve is about 4%. The datum point of Robertson, et al.,[25] needs additional study and confirmation. In addition, the high data points of Paulsen, et al.,[12] measured relative to the (n,p) scattering cross section calls for further investigations. It is suggested perhaps the same authors carry out simultaneous measurements relative to (n,p) and some other standard, or perhaps a study of the response of the hydrogen proportional counter is warranted.

ACKNOWLEDGEMENTS

I would like to acknowledge fruitful and critical discussions with B.R. Leonard, Jr., (BNW), M.R. Bhat (BNL), A.D. Carlson (NBS), M.S. Moore (LANL), R.W. Peelle (ORNL), W.P. Poenitz (ANL), and L. Stewart (LANL). This work was supported by the U.S. Energy Research and Development Administration.

REFERENCES

1. S.F. Mughabghab and D.I. Garber, BNL-325, Neutron Cross Sections, Vol. 1, 3rd edition (1973).

2. R.L. Macklin, J. Halperin, and R.R. Winters, Phys. Rev/C, 11, 1270 (1975).

3. E. Fort and C. Le Rigoleur, NBS special publication 425, Vol. 2, 957 (1975) and private communication. This represents two data sets, one by Fort using the activation technique, the other by Le Rigoleur using prompt γ rays.

4. S.F. Mughabghab, A. Prince, M.D. Goldberg, M.R. Bhat, and S. Pearlstein BNL 50439 (ENDF-215) 1974.

5. G.M. Hale, D.C. Dodder and E.D. Arthur, Los Alamos Scientific Laboratory, private communication. Report LA-6518 (1976).

6. W. Poenitz, Evaluation of $^{235}U(n,f)$ between 100 keV and 20 MeV, ANL/NDM-45 (1979).

7. L. Stewart, R.J. Labauve, and P.G. Young, "Evaluated Nuclear Data for Hydrogen in the ENDF/B-II Format" USAEC Rep. LA-4575, Los Alamos Scientific Laboratory (1971).

8. J.C. Hopkins, and G. Breit "The $^{1}H(n,n)^{1}H$ Scattering Observables Required for High Precision Fast-Neutron Measurements" Nuclear Data A9, 137 (1971).

9. G.M Hale, NBS special publication 425, Vol.1 302 (1975).

10. M. Lindner, R.J. Nagle, and J.H. Landrum, Nucl. Sci. Eng. 59, 381 (1976) and private communication.

11. W.P. Poenitz, Nucl. Sci. Eng. 57, 300 (1975).

12. A. Paulsen, R. Widera, and H. Liskien, Atomkernenergie, 26, 80 (1975).

13. K. Rimawi and R.E. Chrien, NBS special publication 425, Vol. 2, 920 (1975).

14. V.S. Shorin, V.N. Kononov, and E.D. Poletaev Yad. Fiz. 19, 5 (1975) A/N 40222.

15. N. Yamamuro, T. Doi, T. Hayase, Y. Fujita, K. Kobayashi, and R.C. Block Nuclear Cross Sections and Technology, II, 802 (1975).

16. C.L. Le Rigoleur, A. Arnaud, and J. Taste, CEA-N-1662, 1973.

17. J.B. Czirr and M.L. Stelts, Nucl. Sci. and Eng. 52, 299 (1973).

18. R. Gwin, E.G. Silver, R.W. Ingle, and H. Weaver, Nucl. Sci. Eng. 59, 79 (1976).

19. K. Siddapa, M. Sriramachandra Murty, and J. Rama Rao, Nuova Cimento 18A. 218 (1973).

20. D. Drake, I. Bergqvist, and D.K. Mc Daniels Phys. Letters 36B, 557 (1971), private communications A/N 10193/5.

21. O. Schwerer, M. Winkler-Rohatsch, H. Warhanck, and G. Winkler, Nucl. Phys. A264, 105 (1976).

22. C. Le Rigoleur, CEA-N-1662 (1973).

23. M.P. Fricke, W.M. Lopez, S.J. Friesenhahn, A.D. Carlson, and D.G. Costello, Proc. Nuclear Data for Reactors, Conference, Helsinki, Vol. 2, 281 (1970).

See also Fricke, et al., Neutron Cross Sections and Technology, Vol. 1, p252 (1971) Knoxville, Tennessee.

24. J.F. Barry, J. Nucl. Energy 18, 491 (1964).

25. J.C. Robertson, T.B. Ryves, E.J. Axton, I. Goodier, and A. Williams, Jour. Nucl. Ener. 23, 205 (1969).

26. V.B. Chelnokov, V.A. Tolstikov, Yu. Ya. Stavissky, A.A. Bergman, and A.E. Samsonov, INDC(CCP)-32/U,8, 1973.

27. A.E. Johnsrud, M.G. Silbert, and H.H. Barschall, Phys. Rev. 116, 927 (1959).

28 J.A. Miskel, K.V. Marsh, M. Lindner, and R.J. Nagle, Phys. Rev. 128, 2717 (1962).

Table I Summary of Recent ^{197}Au Data

Author	Standard	Energy Range (keV)	Method	Monitor	Sample Detector	Error
Lindner	ENDF/B-IV ^{235}U	121-2730	activation	^{235}U fission counter	NaI ($4\pi\beta\gamma$)	0.4-2.9%
Macklin	$^{6}Li(n,\alpha)^{a}$,4.9eV Resonance of Au	2.75-550	prompt γ's	^{6}Li glass scintillator	Total energy detector	3%
Poenitz	absolute	400-3500	prompt γ's	"Black" and "Grey" neutron detector and ^{6}Li-glass detector	large liquid scintillator	10%
Paulsen	(n,p) Hopkins-Breit	200-3000	activation	recoil proportional counter, recoil proton telescope counter	Ge-Li	4.4%
Le Rigoleur	^{10}B, ^{6}Li [b]	12.13-159.7	prompt γ's	^{10}BNaI(Tℓ), ^{6}Li		
Fort	^{10}B, ^{6}Li	119-503	activation	^{10}BNaI(Tℓ), ^{6}Li	β(prop-) γ(NaI)	4.9%
Gwin	^{10}B ENDF/B-III, 4.9 eV Resonance	10-50 keV	prompt γ's	$^{10}BF_3$ ionization chamber	liquid scintillator	
Shorin	^{10}B,30 keV	5-80	prompt γ's	$^{10}B(n,\alpha\gamma)$ detector	liquid scintillator	~5%
Siddapa	$^{127}I(n,\gamma)$ ^{128}I	23±5(Sb-Be Source)	activation	^{127}I	NaI(Tℓ)	10%
Yamamuro	$^{10}B(n,\alpha_1\gamma)$ 5.200 Ag	24(Fe filter)	prompt γ's	$^{10}B(n,\alpha_1\gamma)$	C_6F_6 total energy detector	5%
Rimawi	$^{10}B(n,\alpha\gamma)$ ENDF/B-IV	24(Fe-filter)	prompt γ's	$^{10}B(n,\alpha_1\gamma)$	Ge-Li	2%
Schwerer	$^{27}Al(n,\alpha)$ ^{24}Na	14.6 MeV	activation	$^{27}Al(n,\alpha)$ ^{24}Na	Ge-Li	57%
Drake	$^{208}Pb(n,\gamma)$ ^{209}Pb	14 MeV	spectrum measurement	counter telescope	NaI(Tℓ)	2.7%
Le Rigoleur	^{10}B NaI	75.25-542.5	prompt γ's	C_6F	C_6F_6 liquid scintillator	3.6-14%

[a]See Ref. [2] for details

[b]Details not specified by authors. See also Fort, et al., Neutron Standard Reference Data, Proceedings of a Panel, Vienna Nov. 1972 IAEA p239.

Table II

ENDF/B-V AU Capture Cross Section 200 - 3500 KeV

E_n(keV)	σ_γ(mb)	E_n(keV)	σ_γ(mb)
200	257.5	560	122.8
210	251.0	580	119.5
220	245.0	600	116.2
230	240.0	650	108.0
240	234.0	700	101.0
250	229.0	750	95.2
260	224.0	800	90.8
270	219.0	850	87.2
280	214.8	900	85.5
290	210.0	950	84.2
300	206.5	1000	83.0
310	201.0	1100	79.2
320	195.0	1200	76.0
330	191.0	1300	73.5
340	186.0	1400	72.0
350	180.5	1500	71.5
360	175.0	1550	71.0
370	171.0	1600	69.0
380	167.0	1700	65.0
390	163.0	1800	61.5
400	159.5	1900	57.8
410	156.0	2000	54.0
420	152.8	2100	50.0
430	150.0	2200	46.0
440	147.0	2300	43.0
450	144.8	2400	40.0
460	142.5	2500	37.5
470	140.2	2600	34.2
480	138.0	2700	32.0
490	136.0	2800	29.5
500	134.6	2900	27.5
520	130.0	3000	26.0
540	126.0	3500	20.5

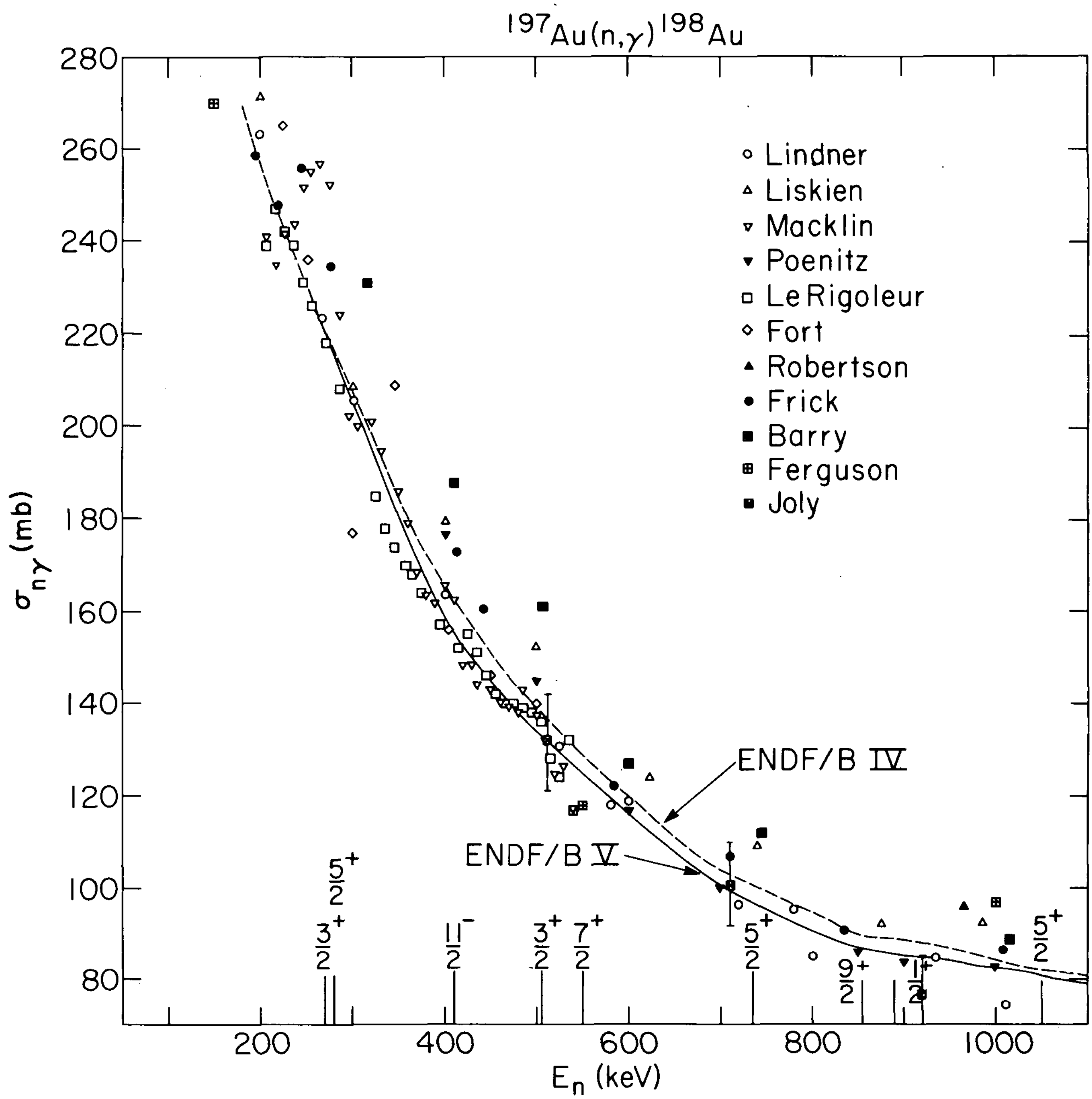

Figure 1. Capture cross section of gold in the energy range 200-1000 keV. The vertical lines represent the thresholds for the inelastic channels.

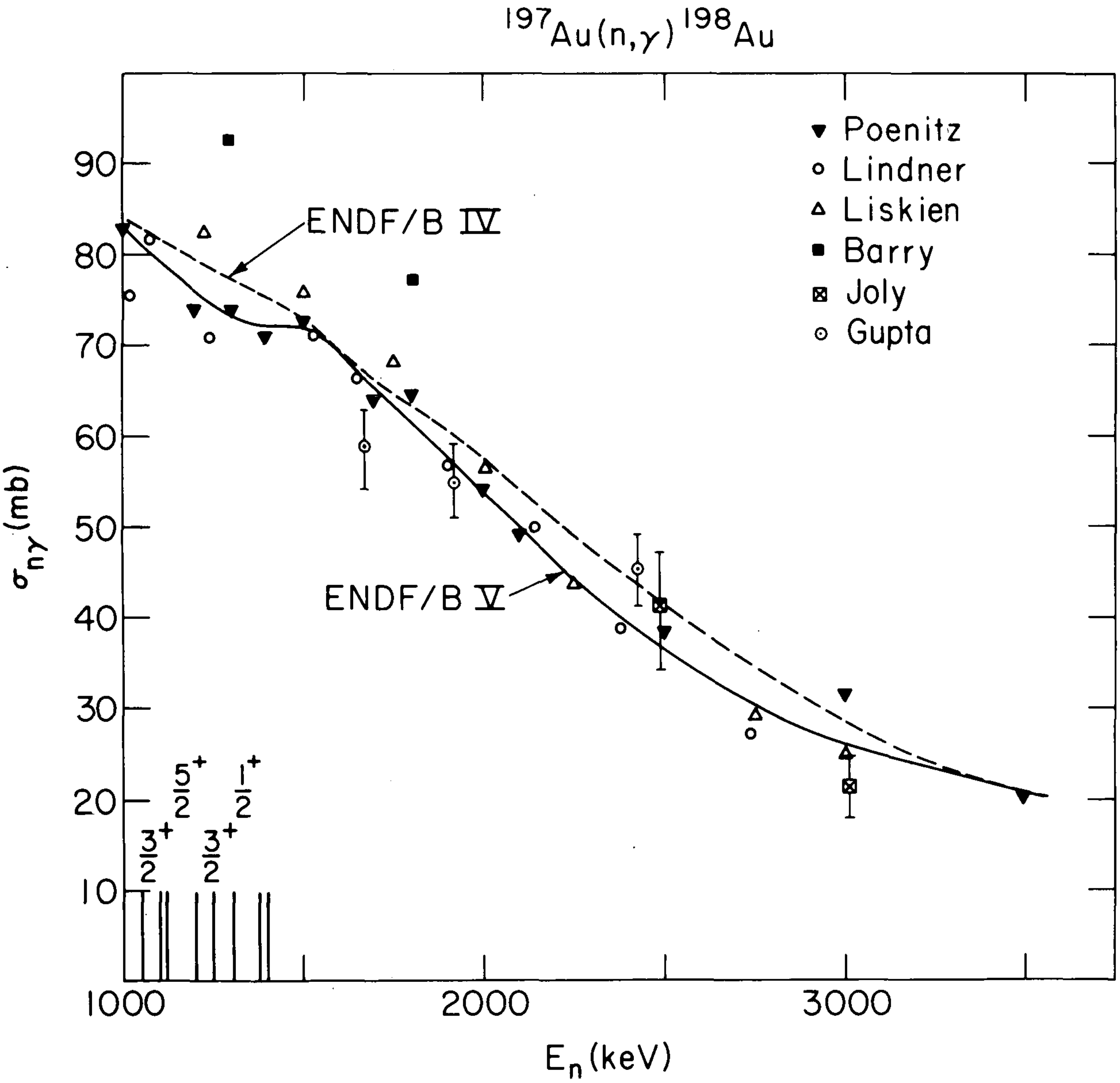

Figure 2. Capture cross section of gold from 1 to 3.5 MeV. The ENDF/B-V evaluation is compared with experimental data.

EVALUATION OF $^{235}U(n,f)$ BETWEEN 100 keV AND 20 MeV*

W. P. Poenitz

The $^{235}U(n,f)$ cross section was evaluated in the energy range from 100 keV to 20 MeV. Experimental data were included up to the 1978 Harwell Conference on Neutron Physics. The evaluation methodology is discussed. The shape and the normalization of the cross section are evaluated in separate steps.

Small changes were made in the shapes of two of the data sets to correct for the use of the H(n,n) cross section by Gammel[19] instead of ENDF/B-V.

The members of the Subcommittee on Normalization and Standards of the Cross Section Evaluation Working Group selected the experiments to be included in determining the normalization factor for the shape evaluation.

INTRODUCTION

The requirement for accurate neutron nuclear data is obvious since such data are widely utilized in applications. Hence, many attempts have been made to understand and describe observations made in experiments. This need resulted in a large number of measurements of cross sections directly required in technical applications or used in other measurements, e.g. standards. Theoretical models were developed in order to explain the experimental data, and to predict subsequently nuclide behavior which might be difficult to measure. Evaluated data files were created to supply numerical values needed for applications which represented usable compromises between often contradictory experimental data and theoretical predictions. Earlier

*This work supported by the U.S. Department of Energy.

evaluations had to use approximations which were more pragmatic than exact as data were sparse in some areas and discrepant in others. However, as experimental data became more abundant and consistent, it was recognized that the general process of arriving at an evaluated data file needed more consideration.[1] Data were often unintentionally correlated due to the use of common mass scales, neutron flux detection techniques or approximations for the interpretation of the experiments. Absolute measurements were made for many nuclei for which relative cross section ratio data were available. This resulted in an over-determined data system with more measured values than unknown quantities which required a simultaneous evaluation in order to obtain a consistent set of data.

An attempt to evaluate a consistent cross-section-data set for the use in reactor calculations was made in 1968,[2] and again with improved techniques in 1970.[1] Procedures were applied which were similar to those used in the evaluation of thermal cross sections and parameters.[3] An independent but similarly motivated evaluation was also reported in 1970.[4] The present evaluation is a first step in a new evaluation of a consistent set of neutron cross sections for the standards($^{6}Li(n,\alpha)$, $^{10}B(n,\alpha)$, $^{197}Au(n,\gamma)$) and for other reactions important for technical applications ($^{235}U(n,f)$, $^{238}U(n,\gamma)$). The present report discusses the specific evaluation of $^{235}U(n,f)$ and describes the general procedures used in the evaluation of specific cross sections and ratios. More details on this evaluation can be found in Ref. 5. A later report will contain the evaluation of the other cross sections and the consistency fit. A new simultaneous evaluation seems desirable because the data base has substantially improved since 1970,[6] and because improved evaluation procedures have been developed.[6,7] More recently, a variety of somewhat differently motivated considerations[8-11] have been helpful in defining the process described and used in the present evaluation.

OBJECTIVE EVALUATION PROCEDURES

The knowledge of the magnitude of a quantity comes directly from one or several measurements, or indirectly from a theoretical model, or from established empirical, systematized rules. The theoretical model and the empirical rules depend on other experimental data for the determination of their parameter sets. Therefore, the knowledge one has of a quantity is ultimately the result of experimentation.[12] The measuring process, for various reasons, is subject to uncertainty, thus when the measurements are repeated they will yield different values with different uncertainties. It is the major task of the evaluation process to derive a single "best value" from the available experimental values and from predictions from theoretical and empirical models. An objective evaluation procedure is based upon these available data and avoids intuition which might be based upon experience but is probably very subjective in nature.

THE EVALUATION OF $^{235}U(n,f)$ CROSS SECTION DATA

The present evaluation is an evaluation of the energy-averaged $^{235}U(n,f)$ cross section. It does describe gross structure (e.g. the step at 1 MeV, the bump at 2 MeV, the rise due to 2nd and 3rd chance fission). It does not describe "fine structure fluctuations" which are known to exist even above 0.1 MeV and it does not describe detailed features of some of the gross structure which might exist. However, such details of the structure are considered and included in the correction and interpretation of individual data points which are used in the evaluation of the average cross section.

1. The Present $^{235}U(n,f)$ Data File

The present data file consists of all data reported up to and including the Conference on "Neutron Physics and Nuclear Data for Reactors and Other Applied Purposes" which took place at Harwell in September 1978. Data reported earlier than the publication by White[13] were only included if re-evaluations were available. It is assumed that older data would need substantial reevaluation efforts because data for neutron source reactions, cross sections and other critical values which might affect the results have undergone substantial changes. Moreover, the weight of these data would be very small as they were usually reported with uncertainties in the 5-10% range. Thus, the effort and costs of a major reevaluation of these older data seemed not to be justified. It should be noted, however, that older data are usually higher than the presently evaluated data and their inclusion would raise the present result. Some of the more prominent older data sets, though not included in the evaluation, are compared with the present result in Section IV.

The major part of the present data file is that documented in Ref. 14 but the file was updated to include newer data. The format of this file is standardized and is such that it permits its ready use in evaluations. Data measured relative to the hydrogen scattering cross section were updated to ENDF/B-V[15] values (Hopkins-Breit analysis).[16] This includes recent measurements[17,18] which used the H(n,n) cross section by Gammel.[19]

A quantity of importance for the normalization of shape data which extend to the eV energy range is the 7.8 - 11.0 eV fission cross section integral. The available values were referenced to the present thermal cross section of ENDF/B-V (583.5 b) and an evaluated 243.7$\pm$1.0 beV was used.

Fluctuations in the ^{235}U(n,f) cross section are well-established below 100 keV and several data sets also indicate fluctuations in the cross section above 100 keV. The analysis of cross section uncertainties caused by fluctuations as a function of the resolution of the experiment by Bowman[20] was used to estimate the additional uncertainties.

Renormalizations due to changes of the reference cross section, fission integral and fission masses were applied to the data sets resulting in permanent changes. Additional uncertainties due to energy uncertainties and cross section fluctuations were taken care of during the different stages of the evaluation.

2. The Evaluation of the Cross Section Shape

Table I indicates the data sets which were used in the calculation of the presently evaluated shape. An energy grid with 63 values was established for use in the shape evaluation. This grid was found sufficient to describe all gross structure of the average cross section between 0.1 and 20.0 MeV. Experimental data points were extrapolated to the grid energy, E_i, if they were found in the interval $[E_i-0.5(E_i-E_{i-1}); E_i+0.5(E_{i+1}-E_i)]$ using the shape of the cross section in the range $[E_{i-1}, E_{i+1}]$. This shape was obtained from another evaluation.[6] The choice of the cross section used in this extrapolation procedure does not influence significantly the outcome of the shape evaluation.

The uncertainty of the value at a grid point was determined from the total uncertainty of the experimental points and was increased by the uncertainties caused by the uncertainty in energy and the uncertainty due to cross section fluctuations.

The values obtained from one data set provide cross section ratios between any two of the energy grid points for which they are available. In forming the ratios, R_{ik}, between the cross section values, σ_i, σ_k from these grid points the arbitrary or absolute normalization of the data set is removed. The different experiments provide contributions to some of the R_{ik}'s which yield a weighted average $\overline{R}_{ik}$ with an uncertainty ΔR_{ik}. By summing (weighted) the contributions to any σ_i, one obtains a system of equations which can be resolved in a "roll-back" procedure by defining a starting point $\sigma_1 = x$, where x is arbitrary.

3. Evaluation of the Normalization

The weighted average of factors obtained from the different absolute data sets was used for the normalization of the arbitrarily normalized shape curve. These factors are given in Table II and were derived as the weighted average of the ratios of the data and the values of the shape curve. At the suggestion of the Subcommittee on Normalization and Standards of the Cross Section Evaluation Working Group, the value by Arlt *et al.*[21] was excluded since it was not well-documented at that time. Also, not used in the normalization of ENDF/B-V were the averages over the ^{252}Cf spontaneous fission neutron spectrum.

4. Evaluation Result and Comparisons

The ENDF/B-V evaluation above 100 keV is listed in Table III. Figure 1 shows a comparison of ENDF/B-V with -IV. The new evaluation is somewhat lower than ENDF/B-IV over much of the range, and substantially so between 1.0 and 1.5 MeV and above 13 MeV. In Figs. 2 and 3, comparisons of some recent absolute measurements with ENDF/B-V are shown. The overall agreement is good, however, the data by Wasson and Meier[30] and by Poenitz[26] suggest somewhat lower cross sections and those by Kari[18] higher values.

REFERENCES

1. W. P. Poenitz, Proceedings of a Symposium on Neutron Standards and Flux Normalization, Argonne National Laboratory, AEC Symposium Series 23, 331 (1970).
2. J. M. Kallfelz, W. P. Poenitz, B. R. Sengal and B. Z. Zolotar, TANSAC, 12, 186 (1969).
3. O. H. Westcott *et al.*, At. Energy Rev. 3, 3, (1965).
4. M. G. Sowerby and B. H. Patrick, Proceedings of the Second International Conference on Nuclear Data for Reactors, Helsinki, 2, 703 (1970).
5. W. P. Poenitz, Evaluation of $^{235}U(n,f)$ between 100 keV and 20 MeV, ANL/NDM-45 (1979).
6. W. P. Poenitz, National Bureau of Standards, Proceedings of a Symposium, NBS SP 493, 261 (1977).
7. W. P. Poenitz and P. Guenther, Proceedings of the NEANDC/NEACRP Specialists Meeting, ANL-76-90, 154 (1976).
8. L. N. Usachev, International Nuclear Data Committee Report, INDC(CCP)-45/L (1974).
9. L. N. Usachev and Yu. G. Bobkov, International Nuclear Data Committee Report, INDC(CCP) - 33/L (1973).
10. L. N. Usachev and Yu. G. Bobkov, International Nuclear Data Committee Report, INDC(CCP) - 19/U (1972).
11. R. W. Peelle, Proceedings of the NEANDC/NEACRP Specialists Meeting, ANL-76-90, 421 (1976).
12. E. Kant, Critic of Pure Reason.
13. P. H. White, Journal of Nuclear Energy Parts A/B, 19, 325 (1965).
14. W. P. Poenitz and P. T. Guenther, Proceedings of the NEANDC/NEACRP Specialists Meeting, Supplement to ANL-76-90 (1976).
15. L. Stewart, R. J. LaBauve and P. G. Young, Los Alamos Informal Report, LA-7663-MS, 4 (1979).
16. J. C. Hopkins and G. Breit, Nuclear Data A, 9, 137 (1971).
17. O. A. Wasson, Proceedings of the NEANDC/NEACRP Specialists Meeting, ANL-76-90, 183 (1976).
18. K. Kari, KFF 2673, Kernforeschungszentrum Karlsruhe, (1978).

19. J. L. Gammel, "Fast Neutron Physics," Part II, Chap. VI, p. 2185, Interscience Pub. Inc., New York (1960).
20. C. D. Bowman, G. P. Lamaze, K. C. Duvall, and R. A. Schrack, Proceedings of the NEANDC/NEACRP Specialists Meeting, ANL-76-90, 270 (1976).
21. R. Arlt *et al.*, International Nuclear Data Committee Report, INDC/GDR/ - 7/6, 10, (1978).
22. R. K. Smith *et al.*, Bull. Am. Phys. Soc. 2, 196 (K4), 5704.
23. D. M. Barton *et al.*, Nucl. Sci. Eng., 60, 369 (1976).
24. J. B. Czirr, Nucl. Sci. Eng., 58, 371 (1975).
25. I. Szabo and J. P. Marquette, Proceedings of the NEANDC/NEACRP Specialists Meeting, ANL-76-90, 208 (1976).
26. W. P. Poenitz, Nucl. Sci. Eng., 64, 894 (1977).
27. W. P. Poenitz, Nucl. Sci. Eng., 53, 370 (1974).
28. D. B. Gayther, National Bureau of Standards, Proceedings of a Conference NBS SP 425, 2, 564 (1975).
29. F. Kaeppeler and F. Dickman, Proceedings of the NEANDC/NEACRP Specialists Meeting, ANL-76-90, 391 (1976).
30. O. A. Wasson and M. Meier, National Bureau of Standards, private communication (1978).
31. A. D. Carlson and B. H. Patrick, International Conference on Neutron Physics and Nuclear Data for Reactors and Other Applied Purposes, Harwell, September 25-29, 1978. Programme and Summaries, pp. 148, 149.
32. M. C. Davis *et al.*, Ann. Nucl. Energy 5, 583 (1978).
33. V. M. Adamov *et al.*, National Bureau of Standards, Proceedings of a Symposium, NBS-SP-493, 313 (1977).
34. I. M. Kuks *et al.*, Conf. on Neutron Physics, Kiev, Vol. 4, 18 (1973).
35. M. Cancé and G. Grenier, Nucl. Sci. Eng., 68, 197 (1978).
36. G. F. Knoll, Proc. Symp. on Neutron Standards and Applications, NBS Special Publication 493, 304 (1977) and private communication.
37. H. T. Heaton II, D. M. Gilliam, V. Spiegel, C. Eisenhauer, and J. A. Grundl, Proceedings of the NEANDC/NEACRP Specialists Meeting, ANL-76-90, 333 (1976).

TABLE I. Shape Evaluation Input

Set	Set Name	Energy Range MeV
1	Smith[22]	2.2 - 20.5
2	Barton[23]	1.0 - 6.0
33	Czirr,[24] Combined Set	0.75 - 20.0
4	Kari[18]	1.0 - 20.0
51 and 52	Szabo[25]	0.01 - 5.5
6	White[13]	0.04 - 14.1
71	Poenitz I[26,27]	0.2 - 8.2
72	Poenitz II[27]	0.3 - 3.5
8	Gayther[28]	0.001 - 0.95
10	Wasson[17]	0.005 - 0.75
111 and 112	Kaeppeler[29]	0.4 - 1.0
17	Wasson and Meier[30]	0.25 - 1.2
153	Carlson,[31] Combined Set	1.2 - 20.0
91	U. Michigan[32]	0.14 - 0.96

TABLE II. Normalization Factors

Set	Set Name	All Normal Factors
1	Smith [22]	1.006 ± 0.066
2	Barton[23]	1.012 ± 0.029
71	Poenitz BND[26,27]	1.008 ± 0.030
74	Poenitz VSO_4[27]	1.003 ± 0.038
73	Poenitz AA[27]	1.002 ± 0.038
4	Kari[18]	1.048 ± 0.039
16	Alkharov[33]	1.060 ± 0.035
12	Kuks[34]	1.051 ± 0.041
18	Cancé[35]	1.007 ± 0.038
6	White[13]	1.032 ± 0.042
17	Wasson, Meier[30]	0.986 ± 0.039
52	Szabo[25]	1.012 ± 0.032
111	Kaeppeler[29]	1.054 ± 0.037
91	U. Michigan[32]	1.019 ± 0.024
10	Wasson[17]	0.991 ± 0.036
251	Arlt[21]	1.004 ± 0.032
14	Adamov[33]	1.048 ± 0.021
92	U. of Michigan Cf[36]	1.006 ± 0.021
13	Heaton[37]	1.001 ± 0.025

TABLE III. $^{235}U(n,f)$ of ENDF/B-V

E_n, MeV	σ, b	E_n, MeV	σ, b
0.100	1.581	3.400	1.184
0.103	1.572	3.600	1.165
0.120	1.520	3.800	1.148
0.140	1.476	4.000	1.132
0.150	1.457	4.200	1.125
0.160	1.440	4.400	1.120
0.180	1.408	4.500	1.111
0.200	1.377	4.700	1.092
0.220	1.343	5.000	1.064
0.240	1.314	5.200	1.052
0.250	1.302	5.300	1.048
0.260	1.291	5.400	1.047
0.280	1.272	5.500	1.047
0.300	1.262	5.600	1.049
0.325	1.249	5.640	1.051
0.350	1.235	5.700	1.055
0.375	1.221	5.800	1.066
0.400	1.209	5.900	1.083
0.425	1.196	6.000	1.112
0.450	1.184	6.200	1.207
0.475	1.174	6.400	1.306
0.500	1.167	6.500	1.364
0.540	1.157	6.700	1.456
0.570	1.151	7.000	1.553
0.600	1.145	7.250	1.650
0.650	1.140	7.500	1.719
0.700	1.137	7.750	1.763
0.750	1.137	8.000	1.782
0.780	1.137	8.150	1.784
0.800	1.139	8.250	1.784
0.830	1.142	8.500	1.782
0.850	1.147	9.000	1.772
0.900	1.168	9.500	1.762
0.940	1.195	10.000	1.749
0.960	1.207	10.500	1.738
0.980	1.217	11.000	1.732
1.000	1.220	11.500	1.732
1.050	1.215	12.000	1.748
1.100	1.215	12.200	1.771
1.150	1.216	12.500	1.826
1.200	1.220	13.000	1.915
1.250	1.223	13.500	1.998
1.400	1.239	14.000	2.068
1.600	1.264	14.500	2.099
1.700	1.278	15.000	2.103
1.800	1.288	15.500	2.093
1.900	1.294	16.000	2.068
2.000	1.298	16.500	2.036
2.100	1.297	17.000	1.986
2.300	1.286	17.500	1.960
2.400	1.278	18.000	1.939
2.600	1.259	18.500	1.945
2.800	1.240	19.000	1.966
3.000	1.219	19.500	1.990
3.200	1.201	20.000	2.024

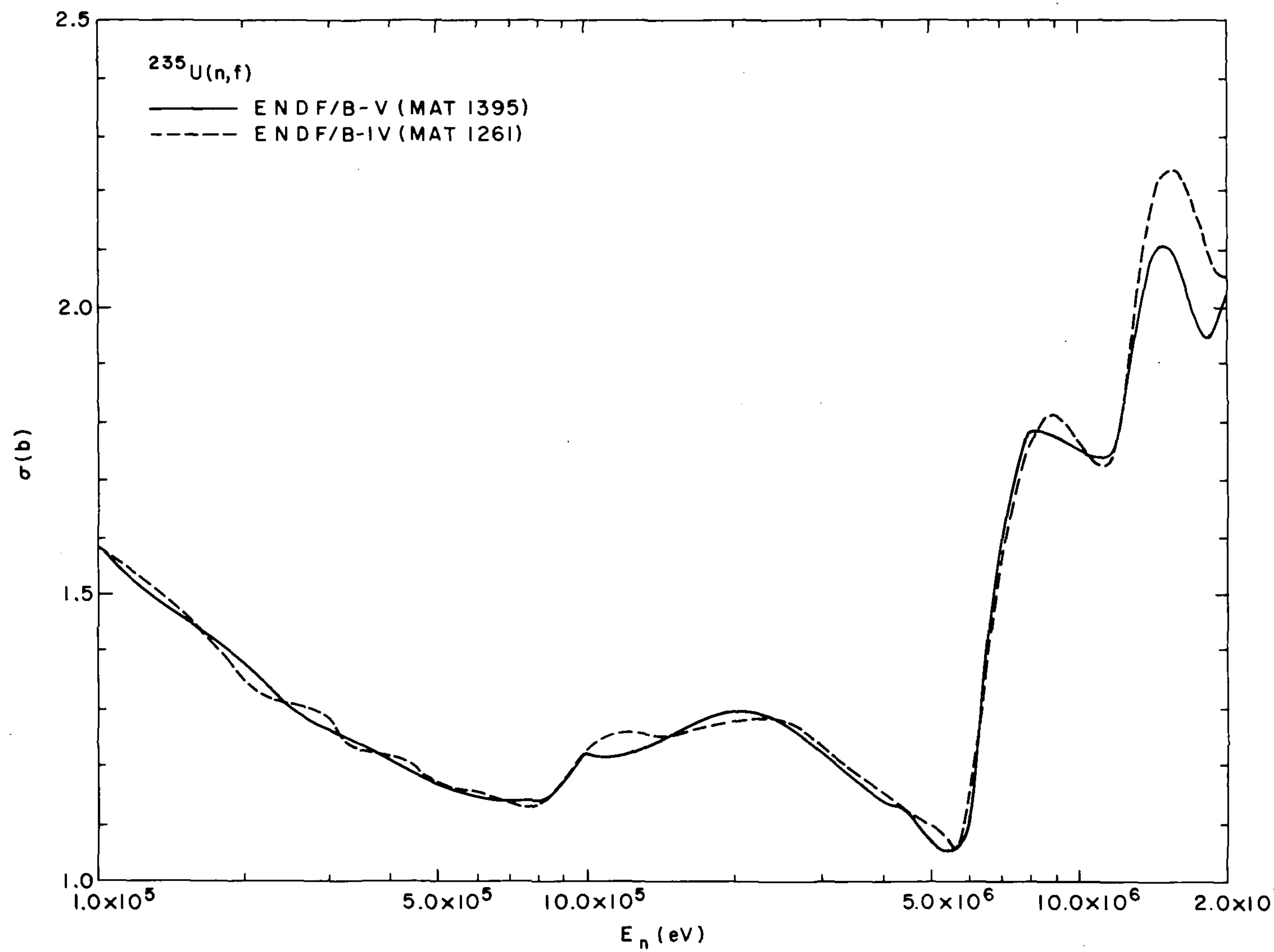

Fig. 1. Comparison of the ENDF/B-IV and ENDF/B-V $^{235}U(n,f)$ cross sections.

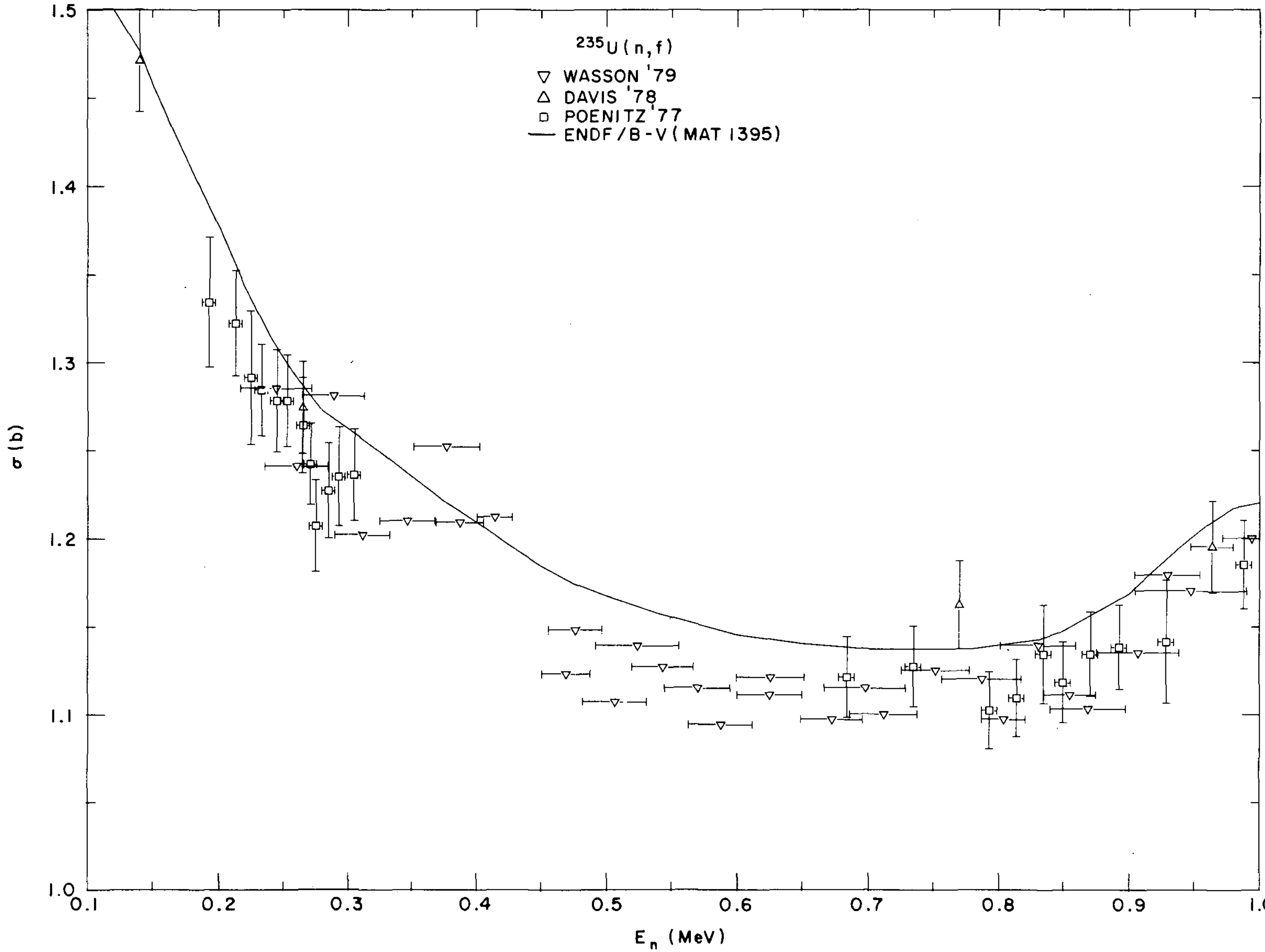

Fig. 2. Recent absolute measurements of the ^{235}U(n,f) cross section below 1 MeV.

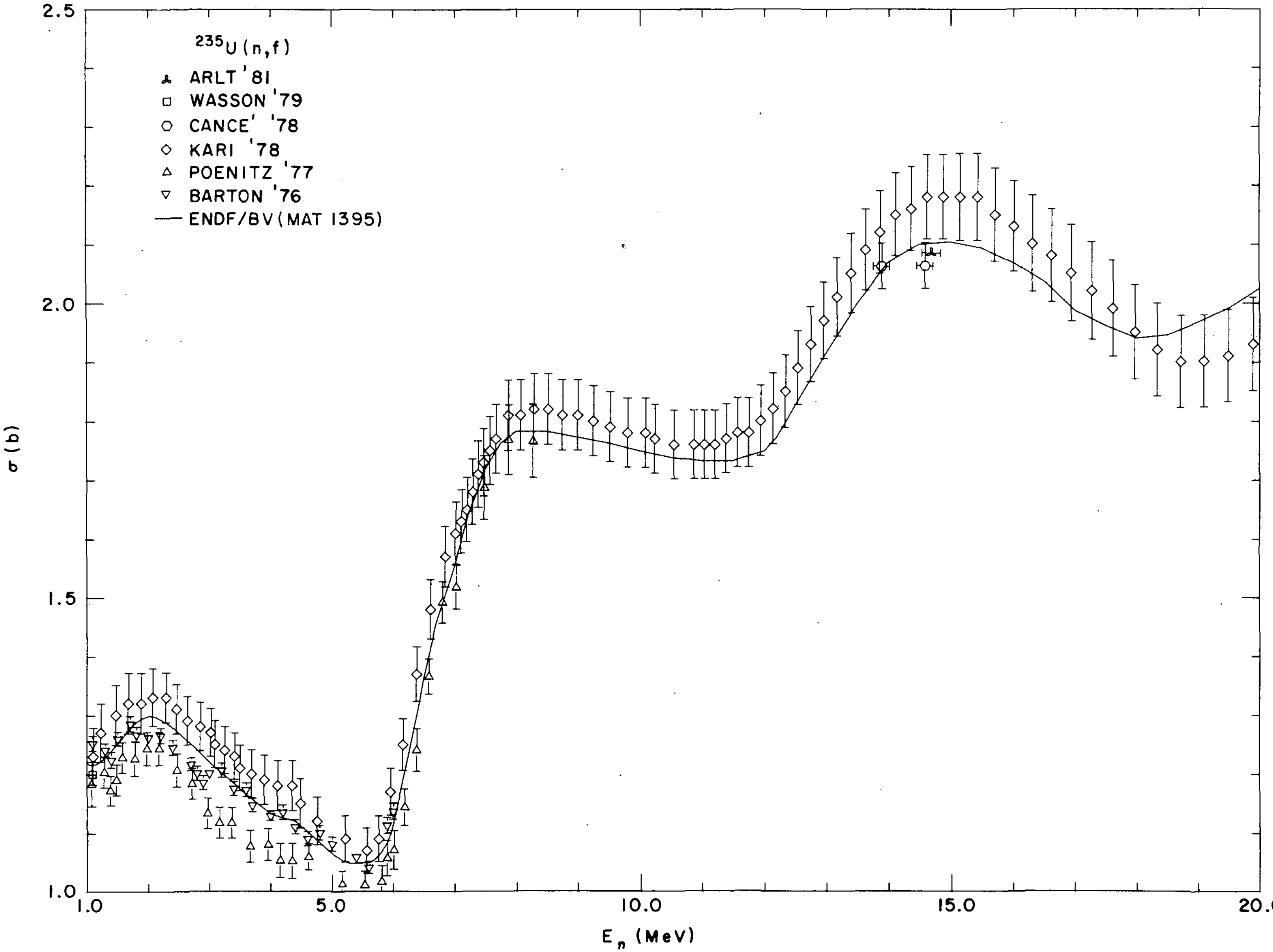

Fig. 3. Recent absolute measurements of the ^{235}U(n,f) cross section above 1 MeV.

Appendix

Numerical Tabulation of Cross Sections and Their Uncertainties

H(N,N) CROSS SECTIONS

NUMERICAL VALUES FROM ENDF/B-V, MAT-1301.
APPLICABLE ENERGY RANGE 0.001 TO 20.0 MEV.
LINEAR-LINEAR INTERPOLATION.

CROSS SECTION VALUES

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
1.00E 00	2.0329E 01	2.00E 00	2.0198E 01	3.00E 00	2.0068E 01
4.00E 00	1.9941E 01	5.00E 00	1.9815E 01	6.00E 00	1.9691E 01
8.00E 00	1.9448E 01	1.00E 01	1.9213E 01	1.50E 01	1.8651E 01
2.00E 01	1.8126E 01	2.50E 01	1.7634E 01	3.00E 01	1.7172E 01
3.50E 01	1.6737E 01	4.00E 01	1.6327E 01	4.50E 01	1.5941E 01
5.00E 01	1.5575E 01	5.50E 01	1.5228E 01	6.00E 01	1.4900E 01
6.50E 01	1.4587E 01	7.00E 01	1.4291E 01	7.50E 01	1.4008E 01
8.00E 01	1.3738E 01	8.50E 01	1.3481E 01	9.00E 01	1.3235E 01
9.50E 01	1.2999E 01	1.00E 02	1.2774E 01	1.10E 02	1.2351E 01
1.20E 02	1.1964E 01	1.30E 02	1.1607E 01	1.40E 02	1.1275E 01
1.50E 02	1.0965E 01	1.60E 02	1.0673E 01	1.70E 02	1.0398E 01
1.80E 02	1.0140E 01	1.90E 02	9.8980E 00	2.00E 02	9.6710E 00
2.20E 02	9.2580E 00	2.40E 02	8.8920E 00	2.60E 02	8.5620E 00
2.80E 02	8.2620E 00	3.00E 02	7.9870E 00	3.20E 02	7.7340E 00
3.40E 02	7.5010E 00	3.60E 02	7.2840E 00	3.80E 02	7.0830E 00
4.00E 02	6.8970E 00	4.20E 02	6.7250E 00	4.40E 02	6.5650E 00
4.60E 02	6.4150E 00	4.80E 02	6.2750E 00	5.00E 02	6.1430E 00
5.50E 02	5.8450E 00	6.00E 02	5.5840E 00	6.50E 02	5.3540E 00
7.00E 02	5.1480E 00	7.50E 02	4.9640E 00	8.00E 02	4.7970E 00
8.50E 02	4.6450E 00	9.00E 02	4.5060E 00	9.50E 02	4.3780E 00
1.00E 03	4.2610E 00	1.10E 03	4.0510E 00	1.20E 03	3.8680E 00
1.30E 03	3.7060E 00	1.40E 03	3.5610E 00	1.50E 03	3.4290E 00
1.60E 03	3.3090E 00	1.70E 03	3.1980E 00	1.80E 03	3.0970E 00
1.90E 03	3.0030E 00	2.00E 03	2.9150E 00	2.20E 03	2.7590E 00
2.40E 03	2.6220E 00	2.60E 03	2.5010E 00	2.80E 03	2.3920E 00
3.00E 03	2.2930E 00	3.20E 03	2.2030E 00	3.40E 03	2.1200E 00
3.60E 03	2.0430E 00	3.80E 03	1.9730E 00	4.00E 03	1.9070E 00
4.20E 03	1.8450E 00	4.40E 03	1.7880E 00	4.60E 03	1.7340E 00
4.80E 03	1.6830E 00	5.00E 03	1.6350E 00	5.20E 03	1.5890E 00
5.40E 03	1.5470E 00	5.60E 03	1.5060E 00	5.80E 03	1.4670E 00
6.00E 03	1.4300E 00	6.20E 03	1.3950E 00	6.40E 03	1.3620E 00
6.60E 03	1.3290E 00	6.80E 03	1.2990E 00	7.00E 03	1.2690E 00
7.50E 03	1.2010E 00	8.00E 03	1.1390E 00	8.50E 03	1.0830E 00
9.00E 03	1.0320E 00	9.50E 03	9.8590E-01	1.00E 04	9.4320E-01
1.05E 04	9.0350E-01	1.10E 04	8.6650E-01	1.15E 04	8.3230E-01
1.20E 04	8.0050E-01	1.25E 04	7.7100E-01	1.30E 04	7.4330E-01

1.35E 04	7.1730E-01	1.40E 04	6.9290E-01	1.45E 04	6.6980E-01
1.50E 04	6.4800E-01	1.55E 04	6.2740E-01	1.60E 04	6.0780E-01
1.65E 04	5.8930E-01	1.70E 04	5.7170E-01	1.75E 04	5.5490E-01
1.80E 04	5.3900E-01	1.85E 04	5.2380E-01	1.90E 04	5.0930E-01
1.95E 04	4.9550E-01	2.00E 04	4.8230E-01		

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
1.0E+03 TO 1.0E+05(EV)	0.5
1.0E+05 TO 1.0E+06	0.7
1.0E+06 TO 1.4E+07	0.9
1.4E+07 TO 2.0E+07	1.0

CORRELATION MATRIX

+1.000			
+0.339	+1.000		
-0.110	+0.330	+1.000	
-0.040	-0.110	+0.335	+1.00

RELATIVE CENTER-OF-MASS NEUTRON ANGULAR DISTRIBUTIONS.
FORM--- SUM OVER A(I)*P(I), I=0,1,2,3 AND 4, A(0)=1.0.
LINEAR-LINEAR INTERPOLATION.

E(KEV)	A(1)	A(2)	A(3)	A(4)
1.0E 00	+0.0000E 00	+0.0000E 00	+0.0000E 00	+0.0000E 00
1.0E 02	-5.5958E-04	+1.4582E-07	+1.0491E-11	-6.2615E-12
2.0E 02	-1.0415E-03	+7.7858E-07	+2.4558E-14	-7.1725E-12
4.0E 02	-1.9165E-03	-8.2911E-06	+8.8759E-09	+9.1619E-10
6.0E 02	-2.7587E-03	+2.2326E-05	-1.5830E-07	+4.0976E-09
8.0E 02	-3.5996E-03	-2.0225E-05	-2.9604E-07	+1.3141E-08
1.0E 03	-4.3923E-03	-2.1837E-05	-9.5840E-07	+5.5044E-08
2.0E 03	-7.8534E-03	-1.4939E-04	-3.2478E-05	+1.3443E-06
4.0E C3	-1.3744E-02	-3.9492E-04	-1.8595E-04	+1.6038E-05
6.0E 03	-1.9007E-02	+3.5263E-04	-5.7961E-04	+4.5184E-05
8.0E 03	-2.3419E-02	+7.5344E-04	-1.1913E-03	+2.7082E-04
1.0E 04	-2.7817E-02	+3.9395E-03	-2.1302E-03	+4.2552E-04
1.2E 04	-3.2412E-02	+7.8464E-03	-3.3448E-03	+1.2151E-03
1.4E 04	-3.5926E-02	+1.2899E-02	-4.6372E-03	+1.9550E-03
1.6E 04	-3.8681E-02	+1.9119E-02	-6.0657E-03	+3.1383E-03
1.8E 04	-4.0592E-02	+2.6532E-02	-7.5378E-03	+4.6980E-03
2.0E 04	-4.1766E-02	+3.5148E-02	-8.9187E-03	+6.5867E-03

SUPPLEMENTAL HIGH-ENERGY H(N,N) CROSS SECTIONS.
VALUES FROM J. HOPKINS AND G. BREIT, NUCL. DATA, 9A, 137 (1971).

CROSS SECTION VALUES

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
2.00E 04	4.8230E-01	2.20E 04	4.3500E-01	2.40E 04	3.9490E-01
2.60E 04	3.6050E-01	2.80E 04	3.3070E-01	3.00E 04	3.0470E-01

HE-3(N,P) CROSS SECTIONS

NUMERICAL VALUES FROM ENDF/B-V, MAT 1146

APPLICABLE ENERGY RANGE THERMAL-50KEV

LOG-LOG INTERPOLATION

CROSS SECTION VALUES

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
1.000E-08	2.6795E 05	1.000E-07	8.4732E 04	2.530E-05	5.3270E 03
1.870E-01	6.1790E 01	2.800E-01	5.0290E 01	4.200E-01	4.1070E 01
6.310E-01	3.3510E 01	1.000E 00	2.6600E 01	1.420E 00	2.2370E 01
2.130E 00	1.8220E 01	3.190E 00	1.4400E 01	4.790E 00	1.1450E 01
4.791E 00	1.1449E 01	7.180E 00	9.1000E 00	7.181E 00	9.0994E 00
1.080E 01	7.2200E 00	1.620E 01	5.7100E 00	2.420E 01	4.5400E 00
3.630E 01	3.5900E 00	5.450E 01	2.8400E 00	8.170E 01	2.2560E 00

LI-6(N,T)HE-4 CROSS SECTIONS

NUMERICAL VALUES FROM ENDF/B-V, MAT-1303.
APPLICABLE ENERGY RANGE THERMAL-100 KEV.

CROSS SECTION VALUES

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
LOG-LOG INTERPOLATION.					
1.00E-08	4.7075E 04	1.00E-05	1.4886E 03	2.53E-05	9.3589E 02
1.00E-04	4.7073E 02	1.00E-03	1.4884E 02	1.00E-02	4.7052E 01
1.00E-01	1.4865E 01	4.00E-01	1.4248E 00	1.00E 00	4.6924E 00
2.00E 00	3.3175E 00	4.00E 00	2.3481E 00	6.50E 00	1.8462E 00
1.00E 01	1.4949E 00	1.50E 01	1.2297E 00	2.00E 01	1.0743E 00
2.50E 01	9.7026E-01	3.00E 01	8.9531E-01		
LINEAR-INEAR INTERPOLATION-					
3.00E 01	8.9531E-01	3.50E 01	8.3871E-01	4.00E 01	7.9464E-01
4.50E 01	7.5964E-01	5.00E 01	7.3154E-01	6.00E 01	6.9063E-01
7.00E 01	6.6488E-01	8.00E 01	6.5081E-01	9.00E 01	6.4679E-01
1.00E 02	6.5235E-01				

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
1.0E-05 TO 2.0E 02(EV)	0.4
2.0E 02 TO 2.0E 03	0.5
2.0E 03 TO 1.0E 04	0.5
1.0E 04 TO 3.0E 04	1.0
3.0E 04 TO 1.0E 05	2.0

CORRELATION MATRIX

+1.00				
+0.99	+1.00			
+0.93	+0.96	+1.00		
+0.67	+0.72	+0.88	+1.00	
+0.30	+0.35	+0.58	+0.89	+1.00

RELATIVE CENTER-OF-MASS TRITON ANGULAR DISTRIBUTIONS.
FORM--- SUM OVER A(I)*P(I), I=0,1 AND 2, A(0)=1.0.

E(KEV)	A(1)	A(2)

LOG-LOG INTERPOLATION.

E(KEV)	A(1)	A(2)
1.00E-08	+7.1589E-06	+3.5095E-12
5.00E 00	+1.5939E-01	+1.8948E-03
1.00E 01	+2.2484E-01	+4.0716E-03
1.50E 01	+2.7486E-01	+6.5505E-03
2.00E 01	+3.1689E-01	+9.3575E-03

LINEAR-LINEAR INTERPOLATION.

E(KEV)	A(1)	A(2)
2.00E 01	+3.1689E-01	+9.3575E-03
4.00E 01	+4.4541E-01	+2.4459E-02
6.00E 01	+5.4039E-01	+4.7464E-02
8.00E 01	+6.1350E-01	+8.1065E-02
1.00E 02	+6.6570E-01	+1.2828E-01

B-10(N,ALPHA-0) CROSS SECTIONS

NUMERICAL VALUES FROM ENDF/B-V, MAT-1305.
APPLICABLE ENERGY RANGE THERMAL TO 100 KEV.
LOG-LOG INTERPOLATION.

CROSS SECTION VALUES

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
1.00E-08	1.2287E 04	1.00E-05	3.8853E 02	2.53E-05	2.4425E 02
1.00E-04	1.2285E 02	1.00E-03	3.8830E 01	1.00E-02	1.2263E 01
1.00E-01	3.8622E 00	1.00E 00	1.2092E 00	1.00E 01	3.8004E-01
2.00E 01	2.7184E-01	3.00E 01	2.2520E-01	4.00E 01	1.9802E-01
5.00E 01	1.7988E-01	6.00E 01	1.6680E-01	7.00E 01	1.5690E-01
8.00E 01	1.4919E-01	9.00E 01	1.4307E-01	1.00E 02	1.3819E-01
1.20E 02	1.3121E-01	1.40E 02	1.2707E-01	1.60E 02	1.2506E-01
1.80E 02	1.2458E-01	2.00E 02	1.2495E-01		

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
1.0E-08 TO 4.0E 01(KEV)	2.2
4.0E 01 TO 1.0E 02	2.0
1.0E 02 TO 1.8E 02	1.2
1.8E 02 TO 2.0E 02	1.6

CORRELATION MATRIX

+1.000			
+0.924	+1.000		
+0.055	+0.323	+1.000	
+0.316	+0.302	+0.627	+1.000

B-10(N,ALPHA-1) CROSS SECTIONS

NUMERICAL VALUES FROM ENDF/B-V,MAT-1305.
APPLICABLE ENERGY RANGE THERMAL TO 100 KEV
LOG-LOG INTERPOLATION

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
1.00E-08	1.8071E 05	1.00E-05	5.7142E 03	2.53E-05	3.5923E 03
1.00E-04	1.8067E 03	1.00E-03	5.7109E 02	1.00E-02	1.8035E 02
1.00E-01	5.6795E 01	1.00E 00	1.7754E 01	1.00E 01	5.4939E 00
2.00E 01	3.8717E 00	3.00E 01	3.1664E 00	4.00E 01	2.7524E 00
5.00E 01	2.4736E 00	6.00E 01	2.2697E 00	7.00E 01	2.1124E 00
8.00E 01	1.9859E 00	9.00E 01	1.8812E 00	1.00E 02	1.7922E 00
1.20E 02	1.6471E 00	1.40E 02	1.5307E 00	1.60E 02	1.4320E 00
1.80E 02	1.3442E 00	2.00E 02	1.2626E 00		

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
1.0E-08 TO 4.0E 01(KEV)	0.3
4.0E 01 TO 1.0E 02	0.7
1.0E 02 TO 1.8E 02	0.8
1.8E 02 TO 2.0E 02	1.2

CORRELATION MATRIX

+1.000			
+0.981	+1.000		
+0.861	+0.928	+1.000	
+0.729	+0.810	+0.921	+1.000

NATURAL CARBON, ELASTIC SCATTERING

NUMERICAL VALUES FROM ENDF/B-V,MAT-1306.
APPLICABLE ENERGY RANGE 10**-5 EV TO 1.8 MEV
LINEAR-LINEAR INTERPOLATION.

CROSS SECTION VALUES

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
.1000E-07	.4739E 01	.1000E-05	.4739E 01	.2530E-04	.4739E 01
.1000E-03	.4739E 01	.1000E-01	.4739E 01	.1000E 01	.4735E 01
.5000E 01	.4716E 01	.1000E 02	.4699E 01	.1500E 02	.4682E 01
.2000E 02	.4665E 01	.2500E 02	.4649E 01	.3000E 02	.4632E 01
.3500E 02	.4615E 01	.4000E 02	.4599E 01	.4500E 02	.4582E 01
.5000E 02	.4566E 01	.7500E 02	.4486E 01	.1000E 03	.4408E 01
.1250E 03	.4333E 01	.1500E 03	.4259E 01	.1750E 03	.4187E 01
.2000E 03	.4117E 01	.2250E 03	.4049E 01	.2500E 03	.3983E 01
.2750E 03	.3918E 01	.3000E 03	.3855E 01	.3250E 03	.3794E 01
.3500E 03	.3734E 01	.3750E 03	.3675E 01	.4000E 03	.3618E 01
.4250E 03	.3563E 01	.4500E 03	.3508E 01	.4750E 03	.3455E 01
.5000E 03	.3403E 01	.5250E 03	.3353E 01	.5500E 03	.3303E 01
.5750E 03	.3255E 01	.6000E 03	.3208E 01	.6250E 03	.3161E 01
.6500E 03	.3116E 01	.6750E 03	.3072E 01	.7000E 03	.3029E 01
.7250E 03	.2987E 01	.7500E 03	.2945E 01	.7750E 03	.2905E 01
.8000E 03	.2865E 01	.8250E 03	.2827E 01	.8500E 03	.2789E 01
.8750E 03	.2752E 01	.9000E 03	.2715E 01	.9250E 03	.2680E 01
.9500E 03	.2645E 01	.9750E 03	.2611E 01	.1000E 04	.2577E 01
.1025E 04	.2545E 01	.1050E 04	.2512E 01	.1053E 04	.2509E 01
.1075E 04	.2481E 01	.1100E 04	.2450E 01	.1125E 04	.2420E 01
.1150E 04	.2390E 01	.1175E 04	.2361E 01	.1200E 04	.2333E 01
.1225E 04	.2305E 01	.1250E 04	.2278E 01	.1275E 04	.2251E 01
.1300E 04	.2225E 01	.1325E 04	.2199E 01	.1350E 04	.2174E 01
.1375E 04	.2149E 01	.1400E 04	.2125E 01	.1425E 04	.2101E 01
.1450E 04	.2078E 01	.1475E 04	.2055E 01	.1500E 04	.2033E 01
.1525E 04	.2011E 01	.1550E 04	.1989E 01	.1553E 04	.1987E 01
.1575E 04	.1968E 01	.1600E 04	.1948E 01	.1625E 04	.1928E 01
.1650E 04	.1908E 01	.1675E 04	.1889E 01	.1700E 04	.1870E 01
.1725E 04	.1851E 01	.1750E 04	.1833E 01	.1775E 04	.1815E 01
.1800E 04	.1798E 01	.1825E 04	.1781E 01	.1850E 04	.1764E 01
.1875E 04	.1748E 01	.1900E 04	.1732E 01	.1925E 04	.1716E 01
.1950E 04	.1701E 01	.1975E 04	.1685E 01	.2000E 04	.1670E 01
.2025E 04	.1659E 01	.2050E 04	.1685E 01	.2052E 04	.1695E 01
.2053E 04	.1702E 01	.2054E 04	.1709E 01	.2056E 04	.1728E 01
.2058E 04	.1754E 01	.2060E 04	.1792E 01	.2061E 04	.1816E 01
.2062E 04	.1847E 01	.2063E 04	.1884E 01	.2064E 04	.1929E 01
.2065E 04	.1987E 01	.2066E 04	.2059E 01	.2067E 04	.2152E 01
.2068E 04	.2274E 01	.2069E 04	.2433E 01	.2070E 04	.2645E 01

.2071E 04	.2930E 01	.2072E 04	.3312E 01	.2073E 04	.3818E 01
.2074E 04	.4451E 01	.2075E 04	.5156E 01	.2076E 04	.5766E 01
.2077E 04	.6043E 01	.2078E 04	.5872E 01	.2079E 04	.5373E 01
.2080E 04	.4765E 01	.2081E 04	.4199E 01	.2082E 04	.3728E 01
.2083E 04	.3356E 01	.2084E 04	.3066E 01	.2085E 04	.2840E 01
.2086E 04	.2663E 01	.2087E 04	.2522E 01	.2088E 04	.2408E 01
.2089E 04	.2317E 01	.2090E 04	.2241E 01	.2091E 04	.2178E 01
.2092E 04	.2124E 01	.2093E 04	.2079E 01	.2094E 04	.2041E 01
.2095E 04	.2007E 01	.2096E 04	.1978E 01	.2097E 04	.1953E 01
.2098E 04	.1930E 01	.2099E 04	.1910E 01	.2100E 04	.1893E 01
.2102E 04	.1862E 01	.2104E 04	.1838E 01	.2106E 04	.1817E 01
.2108E 04	.1800E 01	.2110E 04	.1785E 01	.2112E 04	.1772E 01
.2114E 04	.1761E 01	.2116E 04	.1751E 01	.2118E 04	.1742E 01
.2120E 04	.1735E 01	.2140E 04	.1686E 01	.2160E 04	.1661E 01
.2180E 04	.1644E 01	.2200E 04	.1632E 01	.2220E 04	.1622E 01
.2240E 04	.1614E 01	.2260E 04	.1606E 01	.2280E 04	.1600E 01
.2300E 04	.1595E 01	.2320E 04	.1591E 01	.2340E 04	.1588E 01
.2360E 04	.1585E 01	.2380E 04	.1584E 01	.2400E 04	.1583E 01
.2420E 04	.1583E 01	.2440E 04	.1584E 01	.2460E 04	.1587E 01
.2480E 04	.1590E 01	.2500E 04	.1594E 01	.2520E 04	.1600E 01
.2540E 04	.1608E 01	.2553E 04	.1613E 01	.2560E 04	.1616E 01
.2580E 04	.1627E 01	.2600E 04	.1639E 01	.2620E 04	.1654E 01
.2640E 04	.1671E 01	.2660E 04	.1690E 01	.2680E 04	.1713E 01
.2700E 04	.1740E 01	.2720E 04	.1770E 01	.2740E 04	.1806E 01
.2760E 04	.1848E 01	.2780E 04	.1898E 01	.2785E 04	.1912E 01
.2790E 04	.1927E 01	.2795E 04	.1943E 01	.2800E 04	.1961E 01
.2802E 04	.1969E 01	.2804E 04	.1979E 01	.2806E 04	.1990E 01
.2808E 04	.2007E 01	.2810E 04	.2039E 01	.2811E 04	.2072E 01
.2812E 04	.2140E 01	.2813E 04	.2328E 01	.2814E 04	.3160E 01
.2815E 04	.5071E 01	.2816E 04	.2776E 01	.2817E 04	.2289E 01
.2818E 04	.2159E 01	.2819E 04	.2109E 01	.2820E 04	.2086E 01
.2822E 04	.2070E 01	.2824E 04	.2067E 01	.2826E 04	.2070E 01
.2828E 04	.2076E 01	.2830E 04	.2082E 01	.2835E 04	.2103E 01
.2840E 04	.2126E 01	.2845E 04	.2152E 01	.2850E 04	.2180E 01
.2855E 04	.2210E 01	.2860E 04	.2242E 01	.2865E 04	.2277E 01
.2870E 04	.2315E 01	.2875E 04	.2355E 01	.2880E 04	.2399E 01
.2885E 04	.2447E 01	.2890E 04	.2499E 01	.2895E 04	.2555E 01
.2900E 04	.2616E 01	.2905E 04	.2682E 01	.2910E 04	.2753E 01
.2915E 04	.2830E 01	.2920E 04	.2910E 01	.2924E 04	.2977E 01
.2928E 04	.3043E 01	.2932E 04	.3107E 01	.2936E 04	.3163E 01
.2940E 04	.3207E 01	.2944E 04	.3230E 01	.2948E 04	.3221E 01
.2952E 04	.3171E 01	.2956E 04	.3069E 01	.2960E 04	.2911E 01
.2964E 04	.2701E 01	.2968E 04	.2456E 01	.2972E 04	.2196E 01
.2976E 04	.1946E 01	.2980E 04	.1723E 01	.2984E 04	.1539E 01
.2988E 04	.1396E 01	.2992E 04	.1291E 01	.2996E 04	.1218E 01
.3000E 04	.1170E 01	.3010E 04	.1129E 01	.3020E 04	.1150E 01
.3030E 04	.1198E 01	.3040E 04	.1255E 01	.3050E 04	.1314E 01
.3053E 04	.1332E 01	.3060E 04	.1372E 01	.3080E 04	.1482E 01

.3100E 04	.1583E 01	.3120E 04	.1674E 01	.3140E 04	.1760E 01
.3160E 04	.1840E 01	.3180E 04	.1917E 01	.3200E 04	.1990E 01
.3220E 04	.2061E 01	.3240E 04	.2128E 01	.3260E 04	.2193E 01
.3280E 04	.2255E 01	.3300E 04	.2313E 01	.3320E 04	.2368E 01
.3340E 04	.2418E 01	.3360E 04	.2464E 01	.3380E 04	.2506E 01
.3400E 04	.2542E 01	.3420E 04	.2573E 01	.3440E 04	.2598E 01
.3460E 04	.2618E 01	.3480E 04	.2632E 01	.3500E 04	.2641E 01
.3520E 04	.2644E 01	.3540E 04	.2642E 01	.3553E 04	.2638E 01
.3560E 04	.2635E 01	.3580E 04	.2624E 01	.3600E 04	.2608E 01
.3620E 04	.2588E 01	.3640E 04	.2565E 01	.3660E 04	.2539E 01
.3680E 04	.2510E 01	.3700E 04	.2479E 01	.3720E 04	.2446E 01
.3740E 04	.2412E 01	.3760E 04	.2376E 01	.3780E 04	.2339E 01
.3800E 04	.2302E 01	.3820E 04	.2264E 01	.3840E 04	.2226E 01
.3860E 04	.2187E 01	.3880E 04	.2149E 01	.3900E 04	.2111E 01
.3920E 04	.2074E 01	.3940E 04	.2037E 01	.3960E 04	.2001E 01
.3980E 04	.1966E 01	.4000E 04	.1932E 01	.4010E 04	.1916E 01
.4020E 04	.1900E 01	.4030E 04	.1885E 01	.4040E 04	.1871E 01
.4050E 04	.1858E 01	.4053E 04	.1854E 01	.4060E 04	.1846E 01
.4070E 04	.1835E 01	.4080E 04	.1825E 01	.4090E 04	.1818E 01
.4100E 04	.1813E 01	.4110E 04	.1810E 01	.4120E 04	.1810E 01
.4130E 04	.1814E 01	.4140E 04	.1823E 01	.4150E 04	.1837E 01
.4160E 04	.1857E 01	.4170E 04	.1884E 01	.4180E 04	.1917E 01
.4190E 04	.1958E 01	.4200E 04	.2004E 01	.4210E 04	.2055E 01
.4220E 04	.2107E 01	.4230E 04	.2156E 01	.4240E 04	.2199E 01
.4250E 04	.2232E 01	.4260E 04	.2253E 01	.4270E 04	.2261E 01
.4280E 04	.2257E 01	.4290E 04	.2242E 01	.4300E 04	.2219E 01
.4310E 04	.2191E 01	.4320E 04	.2158E 01	.4330E 04	.2124E 01
.4340E 04	.2089E 01	.4350E 04	.2053E 01	.4360E 04	.2019E 01
.4370E 04	.1985E 01	.4380E 04	.1953E 01	.4390E 04	.1923E 01
.4400E 04	.1893E 01	.4420E 04	.1839E 01	.4440E 04	.1790E 01
.4460E 04	.1745E 01	.4480E 04	.1705E 01	.4500E 04	.1668E 01

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
1 KEV TO 250 KEV	0.46
250 KEV TO 500 KEV	0.46
500 KEV TO 600 KEV	0.53
600 KEV TO 700 KEV	0.53
700 KEV TO 750 KEV	0.53
750 KEV TO 800 KEV	0.53
800 KEV TO 900 KEV	0.53
900 KEV TO 1000 KEV	0.53
1000 KEV TO 1100 KEV	0.53
1100 KEV TO 1200 KEV	0.53
1200 KEV TO 1280 KEV	0.53
1280 KEV TO 1300 KEV	0.53
1300 KEV TO 1400 KEV	0.53
1400 KEV TO 1500 KEV	0.53
1500 KEV TO 1600 KEV	0.60
1600 KEV TO 1700 KEV	0.60
1700 KEV TO 1750 KEV	0.60
1750 KEV TO 1800 KEV	0.60

CORRELATION MATRIX
(IN PERCENT)

100																	
38	100																
33	33	100															
33	33	71	100														
33	33	71	71	100													
33	33	29	29	57	100												
33	33	29	29	29	71	100											
33	33	29	29	29	71	71	100										
33	33	29	29	29	29	29	29	100									
33	33	29	29	29	29	29	29	71	100								
33	33	29	29	29	29	29	29	71	71	100							
33	33	29	29	29	29	29	29	29	29	57	100						
33	33	29	29	29	29	29	29	29	29	29	71	100					
33	33	29	29	29	29	29	29	29	29	29	71	71	100				
29	29	25	25	25	25	25	25	25	25	25	25	25	25	100			
29	29	25	25	25	25	25	25	25	25	25	25	25	25	77	100		
29	29	25	25	25	25	25	25	25	25	25	25	25	25	77	77	100	
29	29	25	25	25	25	25	25	25	25	25	25	25	25	22	22	67	100

CENTER-OF-MASS LEGENDRE COEF.

```
FORM---
    DXSEC=(XSEC/4PI)*SUM( (2L+1)*A(L)*P(L) )
   TABLE GIVES---
        ENERGY AND NUMBER OF COEF.(N)
        FOLLOWED BY COEF. A(1) TO A(N), ASSUMING A(0)=1.
------------------------------------------------------------------------
 E(KEV)= .1000E 01     NO. COEF.=  1
.1401E-03
 E(KEV)= .5000E 01     NO. COEF.=  1
.6982E-03
 E(KEV)= .1000E 02     NO. COEF.=  1
.1391E-02
 E(KEV)= .5000E 02     NO. COEF.=  2
.6728E-02 .7499E-04
 E(KEV)= .1000E 03     NO. COEF.=  2
.1292E-01 .2793E-03
 E(KEV)= .2000E 03     NO. COEF.=  2
.2388E-01 .9736E-03
 E(KEV)= .3000E 03     NO. COEF.=  3
.3316E-01 .1917E-02 .6338E-04
 E(KEV)= .4000E 03     NO. COEF.=  3
.4099E-01 .2995E-02 .1285E-03
 E(KEV)= .5000E 03     NO. COEF.=  3
.4753E-01 .4130E-02 .2241E-03
 E(KEV)= .6000E 03     NO. COEF.=  3
.5292E-01 .5271E-02 .3492E-03
 E(KEV)= .7000E 03     NO. COEF.=  4
.5725E-01 .6392E-02 .4997E-03-.5711E-04
 E(KEV)= .8000E 03     NO. COEF.=  4
.6062E-01 .7483E-02 .6684E-03-.1026E-03
 E(KEV)= .9000E 03     NO. COEF.=  4
.6306E-01 .8550E-02 .8446E-03-.1721E-03
 E(KEV)= .1000E 04     NO. COEF.=  4
.6464E-01 .9614E-02 .1013E-02-.2737E-03
 E(KEV)= .1100E 04     NO. COEF.=  4
.6535E-01 .1071E-01 .1156E-02-.4167E-03
 E(KEV)= .1200E 04     NO. COEF.=  4
.6522E-01 .1189E-01 .1248E-02-.6122E-03
 E(KEV)= .1300E 04     NO. COEF.=  4
.6422E-01 .1321E-01 .1256E-02-.8722E-03
 E(KEV)= .1400E 04     NO. COEF.=  5
.6231E-01 .1477E-01 .1139E-02-.1209E-02 .6183E-04
 E(KEV)= .1500E 04     NO. COEF.=  5
.5945E-01 .1668E-01 .8418E-03-.1634E-02 .8928E-04
```

```
 E(KEV)= .1600E 04      NO. COEF.=  5
.5553E-01  .1906E-01  .2826E-03-.2154E-02  .1262E-03
 E(KEV)= .1700E 04      NO. COEF.=  5
.5038E-01  .2208E-01-.6674E-03-.2753E-02  .1748E-03
 E(KEV)= .1800E 04      NO. COEF.=  5
.4370E-01  .2590E-01-.2261E-02-.3358E-02  .2367E-03
 E(KEV)= .1850E 04      NO. COEF.=  5
.3956E-01  .2814E-01-.3475E-02-.3583E-02  .2725E-03
 E(KEV)= .1900E 04      NO. COEF.=  5
.3459E-01  .3061E-01-.5202E-02-.3630E-02  .3100E-03
 E(KEV)= .1925E 04      NO. COEF.=  5
.3162E-01  .3192E-01-.6391E-02-.3505E-02  .3282E-03
 E(KEV)= .1950E 04      NO. COEF.=  5
.2815E-01  .3329E-01-.7950E-02-.3184E-02  .3445E-03
 E(KEV)= .1960E 04      NO. COEF.=  5
.2655E-01  .3386E-01-.8727E-02-.2967E-02  .3500E-03
 E(KEV)= .1970E 04      NO. COEF.=  5
.2479E-01  .3445E-01-.9625E-02-.2675E-02  .3545E-03
 E(KEV)= .1980E 04      NO. COEF.=  5
.2282E-01  .3508E-01-.1068E-01-.2281E-02  .3576E-03
 E(KEV)= .1990E 04      NO. COEF.=  5
.2057E-01  .3576E-01-.1195E-01-.1746E-02  .3588E-03
 E(KEV)= .2000E 04      NO. COEF.=  5
.1795E-01  .3654E-01-.1351E-01-.1008E-02  .3570E-03
 E(KEV)= .2020E 04      NO. COEF.=  5
.1080E-01  .3894E-01-.1806E-01  .1571E-02  .3379E-03
 E(KEV)= .2040E 04      NO. COEF.=  5
-.2063E-02  .4600E-01-.2688E-01  .7934E-02  .2678E-03
 E(KEV)= .2060E 04      NO. COEF.=  4
-.3518E-01  .9691E-01-.4969E-01  .3288E-01
 E(KEV)= .2070E 04      NO. COEF.=  5
-.6030E-01  .2756E 00-.6113E-01  .7791E-01-.3519E-03
 E(KEV)= .2080E 04      NO. COEF.=  5
.5407E-01  .4256E 00  .3582E-01  .4467E-01  .5298E-03
 E(KEV)= .2090E 04      NO. COEF.=  5
.7744E-01  .1978E 00  .4476E-01-.1026E-01  .9477E-03
 E(KEV)= .2100E 04      NO. COEF.=  5
.6315E-01  .1232E 00  .3079E-01-.1741E-01  .9142E-03
 E(KEV)= .2110E 04      NO. COEF.=  5
.5284E-01  .9624E-01  .2203E-01-.1790E-01  .8753E-03
 E(KEV)= .2120E 04      NO. COEF.=  5
.4583E-01  .8401E-01  .1651E-01-.1744E-01  .8529E-03
 E(KEV)= .2130E 04      NO. COEF.=  5
.4073E-01  .7768E-01  .1276E-01-.1691E-01  .8426E-03
 E(KEV)= .2140E 04      NO. COEF.=  5
.3677E-01  .7418E-01  .1002E-01-.1648E-01  .8402E-03
```

```
E(KEV)= .2150E 04      NO. COEF.=  5
.3352E-01 .7224E-01 .7924E-02-.1616E-01 .8432E-03
E(KEV)= .2300E 04      NO. COEF.=  5
.6207E-02 .8470E-01-.4603E-02-.1697E-01 .1110E-02
E(KEV)= .2450E 04      NO. COEF.=  5
-.1573E-01 .1180E 00-.1183E-01-.2089E-01 .1542E-02
E(KEV)= .2600E 04      NO. COEF.=  5
-.3656E-01 .1685E 00-.1863E-01-.2551E-01 .2041E-02
E(KEV)= .2750E 04      NO. COEF.=  5
-.4791E-01 .2416E 00-.2207E-01-.2924E-01 .2103E-02
E(KEV)= .2780E 04      NO. COEF.=  6
-.4374E-01 .2591E 00-.2020E-01-.3010E-01 .1553E-02 .6195E-04
E(KEV)= .2800E 04      NO. COEF.=  6
-.2817E-01 .2685E 00-.1353E-01-.3224E-01-.2144E-03 .2082E-03
E(KEV)= .2805E 04      NO. COEF.=  6
-.1393E-01 .2683E 00-.7164E-02-.3402E-01-.1776E-02 .3361E-03
E(KEV)= .2810E 04      NO. COEF.=  6
.3059E-01 .2605E 00 .1474E-01-.3815E-01-.6326E-02 .7102E-03
E(KEV)= .2815E 04      NO. COEF.=  6
.1010E 00 .2822E 00 .1867E 00 .6405E-01 .1086E-01-.5477E-03
E(KEV)= .2820E 04      NO. COEF.=  6
-.1161E 00 .3100E 00-.4143E-01-.1114E-01 .1161E-01-.7458E-03
E(KEV)= .2830E 04      NO. COEF.=  6
-.7678E-01 .3055E 00-.3155E-01-.2194E-01 .5970E-02-.2935E-03
E(KEV)= .2840E 04      NO. COEF.=  6
-.6629E-01 .3109E 00-.2785E-01-.2349E-01 .4736E-02-.1950E-03
E(KEV)= .2880E 04      NO. COEF.=  6
-.4665E-01 .3446E 00-.1940E-01-.2141E-01 .3341E-02-.9901E-04
E(KEV)= .2900E 04      NO. COEF.=  6
-.3385E-01 .3644E 00-.1328E-01-.1772E-01 .2856E-02-.8199E-04
E(KEV)= .2920E 04      NO. COEF.=  6
-.1298E-01 .3836E 00-.3016E-02-.1111E-01 .2175E-02-.6937E-04
E(KEV)= .2940E 04      NO. COEF.=  6
.2403E-01 .3919E 00 .1578E-01 .9419E-03 .1039E-02-.6077E-04
E(KEV)= .2960E 04      NO. COEF.=  6
.8727E-01 .3502E 00 .4948E-01 .2166E-01-.8155E-03-.6570E-04
E(KEV)= .2980E 04      NO. COEF.=  6
.1405E 00 .1845E 00 .8226E-01 .3900E-01-.2168E-02-.1101E-03
E(KEV)= .3000E 04      NO. COEF.=  4
.7872E-01 .4030E-01 .5622E-01 .1845E-01
E(KEV)= .3020E 04      NO. COEF.=  6
-.4886E-02 .6621E-01 .1352E-01-.9095E-02 .2606E-02-.1659E-03
E(KEV)= .3040E 04      NO. COEF.=  6
-.4590E-01 .1296E 00-.8942E-02-.2254E-01 .3838E-02-.1537E-03
E(KEV)= .3080E 04      NO. COEF.=  6
-.7010E-01 .2193E 00-.2349E-01-.3037E-01 .4577E-02-.1340E-03
```

```
 E(KEV)= .3120E 04      NO. COEF.=  6
-.7230E-01 .2716E 00-.2572E-01-.3095E-01 .4688E-02-.1233E-03
 E(KEV)= .3200E 04      NO. COEF.=  6
-.6205E-01 .3310E 00-.2134E-01-.2723E-01 .4487E-02-.1138E-03
 E(KEV)= .3300E 04      NO. COEF.=  6
-.4078E-01 .3682E 00-.1015E-01-.1950E-01 .3892E-02-.1115E-03
 E(KEV)= .3400E 04      NO. COEF.=  6
-.1657E-01 .3823E 00 .3931E-02-.1027E-01 .3029E-02-.1163E-03
 E(KEV)= .3500E 04      NO. COEF.=  6
.6739E-02 .3803E 00 .1911E-01-.5875E-03 .1975E-02-.1286E-03
 E(KEV)= .3600E 04      NO. COEF.=  6
.2633E-01 .3674E 00 .3411E-01 .8834E-02 .8050E-03-.1495E-03
 E(KEV)= .3700E 04      NO. COEF.=  6
.4017E-01 .3475E 00 .4802E-01 .1759E-01-.4246E-03-.1803E-03
 E(KEV)= .3800E 04      NO. COEF.=  6
.4670E-01 .3233E 00 .6022E-01 .2559E-01-.1681E-02-.2222E-03
 E(KEV)= .3900E 04      NO. COEF.=  6
.4448E-01 .2958E 00 .7001E-01 .3297E-01-.2955E-02-.2766E-03
 E(KEV)= .4000E 04      NO. COEF.=  6
.3361E-01 .2627E 00 .7576E-01 .4010E-01-.4239E-02-.3441E-03
----------------------------------------------------------------------
```

AU-197 NEUTRON CAPTURE

NUMERICAL VALUES FROM ENDF/B-V, MAT-6379.
APPLICABLE ENERGY RANGE 0.2 TO 3.5 MEV.
LINEAR-LINEAR INTERPOLATION.

CROSS SECTION VALUES

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
.1950E 03	.2493E 00	.1960E 03	.2497E 00	.1970E 03	.2422E 00
.1980E 03	.2482E 00	.1990E 03	.2442E 00	.2000E 03	.2575E 00
.2100E 03	.2510E 00	.2200E 03	.2450E 00	.2300E 03	.2400E 00
.2400E 03	.2340E 00	.2500E 03	.2290E 00	.2600E 03	.2240E 00
.2700E 03	.2190E 00	.2800E 03	.2148E 00	.2900E 03	.2100E 00
.3000E 03	.2065E 00	.3100E 03	.2010E 00	.3200E 03	.1950E 00
.3300E 03	.1910E 00	.3400E 03	.1860E 00	.3500E 03	.1805E 00
.3600E 03	.1750E 00	.3700E 03	.1710E 00	.3800E 03	.1670E 00
.3900E 03	.1630E 00	.4000E 03	.1595E 00	.4100E 03	.1560E 00
.4200E 03	.1528E 00	.4300E 03	.1500E 00	.4400E 03	.1470E 00
.4500E 03	.1448E 00	.4600E 03	.1425E 00	.4700E 03	.1402E 00
.4800E 03	.1380E 00	.4900E 03	.1360E 00	.5000E 03	.1346E 00
.5200E 03	.1300E 00	.5400E 03	.1260E 00	.5600E 03	.1228E 00
.5800E 03	.1195E 00	.6000E 03	.1162E 00	.6500E 03	.1080E 00
.7000E 03	.1010E 00	.7500E 03	.9520E-01	.8000E 03	.9080E-01
.8500E 03	.8720E-01	.9000E 03	.8550E-01	.9500E 03	.8420E-01
.1000E 04	.8300E-01	.1100E 04	.7920E-01	.1200E 04	.7600E-01
.1300E 04	.7350E-01	.1400E 04	.7200E-01	.1500E 04	.7150E-01
.1550E 04	.7100E-01	.1600E 04	.6900E-01	.1700E 04	.6500E-01
.1800E 04	.6150E-01	.1900E 04	.5780E-01	.2000E 04	.5400E-01
.2100E 04	.5000E-01	.2200E 04	.4600E-01	.2300E 04	.4300E-01
.2400E 04	.4000E-01	.2500E 04	.3750E-01	.2600E 04	.3420E-01
.2700E 04	.3200E-01	.2800E 04	.2950E-01	.2900E 04	.2750E-01
.3000E 04	.2600E-01	.3500E 04	.2050E-01	.4000E 04	.1700E-01

THERMAL VALUE(0.0253 EV)= 98.71+-0.3 B.

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
2.0E 02 TO 5.0E 02(KEV)	6.1
5.0E 02 TO 6.0E 02	4.1
6.0E 02 TO 1.0E 03	4.1
1.0E 03 TO 2.5E 03	20.0
2.5E 03 TO 3.5E 03	20.0

CORRELATION MATRIX

+1.000				
+0.040	+1.000			
+0.040	+0.060	+1.000		
+0.000	+0.000	+0.190	+1.000	
+0.000	+0.000	+0.000	+0.960	+1.000

U-235 FISSION CROSS SECTIONS

NUMERICAL VALUES FROM ENDF/B-V, MAT-1395.
APPLICABLE ENERGY RANGE 0.1-20.0 MEV.
LINEAR-LINEAR INTERPOLATION.

CROSS SECTION VALUES

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
.9990E 02	.1599E 01	.1000E 03	.1581E 01	.1030E 03	.1572E 01
.1200E 03	.1520E 01	.1400E 03	.1476E 01	.1500E 03	.1457E 01
.1600E 03	.1440E 01	.1800E 03	.1408E 01	.2000E 03	.1377E 01
.2200E 03	.1343E 01	.2400E 03	.1314E 01	.2500E 03	.1302E 01
.2600E 03	.1291E 01	.2800E 03	.1272E 01	.3000E 03	.1262E 01
.3250E 03	.1249E 01	.3500E 03	.1235E 01	.3750E 03	.1221E 01
.4000E 03	.1209E 01	.4250E 03	.1196E 01	.4500E 03	.1184E 01
.4750E 03	.1174E 01	.5000E 03	.1167E 01	.5400E 03	.1157E 01
.5700E 03	.1151E 01	.6000E 03	.1145E 01	.6500E 03	.1140E 01
.7000E 03	.1137E 01	.7500E 03	.1137E 01	.7800E 03	.1137E 01
.8000E 03	.1139E 01	.8300E 03	.1142E 01	.8500E 03	.1147E 01
.9000E 03	.1168E 01	.9400E 03	.1195E 01	.9600E 03	.1207E 01
.9800E 03	.1217E 01	.1000E 04	.1220E 01	.1050E 04	.1215E 01
.1100E 04	.1215E 01	.1150E 04	.1216E 01	.1200E 04	.1220E 01
.1250E 04	.1223E 01	.1400E 04	.1239E 01	.1600E 04	.1264E 01
.1700E 04	.1278E 01	.1800E 04	.1288E 01	.1900E 04	.1294E 01
.2000E 04	.1298E 01	.2100E 04	.1297E 01	.2300E 04	.1286E 01
.2400E 04	.1278E 01	.2600E 04	.1259E 01	.2800E 04	.1240E 01
.3000E 04	.1219E 01	.3200E 04	.1201E 01	.3400E 04	.1184E 01
.3600E 04	.1165E 01	.3800E 04	.1148E 01	.4000E 04	.1132E 01
.4200E 04	.1125E 01	.4400E 04	.1120E 01	.4500E 04	.1111E 01
.4700E 04	.1092E 01	.5000E 04	.1064E 01	.5200E 04	.1052E 01
.5300E 04	.1048E 01	.5400E 04	.1047E 01	.5500E 04	.1047E 01
.5600E 04	.1049E 01	.5640E 04	.1051E 01	.5700E 04	.1055E 01
.5800E 04	.1066E 01	.5900E 04	.1083E 01	.6000E 04	.1112E 01
.6200E 04	.1207E 01	.6400E 04	.1306E 01	.6500E 04	.1364E 01
.6700E 04	.1456E 01	.7000E 04	.1553E 01	.7250E 04	.1650E 01
.7500E 04	.1719E 01	.7750E 04	.1763E 01	.8000E 04	.1782E 01
.8150E 04	.1784E 01	.8250E 04	.1784E 01	.8500E 04	.1782E 01
.9000E 04	.1772E 01	.9500E 04	.1762E 01	.1000E 05	.1749E 01
.1050E 05	.1738E 01	.1100E 05	.1732E 01	.1150E 05	.1732E 01
.1200E 05	.1748E 01	.1220E 05	.1771E 01	.1220E 05	.1771E 01
.1250E 05	.1826E 01	.1300E 05	.1915E 01	.1350E 05	.1998E 01
.1400E 05	.2068E 01	.1450E 05	.2099E 01	.1500E 05	.2103E 01
.1550E 05	.2093E 01	.1600E 05	.2068E 01	.1650E 05	.2036E 01
.1700E 05	.1986E 01	.1750E 05	.1960E 01	.1800E 05	.1939E 01
.1850E 05	.1945E 01	.1900E 05	.1966E 01	.1950E 05	.1990E 01
.2000E 05	.2024E 01				

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
100 KEV TO 150 KEV	4.0
150 KEV TO 200 MEV	3.0
200 KEV TO 400 KEV	3.0
400 KEV TO 1 MEV	3.5
1 MEV TO 2 MEV	2.5
2 MEV TO 4 MEV	3.0
4 MEV TO 10 MEV	3.5
10 MEV TO 15 MEV	4.0
15 MEV TO 20 MEV	6.0

CORRELATION MATRIX

+1.00								
+0.60	+1.00							
+0.25	+0.60	+1.00						
+0.35	+0.50	+0.60	+1.00					
+0.07	+0.10	+0.15	+0.30	+1.00				
+0.05	+0.10	+0.15	+0.25	+0.40	+1.00			
+0.00	+0.00	+0.00	+0.05	+0.30	+0.40	+1.00		
+0.00	+0.00	+0.00	+0.00	+0.05	+0.25	+0.45	+1.00	
+0.00	+0.00	+0.00	+0.00	+0.03	+0.20	+0.40	+0.80	+1.00
