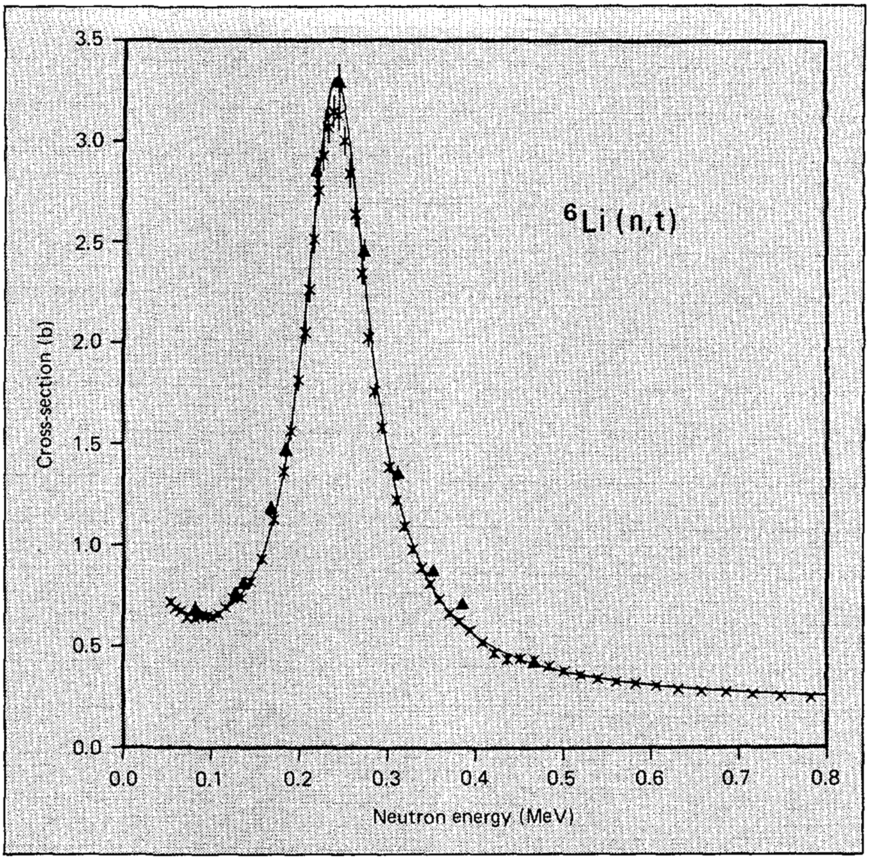

TECHNICAL REPORTS SERIES No. 227

Nuclear Data Standards for Nuclear Measurements

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1983

NUCLEAR DATA STANDARDS
FOR NUCLEAR MEASUREMENTS

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1982 INDC/NEANDC NUCLEAR STANDARDS FILE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1983

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PREFACE

This document of the Nuclear Standards Subcommittee of the International Nuclear Data Committee (INDC) contains the 1982 version of the Nuclear Standards File, and summarizes the status of the individual nuclear standards as of the 12th meeting of the INDC in October 1981, with selective updating to May 1982.

The INDC Nuclear Standards File is under continuous review. In addition, the INDC Standards Subcommittee and the counterpart subcommittee of the Nuclear Energy Agency Nuclear Data Committee (NEANDC) exchange technical information on those items which are common to the Standards Files of both Committees.

The objective of the file is to provide concise and readily usable reference guidelines to essential nuclear standard quantities for a variety of basic and applied endeavours.

The file consists of status summaries for sixteen nuclear data standards and data tabulations. The narrative summaries describe the current status of each of the standards and include references to recent relevant work and areas of continuing uncertainties. These brief reviews were prepared under the auspices of the INDC by outstanding specialists in the respective fields.

The large majority of the recommended numerical data for the standard cross sections is taken from ENDF/B-V, produced by the United States Cross Section Evaluation Working Group. The remainder of the numerical data is from evaluations undertaken by individuals or groups closely connected with nuclear data activities promoted by the INDC and NEANDC. Generally, the numerical data tables include quantitative definitions of the data uncertainties and some guidelines as to their appropriate usage.

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INDC Reference-Data-Type and Review Responsibilities

The responsibility for the individual reference data standards is shared among members of the INDC Standards Subcommittee and their delegates. The responsibility distribution as of 1981/1982 is as follows.

	Responsibility	
Standard	National	Current Personnel
H(n,n)H	UK	C.A. Uttley
$^{6}Li(n,t)^{4}He$	USA	A.B. Smith/J.M. Hale
$^{10}B(n,\alpha)^{7}Li$	CEC	E. Wattecamps
C(n,n)C	USA	A.B. Smith
$^{197}Au(n,\gamma)^{198}Au$	CEC	F. Corvi
$^{235}U(\sigma_f)$	USSR	G.B. Yankov
^{235}U Fiss.Fragm.Anisotropy	India	S.S. Kapoor
$^{238}U(\sigma_f)$	USA	A.B. Smith
$^{27}Al(n,\alpha)$	Austria	H. Vonach
Neutron Energy Standards	UK	G.D. James
Actinide Half-lives	IAEA/CEC	A. Lorenz/R. Vaninbroukx
Thermal Parameters	IAEA/USA	H.D. Lemmel/N. Holden
^{252}Cf Fission Spectrum	IAEA/USSR	H.D. Lemmel/G.B. Yankov
^{252}Cf Nu-bar	USA	A.B. Smith
Neutron Flux Comparisons	France	A. Michaudon/G. Grenier
Gamma-ray Standards	France/IAEA	J. Legrand/A. Lorenz

List of Abbreviations

AECL	Atomic Energy of Canada Ltd.
AEE	Atomic Energy Establishment, UK
AEIP	Atomic Energy Institute, Beijing, People's Republic of China
AERE	Atomic Energy Research Establishment, Harwell, UK
ANL	Argonne National Laboratory, USA
BARC	Bhabha Atomic Research Institute, Bombay, Trombay, India
BCMN	see CBNM
BIPM	Bureau International des Poids et Mesures, Sêvres, France
BNL	Brookhaven National Laboratory, USA
CBNM	CEC-JRC Central Bureau for Nuclear Measurements, Geel, Belgium
CEC	Commission of the European Communities
CEN	Centre d'Etudes Nucléaires, Saclay, France
CINR	Central Institute for Nuclear Research, Rossendorf, German Democratic Republic
ENDF	Evaluated Neutron Data File
ENSDF	Evaluated Nuclear Structure Data File
EPRI	Electrical Power Research Institute, Palo Alto, USA
ETL	Electrotechnical Laboratory, Tokyo, Japan
FOA	Foersvarets Forskningsanstalt, Sweden (National Defence Research Institute)
IAE	I.V. Kurchatov Atomic Energy Institute, Moscow, USSR
IAEA	International Atomic Energy Agency
ICRM	International Committee for Radionuclide Metrology
IMM	D.I. Mendeleev Metrology Institute, Leningrad, USSR
INDC	International Nuclear Data Committee
IUPAC	International Union of Pure and Applied Chemistry
JRC	CEC Joint Research Centre

LASL	Los Alamos Scientific Laboratory, USA (now LANL, Los Alamos National Laboratory)
LLL	Lawrence Livermore Laboratory, USA (now LNL, Livermore National Laboratory)
LMRI	Laboratoire de Métrologie des Rayonnements Ionisants, Saclay, France
NBS	National Bureau of Standards, Washington D.C., USA
NDS	Nuclear Data Section
NEANDC	Nuclear Energy Agency Nuclear Data Committee
NFL	Neutron Physics Laboratory, Studsvik Energieteknik AB, Sweden
NNDC	National Nuclear Data Center, Brookhaven National Laboratory, USA
NPL	National Physical Laboratory, Teddington, UK
NRC	National Research Council of Canada, Ottawa
ORELA	Oak Ridge Electron Linear Accelerator
ORNL	Oak Ridge National Laboratory, USA
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, Fed. Rep. of

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Introduction

The majority of basic and applied nuclear data measurements are made relative to reference standards. It is essential that these standards be well defined, clearly referenceable and easily available. The INDC/NEANDC nuclear standards file provides such standard-reference quantities in a manner not otherwise available.

In order to improve the accuracy and consistency of experimental results it is recommended

that standards tabulated in this report be adopted for all measurements, and

that when converting relative measured values to cross section values the numerical values given herein be employed.

These recommendations will facilitate future evaluation work and ease later renormalizations when improved standard-reference information becomes available.

The standards file consists of tabulated reference values and a status summary for sixteen nuclear data standards.

The narrative summaries consist of concise and up-to-date statements delineating nuclear reference standards judged of importance by the Committee. These statements, prepared by selected specialists, outline the justification for each standard, provide guidelines for use, outline the contemporary status (including shortcomings) and suggest possible avenues toward improvement. The statements explicitly support the accompanying numerical tabulations and set forth other important nuclear standards not amenable to straightforward numerical tabulation.

The numerical tabulations* consist of explicit reference values, generally with associated uncertainties, and with guidelines as to their use. Tabulations are included when the values are judged to be reasonably well defined. Certain important standard values are omitted from this tabulation if the present situation is judged to be in a state of flux.

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* H. Liskien and F.G. Perey gave particular attention to these numerical tabulations in order to assure their accuracy.

THE H(n,n) CROSS SECTION

C.A. Uttley
Atomic Energy Research Establishment,
Harwell, United Kingdom
June 1981

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

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

Status

Until recently frequent use was made of the simple prescription by Gammel in which the angular distribution of scattering is symmetrical about 90°. The parameterization of all relevant n-p and p-p data in terms of phase shifts by Hopkins and Breit (1) indicates a degree of anisotropy and asymmetry about 90° in n-p scattering, even below 10 MeV, which is important in practical applications. Recent angular-distribution data confirm the Hopkins and Breit calculations and the recommendation is that the evaluation based on these calculations by Stewart, LaBauve and Young (2) below 20 MeV should be adopted. This status report is concerned with recent developments in the total and differential n-p scattering cross sections below 30 MeV.

Accuracy of the Total Cross Section

A more detailed tabulation of the recommended Hopkins and Breit calculations is given in the Los Alamos report LA-4574 (2). The estimated standard deviation in the total cross section is ±1 percent and is in agreement with the measurement of Davis and Barschall (3) between 1.5 MeV and 27.5 MeV. A recent evaluation of the effective range parameters by Lomon and Wilson (4) gives total cross sections which do not differ significantly from the Hopkins and Breit values in the MeV region. A recent measurement of σ_T at 132 eV by Dilg (5) results in effective range parameters which disagree significantly with the evaluation of Lomon and Wilson, but a measurement at 24 keV by Fujita et al. (6) agrees with the cross section based on the evaluated parameters. These disagreements of a fraction of a percent in the low-energy total cross section are unlikely to materially affect the recommended values in the region of practical interest.

Some relatively recent results suggested that the ENDF/B-V neutron total cross sections are in error in the energy range 23-29 MeV; corrections to the measured values removed this discrepancy (7,8).

Accuracy of the Differential Scattering Cross Section

Until recently few measurements of the differential n-p scattering cross section have been made over an adequate angular range below 30 MeV to test the analysis of Hopkins and Breit. Their analysis was based on energy-dependent phase-shift analyses by the Yale (9) and Livermore (10) groups. The agreement between the two analyses as represented by Hopkins and Breit up to 30 MeV is better than 2 percent for $\sigma(0)$ and within 1 percent for $\sigma(180)$. The values of $\sigma(180) - \sigma(0)$ from 1 to 30 MeV vary by as much as 22 percent, however, and indicate the uncertainty in the P-wave phases, particularly $\delta(^1P_1)$, which determine the asymmetry in scattering at low energies. The uncertainty in $\delta(^1P_1)$ and its energy dependence has been stressed recently by Binstock (11) and by Voignier (12).

A single-energy phase-shift analysis of nucleon-nucleon scattering data near 50 MeV by Bryan and Binstock (13) illustrates the sensitivity of the value of $\delta(^1P_1)$ to the differential n-p scattering data included in the analysis. They point out the need for new and more precise differential n-p scattering data both at 50 MeV and in the energy range 20-30 MeV, especially at forward angles, so that better comparison can be made with model predictions of $\delta(^1P_1)$.

The relative differential cross section data at 24 MeV by Rothenberg (14) and by Burrows (15) over the (centre of mass) angular ranges 89° to 164° and 71° to 158°, respectively, have been normalized to the total cross section recommended by Hopkins and Breit. When these data are included with those of Masterson (16), who measured the absolute cross section at 39° and 50.5° at the same energy, they agree closely with the Yale phase parameterization.

Recent n-p polarization data at 21.1 MeV by Morris et al. (17) and by Jones and Brooks (18) have been included with the Wisconsin data of Rothenberg, Burrows and Masterson in a phase-shift analysis of nucleon-nucleon scattering data in the energy range 20-30 MeV by Bohannon et al. (19). The relative differential scattering data at 25.8 MeV by Montgomery et al. (20) over a (centre of mass) angular range 20° to almost 180° has also been included in a phase-shift analysis by Arndt et al. (21). In this work both a single energy analysis of data between 20 and 30 MeV has been carried out and an energy-dependent analysis of all data between 0 and 425 MeV. The phase parameters obtained from the two recent analyses by Bohannon et al. and Arndt et al. at 25 MeV are in agreement but the large uncertainties on the values of $\delta(^1P_1)$ of $-5.18 \pm 0.47°$ (Bohannon) and $-4.49 \pm 0.94°$ (Arndt) indicate that more differential scattering data are needed over a wide angular range. These recent values of $\delta(^1P_1)$ are also in reasonable agreement with those of $-4.90 \pm 0.48°$ and $-4.61 \pm 0.08°$ obtained from the Yale and Livermore (constrained) analyses, respectively, on which the Hopkins and Breit analysis is based.

New data on the 180° cross section for n-p scattering between 23 and 29 MeV were reported by Drosg (7), who measured values (5.7 ± 3.3) percent lower than those calculated from the recommended Yale phase shifts.

However, recent measurements by Drosg have not confirmed these low values. These results have an important bearing on the accuracy of neutron flux measurements using proton recoil counter telescopes.

New Measurements

The relative cross section $\sigma(\theta_C)/\sigma(\theta/2)$ from the angular distribution measurement at 27.3 MeV of Cookson et al. (22) was compared with the predictions from the phase-shift analyses of Bohannon et al., Arndt et al. and the Livermore (constrained) phase-shift set. A comparison is also made with the parameterization of Binstock (11) based on phase calculations from the Bryan-Gersten one-boson-exchange model. The data favour the asymmetry in scattering expected from the phase-shift analyses rather than the model calculation, which predicts a smaller value of $\delta(^1P_1)$ and therefore greater asymmetry about $\pi/2$.

A measurement of the total cross section from 5 to 200 MeV was reported by Lisowski et al. (23). Their data agree with the ENDF/B-V evaluation (up to 20 MeV) to within 1 percent and there is general agreement at higher energies with the data of Brady et al. (25 to 60 MeV) (24), Groce and Sowerby (20 to 80 MeV) (25), and Measday and Palmieri (90 to 150 MeV) (26). The semi-empirical fit of Gammel up to 40 MeV is also in good agreement with their total cross section.

The n-p analysing power data of Tornow et al. have recently been discussed in detail (27). Their data for the analysing power at 90° (centre of mass) between 13.5 and 16.9 MeV are in good agreement with the prediction from triplet P-wave phase shifts of Arndt et al., but the shape and magnitude at large (centre of mass) angles at 16.9 MeV is not reproduced by any of the global nucleon-nucleon phase-shift sets. Much better agreement with the 16.9 MeV data is obtained using phase shifts from the single-energy solution of Arndt et al., obtained by fitting nucleon-nucleon data between 15 and 35 MeV; but the best agreement is with the predictions from the phase-shift analysis of n-p data over the energy range 10-23 MeV carried out by Fischer et al. (28). This analysis yields the larger spin-orbit interaction in the nucleon-nucleon F states which is necessary to fit the analysing power data at the larger (centre of mass) scattering angles.*

Measured neutron total cross sections have recently been reported by Larson (30). The experimental results are consistent with the analysis of Arndt et al. (21) as shown in Fig. 1.

Poenitz and Whalen (31) have measured neutron total cross sections at 0.5, 1.0 and 2.0 MeV to accuracies of 0.2 percent, 0.2 percent and 0.4 percent, respectively. From these results, and other recently reported experimental values, a parameter set for the shape-independent effective-range approximation was deduced. The results imply systematically lower neutron total cross section values in the MeV range than given by ENDF/B-V by fractional percentage amounts as illustrated in Fig. 2.

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* This question is not resolved in the n-p analysing power measurements of Brock et al. (29) at 14.1 MeV.

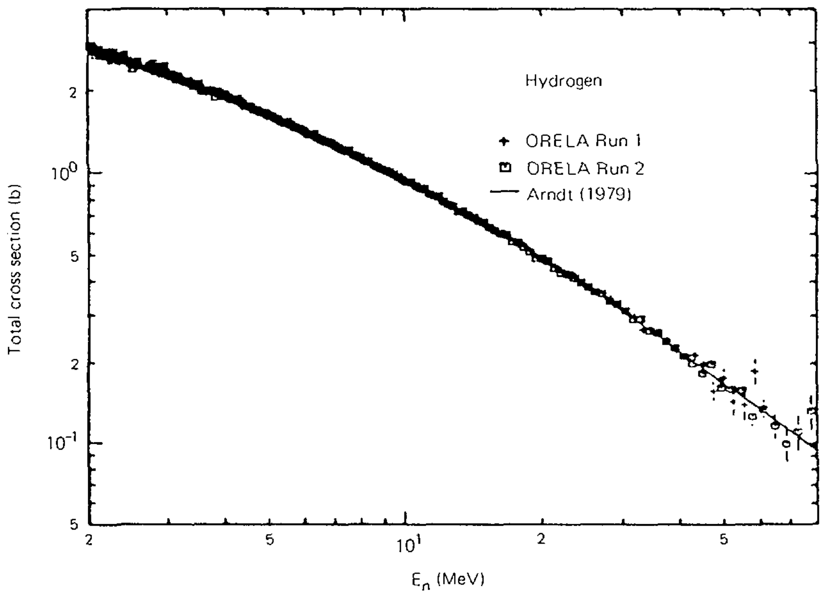

FIG.1. Comparison of measured neutron total cross section of Larson (30) with the predictions of Arndt et al. (21).

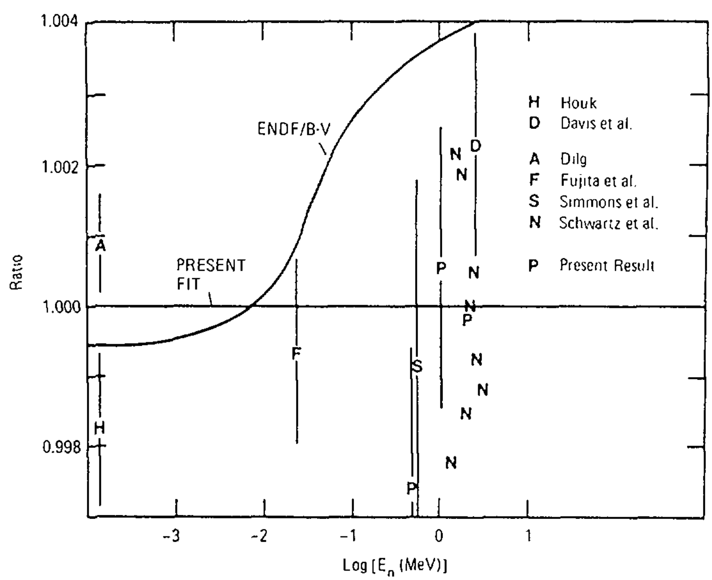

FIG.2. Comparison of neutron total cross sections deduced by Poenitz and Whalen (31) with those given in ENDF/B–V.

Comments and Recommendations

Differential n-p scattering cross section data below 30 MeV are not sufficiently accurate for distinguishing between the calculation of Hopkins and Breit using both the Yale and Livermore (constrained) phase parameters and those based on the more recent single-energy phase-shift analyses of Bohannon et al. and Arndt et al. A positive step would be to include the accurate n-p analysing power data of Tornow et al. in a new analysis of all nucleon-nucleon scattering observables in the energy range 14 to 35 MeV.

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H(n,n) CROSS SECTIONS - Recommended Reference Data

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 (eV)	UNCERTAINTY (PERCENT)
1.0E+03 TO 1.0E+05	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 Centre-of-Mass Neutron Angular Distributions

Legendre polynomial 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 03	-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

THE $^6Li(n,t)^4He$ CROSS SECTION*

G.M. Hale
Los Alamos National Laboratory, USA
March 1982

Because of its relatively large cross section and positive Q-value, and the convenience of counting the light triton and alpha-particle products, this reaction is widely used as a standard. The recommended energy range for use as a standard is thermal to 100 keV. At ~100 keV the cross section begins to deviate substantially from a 1/v behavior. However, applications in which the cross section is used as a standard at energies above the 240 keV resonance and up to a few MeV are not uncommon. The cross section at energies up to several MeV is also of interest because lithium is envisaged as a tritium-breeding medium in most fusion designs. With the standards application mainly in mind, we will limit the discussion of this review to energies below 1 MeV.

Status

Measurements of the neutron cross sections for ^6Li made before 1975 were inconsistent with unitary constraints relating them, particularly near the peak of the 240 keV resonance. That situation has improved significantly in the past few years in that recent measurements of the (n,t), total, and elastic-scattering cross sections agree with each other to the order of a few percent and with calculations (1-3) that impose unitary consistency.

The most comprehensive of these calculations is an R-matrix analysis (1) from which low-energy neutron cross sections for ^6Li (including the standard (n,t) cross section) were obtained for Version V of ENDF/B. Included in this analysis were recent LASL measurements of t-α differential cross sections and analysing powers (4) as well as the new measurements of the total cross section by Harvey and Hill (5) (ORNL) and of relative (n,t) cross sections by Lamaze et al. (6) (NBS). The R-matrix analysis gives a peak (n,t) cross section of 3.31 b at 240 keV and a peak total of 11.26 b at 245 keV. The 5 keV difference between the peaks of the total and (n,t) cross sections, as predicted in the analysis, agrees closely with the measurements in Refs (5,6), without shifting either energy scale. The cross sections predicted at the peak, however, are ~2 percent and 5 percent higher, respectively, than these measurements indicate. At energies below 200 keV, the agreement of the calculated $\sigma_{n,t}$ cross section with the relative data of Lamaze et al.** is generally better than 2 percent, and the agreement of the calculated σ_T

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* As given in the Brookhaven National Laboratory Report BNL-300 (1979) and edited in March 1982.

** The NBS relative data were converted using the Gammel representation for the (n,p) cross section which, as Poenitz has pointed out, differs from the Hopkins-Breit representation by ~1 percent in the low-energy region.

with the data of Harvey and Hill is generally better than 1 percent, except for a region around 150 keV where the difference is ~5 percent. The predicted thermal value of the (n,t) cross section is in excellent agreement with the recommended value of 936 b.

Knitter et al. (3) have reported measurements of σ_T between 80 keV and 3 MeV as well as an extension of earlier ^{6}Li(n,n) angular distribution measurements down to 100 keV. Recent work by Smith et al. (7) at ANL supplements the Geel total cross section data and extends the scattering measurements to 4 MeV. Fitted values (3,7) of the total, elastic, and (n,t) cross sections based on these measurements agree very well with the Version V results. The (fitted) resolution-corrected value in Ref (3) for the peak neutron total cross section is 11.27 ± 0.12 b at 247 ± 3 keV, while that obtained from the new ANL measurements is 11.2 ± 0.2 b at 244.5 ± 1.0 keV.

Among the new measurements of the ^{6}Li(n,t) integrated cross section reported since the Version V standards analysis was completed are those of Gayther (8) at Harwell and of Renner et al. (9) at ORNL. The Gayther (8) data, measured relative to ^{235}U(n,f) at energies between 3 and 800 keV, agree very well with the Version V ^{6}Li(n,t) results when converted with Sowerby's ^{235}U(n,f) evaluations. This agreement may be fortuitous, since the Sowerby evaluation does not represent current thinking about the "best" ^{235}U(n,f) cross sections in this energy range. The Renner et al. measurements (9), taken at "iron windows" between 80 and 470 keV, are also consistent with the Version V results, except possibly for a small normalization difference, as determined from a later fit in which the Lamaze et al. data were replaced by the Renner et al. (9) data (see Figs 1 and 2).

The measurements of Brown et al. (10) at LASL of $\sigma_{n,t}$ (0°) and $\sigma_{n,t}$ (180°) from the T(α,^{6}Li)n inverse reaction confirm a resonance energy of 240 keV and generally agree well with the Version V predictions. Measurements made with thin targets of the asymmetry of the ^{6}Li(n,t) angular distribution at 2 and 24 keV reported recently by Stelts et al. (11) agree well with predictions of the Version V analysis. Raman et al. (12) have also studied the asymmetry of the ^{6}Li(n,t) angular distributions from 0.5 eV to 25 keV in a thick-target geometry.

Macklin et al. (13) have recently recalibrated their ^{6}Li flux monitor in the 0.07-3 MeV range by comparing with the ^{235}U(n,f) cross section. The monitor response, when converted with the Version V ^{235}U(n,f) cross section, is in substantially better agreement with the Version V ^{6}Li(n,t) cross sections below 500 keV than that obtained previously. There remains, however, an apparent difference in the width of the 240 keV resonance.

Conclusions and Recommendations

A long-standing restriction on the usefulness of the ^{6}Li(n,t) cross section at all but the lowest energies has been the lack of reliably determined neutron cross sections for ^{6}Li over the 240 keV resonance. The recent measurements and the Version V ENDF evaluation represent a considerable improvement in that situation, achieving generally good internal agreement and, perhaps more important, unitary consistency among the cross sections over the resonance. Therefore, an appropriate goal of the next update of the ^{6}Li ENDF evaluation would be to produce a

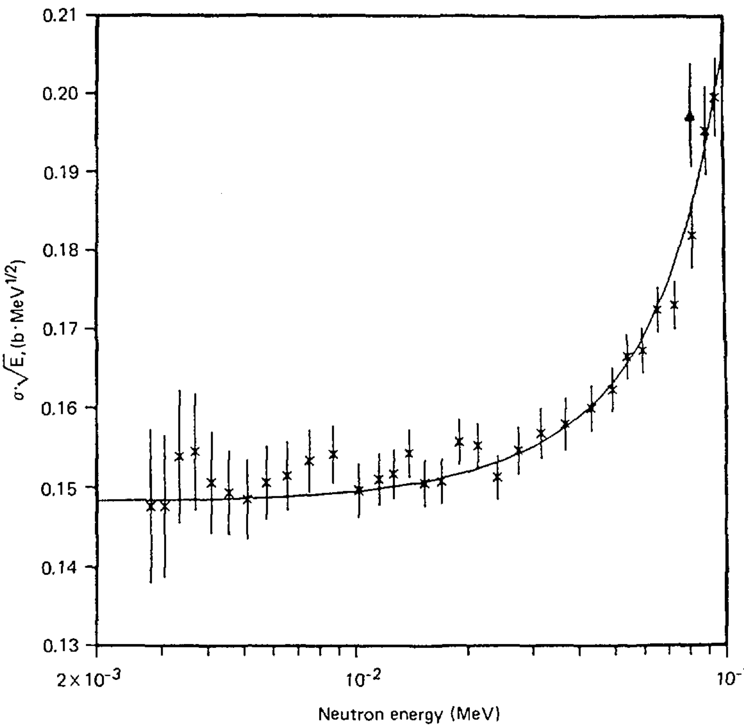

FIG.1. ENDF/B–V $^6Li(n,t)$ cross section (solid curve) compared with the measurements of Lamaze et al. (6) (X) and of Renner et al. (9) (▲) at energies below 100 keV. The cross sections are scaled by $\sqrt{E}$ to remove the 1/v dependence at low energies.

$^6Li(n,t)$ cross section that can be recommended as a standard up to much higher energies than the present 100 keV limit.

While the data that have appeared since the evaluation was completed tend to affirm that the present ENDF evaluation is close to that goal, they also point to discrepancies that should be resolved. Some of these are as follows:

> Differences over the resonance between the $^6Li(n,t)$ measurements of Renner et al. (9), which appear to be supported by the recent flux determination of Macklin et al. (13), and those of Lamaze et al. (6) at NBS.
>
> Differences over the resonance, apart from energy shifts, between measurements of the total cross section by Knitter et al. (3), which appear to be supported by Smith et al. (7), and those of Harvey and Hill (5).

The Renner et al. measurements (9) must be considered in conjuntion with the Harvey and Hill measurements (5) of σ_T, since the target thickness in the former experiment was determined by the latter.

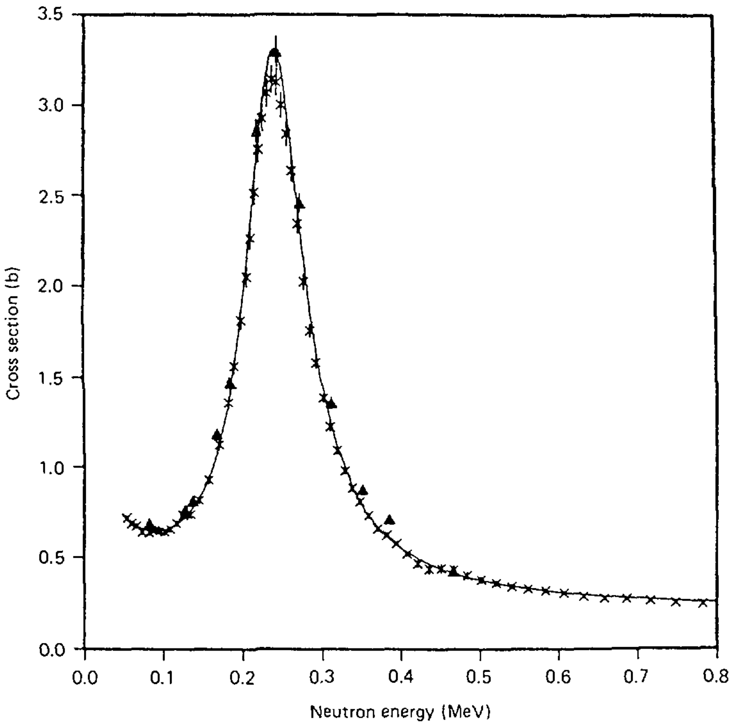

FIG.2. ENDF/B-V $^{6}Li(n,t)$ cross section (solid curve) compared with the measurements of Lamaze et al. (6) (X) and of Renner et al. (9) (▲) at energies between 50 and 800 keV.

Another area of experimental concern, if the energy range of the standard is to be extended, is the region 0.8-3 MeV where the few existing measurements disagree severely. This region contains the next identifiable resonance feature in the ^{6}Li(n,t) cross section above the 240 keV resonance - a "shoulder" at ~2 MeV due to the 3/2 state. Experiments are in progress at Uppsala (14) to measure ^{6}Li(n,α) and T(α,^{6}Li) angular distributions in the vicinity of this anomaly.

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Editor's Comment:

The Committee commented on several aspects of this standard. It was noted that $^{10}B/^6Li$ ratio values measured at the National Bureau of Standards were not entirely consistent with ENDF/B-V at very low energies. Inverse reaction studies are under way at Uppsala University corresponding to neutron energies of 0.2 to 2.5 MeV. W. Poenitz has initiated measurements designed to concurrently determine neutron total, elastic scattering and (n,α) cross sections in the keV range.
A relatively simple empirical expression has been developed at Obninsk that describes the $^6Li(n,t)$ cross section to 900 keV to average accuracies of 0.5 percent. Some concern was expressed for the apparent lack of correlation between standards (e.g. ^6Li, ^{10}B and ^{235}U) as expressed through the ENDF/B evaluation process. There was discussion of the reaction mechanism in the $n + {}^6Li$ process. A consistent problem is the postulated $\ell = 0$ resonance often employed in R-matrix interpretations in order to account for the low-energy cross section behaviour (e.g. the analysis involved in the ENDF/B-V evaluation). Such a resonance has not been directly observed in either ^7Li or the complementary ^7Be system.
An alternative deuteron exchange mechanism has been suggested by Weigmann and Manakos (Z. Phys. A289 (1979) 383). Experimental tests by Knitter et al. (BCMN) of this latter concept involving the measurement of triton angular distributions up to energies of 300 keV have not yet been conclusive. Smith et al. (Nucl. Phys. A373 (1982) 305) examined measured neutron total and scattering cross sections in the context of the

possible exchange mechanism with results that tended to be consistent with the concept but are not conclusive. Hale proposes a far more rigorous examination of the exchange concept, in particular assuring unitarity.

A.B. Smith
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USA
3/82.

^{6}Li(n,t) CROSS SECTIONS - Recommended Reference Data

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	7.4248E 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-LINEAR 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 (eV)	UNCERTAINTY (PERCENT)
1.0E-05 TO 2.0E 02	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 Centre-of-Mass Triton Angular Distributions

Legendre polynomial 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			
	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			
	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

THE $^{10}B(n,\alpha)$ CROSS SECTION

E. Wattecamps
CBNM, Geel, Belgium
February 1982

Natural-boron or ^{10}B-enriched samples are often used for neutron flux determinations. A large variety of detectors are used, and the reaction underlying the detection systems is either $^{10}B(n,\alpha\gamma)^7Li$ or $^{10}B(n,\alpha)^7Li$. Different symbols are frequently employed: $(n,\alpha\gamma)$ is identical with (n,α_1); and (n,α), also called total (n,α), is equal to the sum of (n,α_1) and (n,α_0). The α_0 refers to an α-emission with energy $E\alpha = 1.7891$ MeV, leaving the residual nucleus ^7Li in the ground state. The α_1 refers to an α-emission with an energy of $E\alpha = 1.4832$ MeV, leaving the residual nucleus ^7Li in its first excited state, which decays by prompt emission of a gamma of 478.5 keV.

The cross sections $\sigma(n,\alpha)$ and $\sigma(n,\alpha_1)$ recommended as standards from thermal to 100 keV by the Sub-Committee on Normalization and Standards of the US Cross Section Evaluation Working Group are listed below.

Status

From thermal energy up to 40 keV the uncertainty on the recommended (n,α_1) value in ENDF/B-V is claimed to be 0.3 percent. The uncertainty rises with increasing energy and amounts to 1.2 percent at 200 keV.

These uncertainties are much smaller than the accuracies requested in WRENDA 81/82. However, 19 priority I requests in the energy range from 1 keV to 10 MeV with accuracies from 1 percent to 5 percent are not withdrawn, namely: seven for absolute total (n,α), six for ratio measurements of (n,α_0) to (n,α_1) and seven for absolute (n,α_1) measurements. A new request was submitted for angular distribution measurements of (n,α_1) from 50 keV to 200 keV. Total (n,α) cross sections from 10 meV to 10 eV with an accuracy of 1 percent are also requested.

Since the release of the ENDF/B-V evaluation a few papers on relevant works have been published.

1. Neutron capture cross section standards for BNL-325, fourth edition, by Holden (1).

   Appendix 1 of Holden's paper deals with the variation of the thermal (n,α) cross section due to variations of the natural isotopic composition. No new data are published. The need for careful determination of the isotopic composition of natural boron is underlined. A list of the most accurate $\sigma(n,\alpha)$ values at thermal energies is given together with the recommended value of 3838 ± 6 b.

2. A comparison of (n,α) cross section measurements for $^{10}BF_3$ and solid ^{10}B from 0.5 to 10 000 eV by Carlson et al. (2).

Measurements made by Carlson et al. of (n,α) reaction rate ratios of BF_3 to solid boron from 0.5 eV to 10 000 eV show a constant energy-independent value with an accuracy better than 1 percent. Theoretical investigations of the effect of atomic binding predict an increase of 8 percent in the observed $\sigma(n,\alpha)$ value of boron bound in the BF_3 molecule relative to the free-atom cross section in evaporated boron. Experimental evidence and theoretical predictions remain in contradiction.

3. Measurement of the $^{10}B/^{6}Li$ cross section ratio below 1 keV by Czirr and Carlson (3).

   The measurements made by Czirr and Carlson of $^{10}B(n,\alpha)$ to $^{6}Li(n,\alpha)$ reaction ratios from 1 eV to 1000 eV are consistent with calculated ratios obtained with ENDF/B-V values from 1000 eV down to 20 eV, but below 20 eV a deviation of 2 percent remains unexplained. Recent ^{235}U fission cross section measurements made at ORNL relative to $^{10}B(n,\alpha)$ and at LLL using $^{6}Li(n,\alpha)$ yield an energy-dependent shape of LLL/ORNL fission cross section ratio that varies by 7 percent from 20 eV to 1000 eV.

4. The ratio of $^{10}BF_3$ and $^{3}He(n,p)$ cross sections between 0.025 eV and 25000 eV, by Bowman et al. (4).

   The ratio of the $^{10}BF_3$ and $^{3}He(n,p)$ cross sections between 0.025 eV and 25 000 eV as measured by Bowman and Behrens indicates a deviation of 6 percent at 2 keV between measured and calculated ratios deduced from ENDF/B-V values. Deviations from 1/v in the ratio below 100 eV are surprising.

5. $^{7}Li(\alpha,n)^{10}B$ differential cross-section measurements from threshold to E_α = 5.1 MeV by Sealock et al. (5).

   The measurements of Sealock et al. on $^{7}Li(\alpha,n)^{10}B$ were performed to investigate the discrepancy in (n,α_0) measurements of the inverse reaction near 350 keV and to provide angular distributions for R-matrix analysis. The shape of measured angular distributions in the α-particle energy range from 4.4 MeV to 5.1 MeV is well fitted by the R-matrix calculations of Hale. Calculated absolute values and measured data of Macklin and Gibbons are both about 30 percent lower than the present measured values, thus leaving a disquieting discrepancy.

6. Evaluation methods for neutron cross section standards by Bhat (6).

   At the recent Brookhaven conference on nuclear data evaluation methods and procedures, Bhat and Hale described the means for evaluation and the power of R-matrix methods for use in the evaluation of neutron cross section standards. Their contribution was essential in the ENDF/B-V evaluation together with the introduction of the variance-covariance file.

7. Use of R-matrix methods for light element evaluations by Hale (7).

Recommended (n,α_0) and (n,α_1) values are listed below together with the associated uncertainties and the error correlation matrix. The most impressive feature of the present status of the boron-10 standard is the small uncertainty claimed for the recommended values in the ENDF/B-V file. On the other hand relatively large deviations are obtained between calculated and measured reaction rate ratios of commonly accepted standards. To get more insight into the derivation of the ENDF/B-V uncertainties it is necessary to have available the underlying information.

Improving the accuracy of the underlying experimental data base is a very demanding task. In recent years only a small number of relative measurements and no absolute measurements have been performed.

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$^{10}B(n,\alpha_o)$ CROSS SECTION - Recommended Reference Data

NUMERICAL VALUES FROM ENDF/B-V, MAT-1305.
APPLICABLE ENERGY RANGE THERMAL TO 200 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 (keV)	UNCERTAINTY (PERCENT)
1.0E-08 TO 4.0E 01	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

$^{10}B(n,\alpha_1)$ CROSS SECTIONS - Recommended Reference Data

NUMERICAL VALUES FROM ENDF/B-V,MAT-1305.
APPLICABLE ENERGY RANGE THERMAL TO 200 keV.
LOG-LOG INTERPOLATION.

Cross Section Values

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 (keV)	UNCERTAINTY (PERCENT)
1.0E-08 TO 4.0E 01	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

THE C(n,n) CROSS SECTION

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Argonne National Laboratory, USA
February 1982

The primary use of this cross section is as a scattering standard at energies of less than 2 MeV where the neutron total and elastic scattering cross sections are essentially identical. The cross section in this energy range varies slowly with energy and is largely free of resonance structure. Similar use as a standard can be made to ~4.8 MeV (i.e. to the inelastic scattering treshold) if care is taken to avoid prominent resonance structure. High-purity samples are readily available and the target mass is sufficiently heavy to reduce centre-of-mass energy loss to amounts well below that encountered in the use of the primary H(n,n) scattering standard. Prominent resonances, notably at 2.087 MeV, provide good energy reference points and, at some energies (e.g. near 3.5 MeV) the elastic scattering distributions display well-defined minima that are useful in experimental angle calibrations.

Status and Recent Results

A very extensive review including new measurements and a R-matrix interpretation, has been published by Fu and Perey (1). This review is the background for the ENDF/B-V file, relevant portions of which are given in

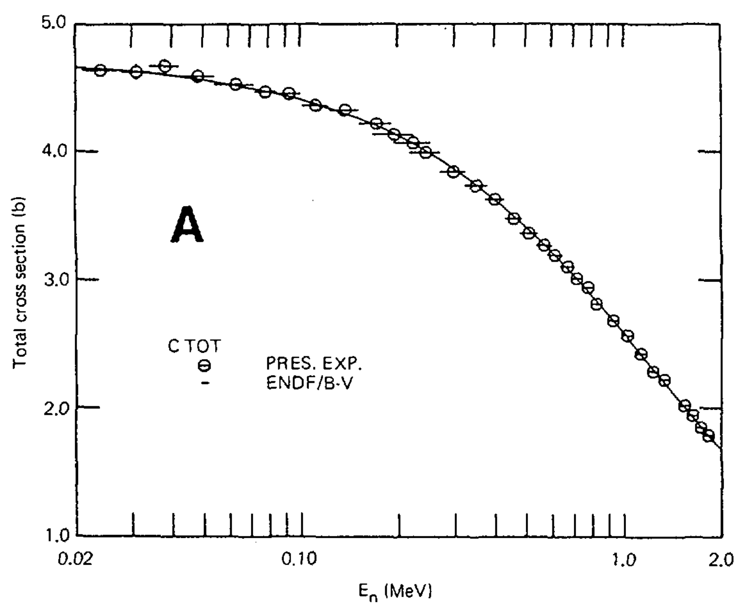

FIG.1. Comparison of the neutron total cross sections of natural carbon measured by Poenitz et al. (3) with the corresponding values given in ENDF/B−V.

the tabulations presented here. Concurrent with the work of Ref. (1), Holt, Smith and Whalen (2) have reported new neutron total and scattering measurements together with an R-matrix interpretation. The latter work is consistent with that of Ref. (1) and supports the ENDF/B-V evaluation to accuracies of <1 percent. Recent precision neutron total cross section measurements by Poenitz et al. (3), shown in Fig. 1, verify the ENDF/B-V file to fractional percent accuracies. Knox and Lane (4) have recently completed an extensive R-matrix interpretation of the (n + ^{12}C) process from thermal to 9 MeV. Their results, illustrated in Fig.2, are consistent with those of Refs (1,2) at lower energies and extend the quantitative interpretations to 9 MeV. A consequence is improved definition of the ^{13}C level structure and a sound interpolation of the available data base. There are shortcomings in the latter; particularly with respect to the (n,n') cross sections where experimental values remain discrepant (5, 6). All of the above work ignores the small contributions from the (n + ^{13}C) process. These can be a concern in precise applications of the standard as the (n + ^{13}C) process is known to display considerable resonance structure (7).

The energy of the 2078 keV resonance is a valued energy-scale reference point. Contemporary knowledge of this resonance energy, as summarized by James (8) is outlined in Table I. In addition, there is a very narrow and prominent resonance (d-5/2) at ~2.82 MeV. Unfortunately, its precise energy is not well known.

Conclusions and Recommendations

1. ENDF/B-V defines the neutron total cross section to accuracies of ~1 percent to above 5 MeV. These values should be routinely used to verify neutron-total-cross-section measurements.

2. Below 2 MeV the neutron differential elastic scattering cross sections given by ENDF/B-V are accurate to <1 percent. Relevant accuracy guidelines are given in Table II. In this energy range the (n + ^{12}C) reaction is a suitable scattering standard. If care is taken to avoid resonance energies, it can be similarly employed to ~4.8 MeV. The fact that the neutron total and elastic scattering cross sections are essentially equivalent can be exploited in some measurement methods (9).

3. The 2078.5 ± 0.32 keV resonance energy is a recommended energy calibration point. Additional energy calibration points are available at 6.6478 ± 0.0006 and 4.9368 ± 0.0004 MeV (10).

4. Perturbations due to the small contributions of the (n + ^{13}C) process are a continuing matter of concern in precise applications of this standard. Detailed studies of the (n + ^{13}C) process are encouraged so that the exact nature of these perturbations can be assayed.

5. The known 2.82 MeV (d-5/2) resonance is very narrow and of large magnitude. It could serve as a useful energy calibration point if its energy were precisely known. Measurements toward that end are encouraged.

6. This scattering standard could be very useful to 10 MeV if the elastic scattering cross sections were well known at selected energies in the range 5-10 MeV. This experimental information, coupled with recent R-matrix interpretations (4), could potentially define the elastic scattering cross section away from prominent resonances to accuracies of

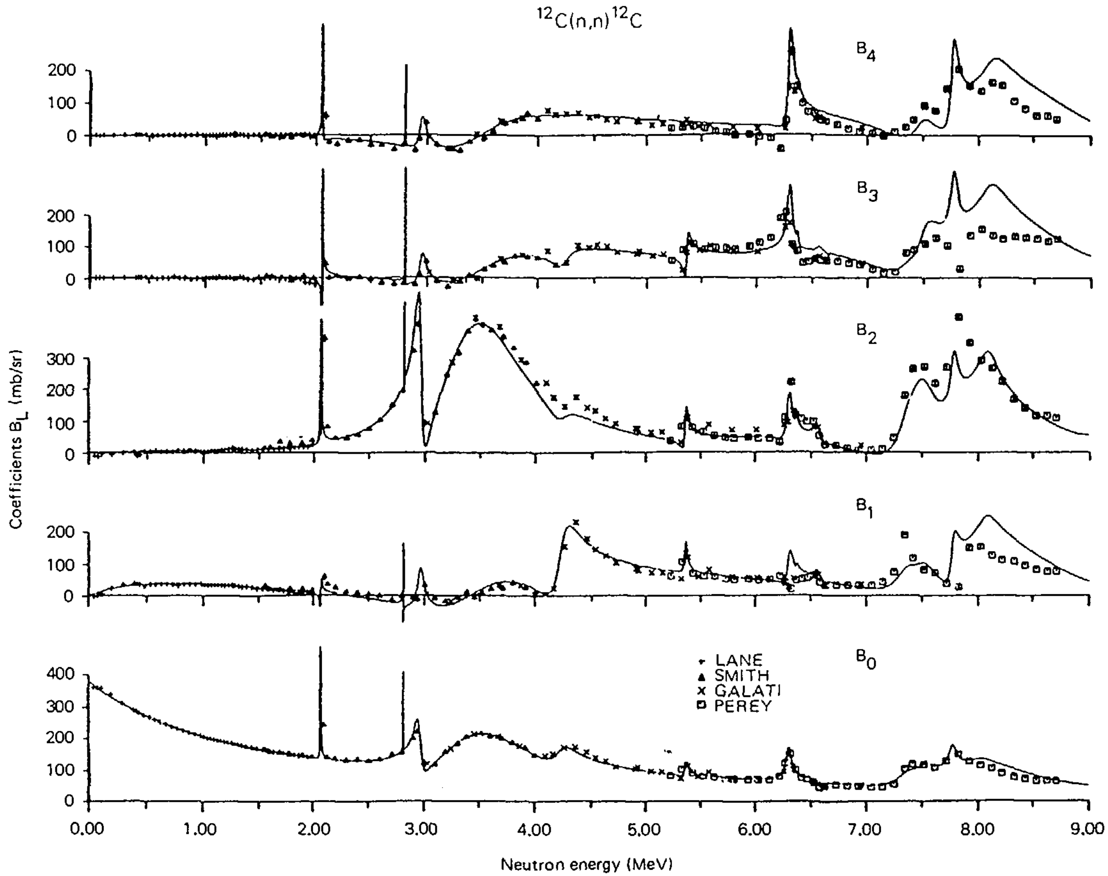

FIG.2. Differential elastic scattering cross sections of ^{12}C. The solid curves represent the result of an R-matrix interpretation by Knox and Lane (4).

Table I. Measured Peak Energy of 2078 keV Carbon Resonance[a]

Origin	Date	Energy (keV)
Harwell (50 m)	8/76	2079.2 ± 1.1
Harwell (100 m)	8/76	2078.31 ± 0.44
Harwell (dL/dt)	8/76	2077.45 ± 0.84
Davis and Noda	/69	2079 ± 3
Heaton et al.	/75	2079 ± 3
James (average of above Harwell results)	/77	2078.33 ± 0.89
Meadows	/77	2078.2 ± 2.8
Perey et al.	/72	2077.8 ± 1.5
Bockhoff et al.	/76	2077 ± 1
Cierjacks et al.	/68	2077 ± 1
Average 2078.05 ± 0.32		

[a] Detailed information is given in Ref. (8).

Table II. One-Standard-Deviation Uncertainties (percent) of the Recommended Differential Cross Sections[a]

	deg., centre of mass					
E (MeV)	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	1.14	1.14	1.14	4.02

[a] These values from the error file given in Ref. (1).

~1 percent. Measurements toward this end are encouraged. Consideration should also be given to the current discrepancies between measured (n,n') cross section values as these inelastic quantities play a significant role in the theoretical interpolation of measured elastic scattering data.

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C(n,n) CROSS SECTIONS - Recommended Reference Data

NUMERICAL VALUES FROM ENDF/B-V,MAT-1306.
APPLICABLE ENERGY RANGE 10E-5 eV TO 2 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

* Higher energy values are given in Ref. (1).

Uncertainties

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

CORRELATION MATRIX (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

Relative Centre-of-Mass Neutron Angular Distributions

Legendre polynomial form: Sum over A(I)*P(I), I = 0,1,2,3,4 and 5, A(0) = 1.0

E (keV)	A(1)	A(2)	A(3)	A(4)	(A(5)
.1000E 01	.4203E-03				
.5000E 01	.2095E-02				
.1000E 02	.4173E-02				
.5000E 02	.2018E-01	.3749E-03			
.1000E 03	.3876E-01	.1397E-02			
.2000E 03	.7164E-01	.4868E-02			
.3000E 03	.9948E-01	.9585E-02	.4437E-03		
.4000E 03	.1230E-00	.1498E-01	.8995E-03		
.5000E 03	.1426E-00	.2065E-01	.1569E-02		
.6000E 03	.1588E-00	.2636E-01	.2444E-02		
.7000E 03	.1718E-00	.3196E-01	.3498E-02	-.5140E-03	
.8000E 03	.1819E-00	.3742E-01	.4679E-02	-.9234E-03	
.9000E 03	.1892E-00	.4275E-01	.5912E-02	-.1549E-02	
.1000E 04	.1939E-00	.4807E-01	.7091E-02	-.2463E-02	
.1100E 04	.1961E-00	.5355E-01	.8092E-02	-.3750E-02	
.1200E 04	.1957E-00	.5945E-01	.8736E-02	-.5510E-02	
.1300E 04	.1927E-00	.6605E-01	.8792E-02	-.7850E-02	
.1400E 04	.1869E-00	.7385E-01	.7973E-02	-.1088E-01	.6801E-03
.1500E 04	.1784E-00	.8340E-01	.5893E-02	-.1471E-01	.9821E-03
.1600E 04	.1666E-00	.9530E-01	.1978E-02	-.1939E-01	.1388E-02
.1700E 04	.1511E-00	.1104E-00	-.4672E-02	-.2478E-01	.1923E-02
.1800E 04	.1311E-00	.1295E-00	-.1583E-01	-.3022E-01	.2604E-02
.1850E 04	.1187E-00	.1407E-00	-.2433E-01	-.3225E-01	.2998E-02
.1900E 04	.1038E-00	.1531E-00	-.3641E-01	-.3267E-01	.3410E-02
.1925E 04	.9486E-01	.1596E-00	-.4474E-01	-.3155E-01	.3610E-02
.1950E 04	.8445E-01	.1665E-00	-.5565E-01	-.2866E-01	.3789E-02
.1960E 04	.7965E-01	.1693E-00	-.6109E-01	-.2670E-01	.3850E-02
.1970E 04	.7437E-01	.1723E-00	-.6738E-01	-.2408E-01	.3900E-02
.1980E 04	.6846E-01	.1754E-00	-.7476E-01	-.2053E-01	.3934E-02
.1990E 04	.6171E-01	.1788E-00	-.8365E-01	-.1571E-01	.3947E-02
.2000E 04	.5385E-01	.1827E-00	-.9457E-01	-.9072E-02	.3927E-02

THE $^{197}Au(n,\gamma)$ CROSS SECTION

F. Corvi
CBNM, Geel, Belgium
January 1982

Because of its monoisotopic nature, its chemical purity, its large thermal neutron capture cross section and capture resonance integral, and the simple decay scheme of the product nucleus formed by neutron capture, the capture cross section of gold has become one of the basic standards.

Status

In the following are listed only those works which bring additional information compared to the 1980 Version of the Nuclear Standards File (INDC-36/LN).

1) Joly et al. (1) have published final data which supersede those presented in Ref. (5) of Version 1980. Gamma-ray spectra were detected with a NaI(Tl) spectrometer composed of a central and an annulus crystal, working in anti-Compton and first-escape modes. The net pulse height spectrum was converted to a gamma-ray distribution using a least squares unfolding method and then extrapolated to zero energy by means of a statistical model calculation. The neutron flux was measured by a long counter and by a proton recoil telescope. The results are given in Table I: the total errors of the cross sections range from 7 percent at 0.5 MeV to 20 percent at 3.0 MeV.

2) Davletshin et al. (2) have measured the activation cross section of Au from 0.35 to 1.4 MeV relative to H(n,n). The results are given in Table II: the authors have repeated the measurements in slightly different experimental conditions in order to get a feeling for the systematic errors involved. They found that the mean square spread of the average values at those energies for which experiments were repeated was 4.5 percent compared to an average evaluated error of 3.1 percent.

   Below 1 MeV these data are on average about 16 percent larger than the ENDF/B-V values while above 1 MeV they are slightly lower.

3) Kononov et al. (3) measured the capture cross section of Au in the energy range 15-480 keV. The capture events were detected by a spherical liquid scintillator of diameter 32 cm, filled with a heavy-hydrogen-free scintillator. The relative flux was measured by a ^{10}B plate viewed by a NaI(Tl) crystal. The capture cross sections were normalized by the saturated resonance technique. Since the data are presented only in the form of a curve, no detailed comparison with other sets of results is possible.

4) Macklin (4) measured the gold capture cross section in a continuous way from 100 to 2000 keV, using the pulsed "white source" of ORELA. Gamma rays where detected by two liquid scintillators and the data were weighted in order to achieve a response proportional only to the total energy emitted. The neutron flux was monitored with a 0.5 mm thick ^{6}Li glass below 70 keV and with a ^{235}U fission chamber above. The detector efficiency

Table I. Data from Joly et al.(1)

NEUTRON ENERGY (MeV)	CROSS SECTION (mb)
0.52 ± 0.08	130 ± 9
0.72 ± 0.08	100 ± 8
0.94 ± 0.07	76 ± 8
2.00 ± 0.06	52 ± 8
2.50 ± 0.06	30 ± 6
3.00 ± 0.05	20 ± 4

Table II. Data from Davletshin et al.(2)

NEUTRON ENERGY (keV)	CROSS SECTION (mb)	REL. ERROR (PERCENT)
348 ± 15	223.0	2.7
348 ± 23	200.8	2.7
352 ± 19	212.7	3.1
590 ± 23	131.5	3.5
597 ± 16	126.6	3.2
700 ± 41	121.0	2.9
1188 ± 38	74.8	3.4
1400 ± 27	67.7	2.7

was calibrated at the saturated 4.9 eV resonance in a preliminary experiment. The calculated overall uncertainty rises from 3.6 percent at 100 keV to 4.7 percent at 2000 keV.

Macklin's data are listed in Table III: it should be noted that these are not point values but rather averages over 5, 25 or 100 keV intervals, according to the energy. In particular, the data below 200 keV, which were originally given by the author in 1 keV steps, have been compressed here into 5 keV intervals for convenience. Macklin's data agree well with those of Joly et al. (1) and Gupta et al. (5) but lie 5 to 10 percent lower than the ENDF/B-V values.

5) Bergqvist (6) performed activation measurements on Au in the MeV region. His results, listed in Table IV, should be considered as preliminary. In particular, while no changes are foreseen for the results with E_n > 2.45 MeV, the energy calibration of the two lowest energy points should be checked. This is important because the cross section of the reaction $^{115}In(n,n')^{115m}In$, which is used as a secondary neutron flux standard, increases rapidly with energy in the low-energy range. Above 2.5 MeV the data are about 20 percent lower than the ENDF/B-V values.

6) Magnusson et al. (7) measured the activation cross section at a neutron energy of 14.7 ± 0.3 MeV. The result is $\sigma(n,\gamma)$ = 1.09 ± 0.23 mb, to be compared to the value 2.1 ± 1.2 mb of Schwerer et al. (8).

Table III. Data from Macklin (4)

MID NEUTRON ENERGY (keV)	CROSS SECTION (mb)	MID NEUTRON ENERGY (keV)	CROSS SECTION (mb)
102.5	275.4 ± 3.6	282.5	211.2 ± 4.2
107.5	267.7 ± 3.9	287.5	187.6 ± 3.9
112.5	266.5 ± 3.5	292.5	183.0 ± 4.0
117.5	254.4 ± 3.5	297.5	175.4 ± 3.9
122.5	255.4 ± 3.6	312.5	175.3 ± 1.8
127.5	251.7 ± 3.6	337.5	163.9 ± 1.7
132.5	268.1 ± 3.7	362.5	155.7 ± 1.7
137.5	267.7 ± 3.8	387.5	152.1 ± 1.7
142.5	253.3 ± 3.8	412.5	142.5 ± 1.7
147.5	244.8 ± 3.7	437.5	141.7 ± 1.9
152.5	247.3 ± 3.8	462.5	141.4 ± 1.9
157.5	244.5 ± 3.8	487.5	133.0 ± 1.8
162.5	235.2 ± 3.8	512.5	125.7 ± 1.8
167.5	249.4 ± 3.9	537.5	121.9 ± 1.9
172.5	243.3 ± 3.9	562.5	112.9 ± 1.9
177.5	229.6 ± 3.7	587.5	109.8 ± 1.9
182.5	238.1 ± 3.8	612.5	102.3 ± 2.0
187.5	228.6 ± 3.8	637.5	94.8 ± 1.9
192.5	237.5 ± 4.1	662.5	92.2 ± 1.9
197.5	236.7 ± 4.0	687.5	92.0 ± 1.8
202.5	228.7 ± 3.9	712.5	88.6 ± 1.8
207.5	220.8 ± 3.9	737.5	89.7 ± 1.9
212.5	233.9 ± 4.0	762.5	87.3 ± 1.9
217.5	233.9 ± 4.1	787.5	82.2 ± 1.8
222.5	221.7 ± 4.0	850.0	81.1 ± 1.0
227.5	224.5 ± 4.1	950.0	74.5 ± 1.1
232.5	227.0 ± 4.1	1050.0	75.0 ± 1.3
237.5	223.3 ± 4.1	1150.0	71.9 ± 1.2
242.5	214.3 ± 4.0	1250.0	71.5 ± 1.3
247.5	213.4 ± 4.1	1350.0	67.4 ± 1.5
252.5	213.6 ± 4.0	1450.0	69.3 ± 1.7
257.5	226.3 ± 4.3	1550.0	66.0 ± 1.8
262.5	214.5 ± 4.1	1650.0	64.1 ± 1.9
267.5	217.4 ± 4.2	1750.0	58.7 ± 1.9
272.5	222.4 ± 4.3	1850.0	53.4 ± 2.0
277.5	210.0 ± 4.3	1950.0	57.7 ± 2.5

Table IV. Preliminary data from Bergqvist (6)

NEUTRON ENERGY (MeV)	CROSS SECTION (mb)
1.96	64.3 ± 4.7
2.21	50.8 ± 3.3
2.45	35.8 ± 2.4
2.68	25.8 ± 1.7
2.93	22.6 ± 1.6
3.17	18.7 ± 1.5
3.42	16.3 ± 1.3
3.69	15.2 ± 1.1
3.93	13.6 ± 0.8
4.18	12.0 ± 0.9

Conclusions and Recommendations

1) There seems to be a general consensus that the most recent measurements have cross section values lower than the ENDF/B-V points for $E_n > 1$ MeV. Moreover Macklin's work suggests that this trend continues also at lower energies.

2) It is well known that fluctuations of the gold capture cross section limit its use as a standard to the region above 200 keV, particularly for "mono-energetic" neutron sources. It should however be kept in mind that the structure of a cross section does not necessarily hinder its precise determination as long as averages in given energy intervals are considered. These values, coupled to an accurate knowledge of the shape of the neutron spectrum (as it is usually the case for "white" sources), can ensure an adequate standard. Moreover averages over intervals have smaller statistical errors and are more liable to show up discrepancies between different measurements.

   It is therefore suggested that in the "fluctuation" region (say from 5 to 200 keV) experimentalists give, whenever possible, in parallel with a pointwise representation, also averages in determined energy intervals as is already done for example for ^{235}U and other important fissile isotopes.

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^{197}Au (n,γ) CROSS SECTIONS - Recommended Reference Data

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 $\pm$ 0.3 b.

Uncertainties

ENERGY RANGE (keV)	UNCERTAINTY (PERCENT)
2.0E 02 TO 5.0E 02	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

THE ^{235}U FISSION CROSS SECTION

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February 1982

The ^{235}U fission cross section has a unique importance for reactor calculations as well as for cross section measurements. Also, many fission and capture cross sections are measured relative to ^{235}U in the high-energy range.

This resumé summarizes the current status of the ^{235}U fission cross section. Information prior to 1978 is reasonably well summarized in the previous publications of the standards file INDC-30/L and INDC-36/LN, and is the basis for the ENDF/B-V numerical standards file which is reproduced below. The recommended range of application of this cross section is from 0.1 to 20.0 MeV, though some new results improve the situation at lower energies.

Reviewer's Comments

Several precise measurements of the ^{235}U fission cross section were reported at the 5th All-Union Conference on Neutron Physics, Kiev (USSR), 15-19 September 1980. New information has also been reported at the INDC Meeting, 4-9 October 1981, from the Technical University, Dresden (German Democratic Republic), Bruyères-le-Chatel (France) and the National Bureau of Standards (USA). In addition, the review includes information from the Central Bureau for Nuclear Measurements, Geel (Belgium).

Mostovaya et al. (1) (I.V. Kurchatov Atomic Energy Institute, Moscow) measured the fission cross section using the time-of-flight method on the 60 MeV electron linac over the energy range of 0.1-100 keV with an accuracy of 1.5-2.0 percent. The results are given in Table I. They span the energy range that has long been uncertain. The value of the cross section over the energy interval 0.09-0.1 MeV is 1.51 ± 0.01 b; the corresponding ENDF/B-V value is 1.60 b.

Corvi (2) (CEC, JRC, Central Bureau for Nuclear Measurements, Geel) measured the fission cross section in the same energy range of 0.1-100 keV on the linac with a relative energy resolution of 0.27 percent. The data were normalized to the ENDF/B-V value of the low energy-fission integral between 7.8 and 11 eV, I = 241.2 b.eV. If the error of such a standard is neglected, the uncertainties of the values given in Table II should not exceed ±2 percent over the entire energy range.

Zhagrov et al. (3) (V.G. Khlopin Radium Institute, Leningrad) determined the fission cross section at 46 ± 7 keV and 120 ± 9 keV. The neutrons were produced by the $^{7}Li(p,n)^{7}Be$ reaction. The neutron flux was measured by the circulated $MnSO_4$ bath method. Their results were 2.08 ± 0.08 b and 1.51 ± 0.06 b, respectively. The latter value is in good agreement with the ENDF/B-V evaluation (1.52 b).

Table I. ^{235}U Fission Cross-Section (Ref.(1))

E_1-E_2 (keV)	XSEC (b)	E_1-E_2 (keV)	XSEC (b)	E_1-E_2	σ_f
0.1-0.2	21.88 ± 0.04	1 - 2	7.33 ± 0.02	10- 20	2.49 ± 0.01
0.2-0.3	20.87 ± 0.04	2 - 3	5.29 ± 0.02	20- 30	2.09 ± 0.01
0.3-0.4	12.97 ± 0.04	3 - 4	4.85 ± 0.03	30- 40	-
0.4-0.5	14.04 ± 0.06	4 - 5	4.34 ± 0.03	40- 50	1.84 ± 0.01
0.5-0.6	15.33 ± 0.06	5 - 6	3.95 ± 0.03	50- 60	1.82 ± 0.01
0.6-0.7	11.70 ± 0.06	6 - 7	3.45 ± 0.03	60- 70	1.74 ± 0.01
0.7-0.8	11.30 ± 0.06	7 - 8	3.28 ± 0.02	70- 80	1.67 ± 0.01
0.8-0.9	8.37 ± 0.05	8 - 9	3.00 ± 0.02	80- 90	1.60 ± 0.02
0.9-1.0	7.60 ± 0.05	9 - 10	3.09 ± 0.02	90-100	1.51 ± 0.01

Table II. Average ^{235}U Fission Cross Section (Ref.(2))

E_1-E_2 (keV)	σ_f (b)	E_1-E_2 (keV)	σ_f (b)	E_1-E_2 (keV)	σ_f (b)
0.1-0.2	20.37	1 - 2	7.178	10- 20	2.460
0.2-0.3	20.16	2 - 3	5.231	20- 30	2.104
0.3-0.4	12.80	3 - 4	4.684	30- 40	1.975
0.4-0.5	13.18	4 - 5	4.157	40- 50	1.835
0.5-0.6	14.88	5 - 6	3.813	50- 60	1.781
0.6-0.7	11.24	6 - 7	3.235	60- 70	1.727
0.7-0.8	10.83	7 - 8	3.148	70- 80	1.652
0.8-0.9	8.051	8 - 9	2.937	80- 90	1.580
0.9-1.0	7.322	9 - 10	3.080	90-100	1.532

The fission cross section of ^{235}U reported by Arlt et al. (4-6) has been determined by the time correlated associated-particle technique and an on-line data acquisition system. The measurements were performed at E_n = 2.6 MeV using the neutron generator at the Technical University of Dresden and at E_n = 8.2 and 8.4 MeV using the 5 MV tandem generator of the CINR Rossendorf (German Democratic Republic). The foils with ^{235}U were prepared and calibrated at V.G. Khlopin Radium Institute, Leningrad. The first reported value at 2.6 MeV was 1.215 ± 0.024 b (4).

As a result of two independent experiments (5), the final value of 1.215 ± 0.019 b at 2.56 MeV was obtained. The results at 8.2 MeV and 8.4 MeV were 1.741 ± 0.057 b (4) and 1.801 ± 0.043 b (6), respectively. These are in good agreement with the ENDF/B-V evaluation (1.78 b).

Cancé et al. (7) (Bruyères-le-Chatel) made a direct measurement of the ratio of fission to neutron-proton scattering cross sections with back-to-back deposits of ^{235}U and polyethylene. Two measurements have been made: the first at 2.5 ± 0.04 MeV in order to check the experimental method, the second at 4.45 ± 0.01 MeV. The cross section values are 1.26 ± 0.03 b and 1.13 ± 0.03 b, respectively; the corresponding value of the ENDF/B-V evaluation at 4.6 MeV is 1.11 b. The 2.6 MeV cross section value by Arlt et al. (5) and the 2.5 MeV value by Cancé et al. (7) are compared with the earlier values at similar energies in Fig. 4. The numerical result of the ENDF/B-V evaluation is 1.25 b.

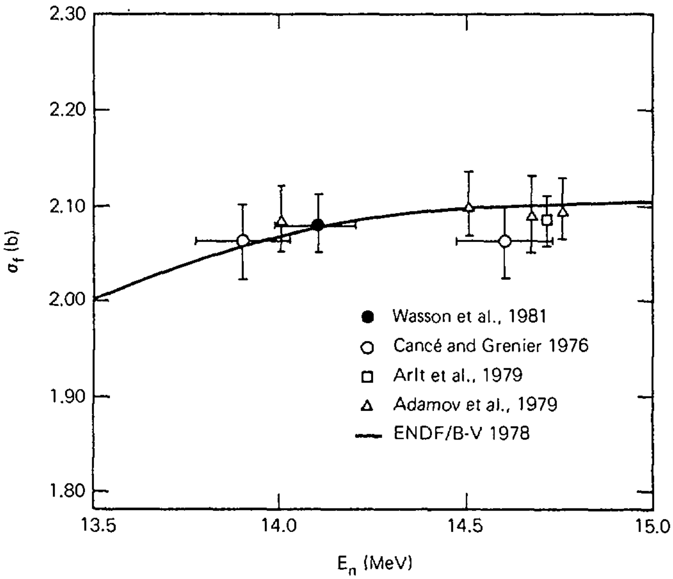

FIG.1. Comparison of the 1981 Wasson et al. (8) value with ENDF/B–V and previously reported values in the 14 MeV range.

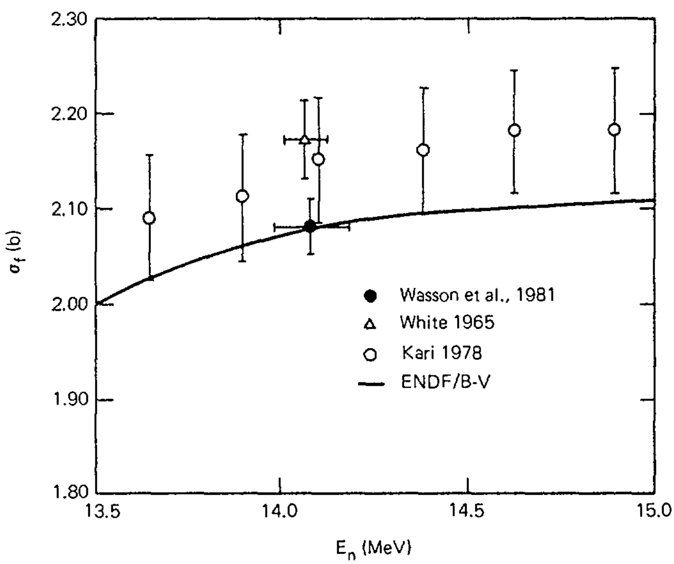

FIG.2. Comparison of Wasson et al. (8) value with previous results.

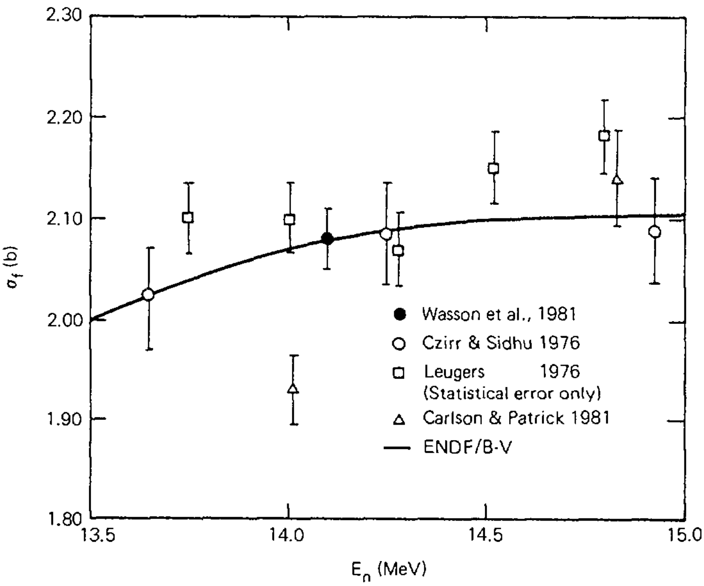

FIG.3. Comparison of Wasson et al. (8) value with previous results.

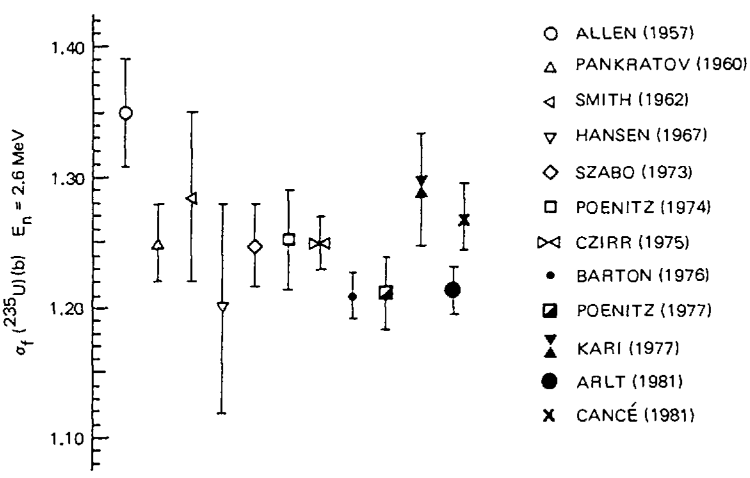

FIG.4. Comparison of the 1981 Arlt et al. (5) result at 2.6 MeV with previously reported values at similar energies.

Wasson et al. (8) (National Bureau of Standards, Washington) completed measurements at 14.1 ± 0.01 MeV with a result of 2.080 ± 0.030 b. They used the time correlated associated-particle technique with the $^3H(d,n)^4He$ reaction. This value is compared with the ENDF/B-V evaluation and some earlier values around 14 MeV in Figs. 1, 2 and 3. The present status of the measurements using the above technique is shown in

Fig. 1. These results are consistent within the accuracy of about 1.5 percent. An inspection of the figures suggests that the accuracy of this standard may be better than 1 percent near 14 MeV.

Carlson (9) has reported that a precision measurement programme over the energy range of 0.3-1.5 MeV is in progress at the National Bureau of Standards (USA). As a result of these measurements, and in view of the values noted above and those reported previously, it can be concluded that the energy range from 3.0 to 6.0 MeV is likely to be the major one where uncertainties remain.

In addition, an experiment by Bergman et al. (10) is in progress to measure the fission cross section using a neutron spectrometer based on the slowing-down technique over the energy range 0.1-50.0 keV to average accuracies of 1.5 percent - 2.0 percent.

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^{235}U FISSION CROSS SECTIONS - Recommended Reference Data

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	.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	.2045E 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

THE ^{235}U FISSION FRAGMENT ANISOTROPIES

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March 1982

A knowledge of fission fragment anisotropies is important in the evaluation of experimental fission cross section measurements in which fission fragments are detected in a small range of angles. Fission fragment anisotropies also provide important information on the quantum states available at the saddle point of the fissioning nucleus and these in turn provide a basis for theoretical understanding of the fission cross sections. This is the first review of the status of the measured fragment anisotropies for different neutron energies for ^{235}U. The present summary has resulted from a thorough literature survey in an attempt to include all published results; it also uses some recent unpublished data communicated privately. A fit to the anisotropy data on the basis of statistical theory has also been obtained.

Description of the Data

The measured fragment anisotropies W(0°)/W(90°) in the neutron energy range E_n = 0 to 23 MeV taken from Refs (1-15) are given in Figs 1 and 2. The measured anisotropies describing fragment angular distributions in the neutron energy range 50 to 1850 keV, as reported recently by Musgrove et al. (14) are given in Table I. Recently, series of measurements were completed by Meadows and Budtz-Jorgensen (Central Bureau of Nuclear Measurements, Geel, Belgium) and their results (15) have been included in the figures and also reproduced separately in Table I.

Comments

Although the average trend of the variation of the anisotropy with the neutron energy is clearly brought out in Figs 1 and 2, the different measurements of the anisotropy are generally in agreement to only within a value of 0.05. Comparing the two most recent measurements (14, 15) it is seen that the anisotropies communicated by Meadows and Budtz-Jorgensen (15) appear to be systematically lower by a few percent than those of Ref. (14). For example, at 300 keV and 1040 keV, where both have reported measurements, the values reported in Ref. (15) are 1.098 and 1.017 as compared to 1.170 and 1.040 in Ref. (14). The measurements of Ref. (14) are based on the use of semiconductor detectors with well defined geometric angles, while those of Ref. (15) are based on an indirect determination of the angle using gridded ion-chambers. Further careful measurements at both 300 keV and 1040 keV will be useful in resolving the discrepancy between the above two recent measurements.

The solid line in Figs 1 and 2 is the calculated (16) fragment anisotropy in the neutron energy range E_n < 11 MeV on the basis of the statistical theory (17), taking into consideration second chance fission, but assuming negligible contribution of the fissions following direct interactions. The solid line resulted from the values of K_0^2 (the

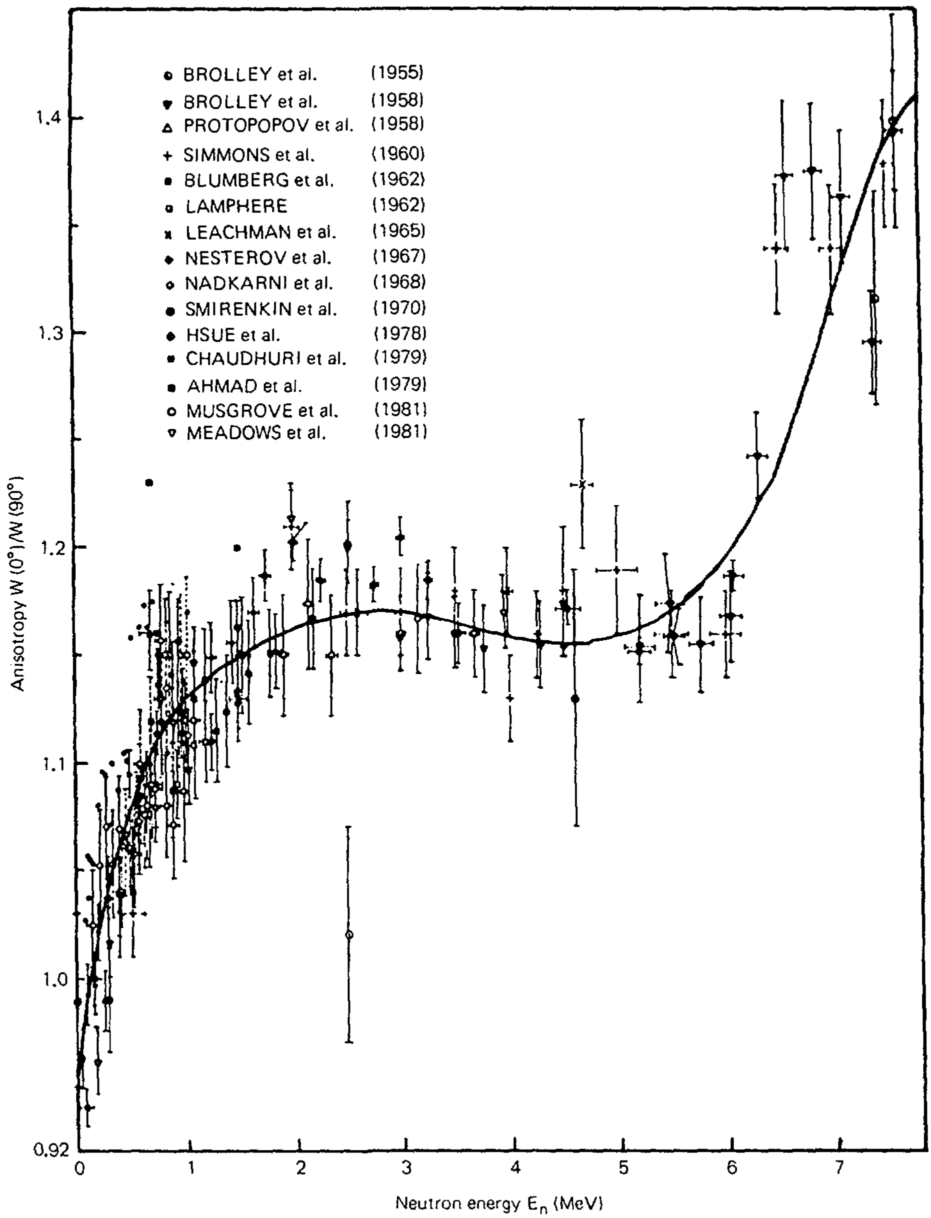

FIG.1. Measured fragment anisotropies for 0–8 MeV (1–15).

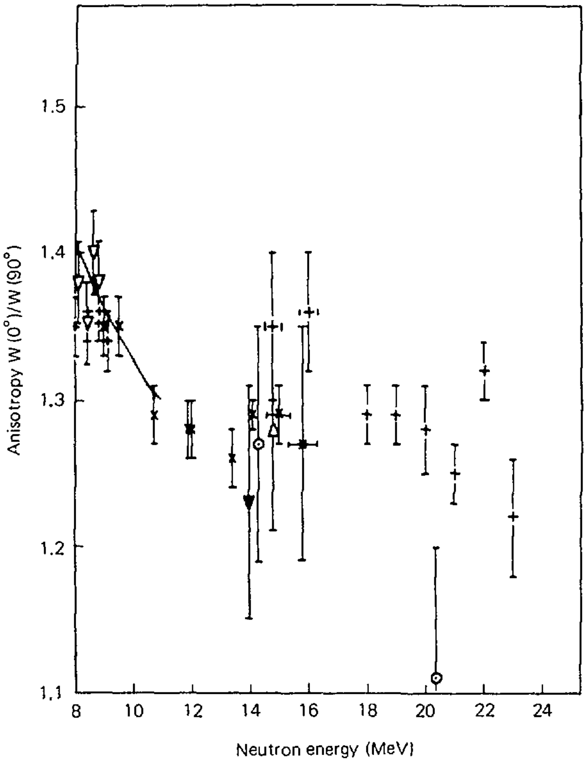

FIG.2. Measured fragment anisotropies for 8–23 MeV (1–15).

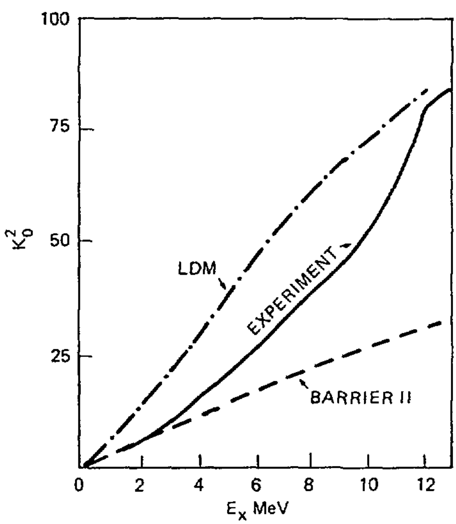

FIG.3. Variation of K_0^2 with excitation energy.

Table I. Angular anisotropy for neutron induced fission of ^{235}U

Ref.(14)		Ref.(15)	
E_n (keV)	W(0°)/W(90°)	E_n (MeV)	W(0°)/W(90°)
50 ± 15	0.963 ± 0.014	0.179 ± 0.024	0.9624 ± 0.0149
100 ± 15	0.993 ± 0.014	0.298 ± 0.024	1.0172 ± 0.0158
150 ± 15	0.998 ± 0.014	0.467 ± 0.022	1.0671 ± 0.0160
200 ± 20	1.022 ± 0.013	0.598 ± 0.021	1.0926 ± 0.0161
300 ± 15	1.043 ± 0.014	0.748 ± 0.020	1.0789 ± 0.0161
400 ± 15	1.031 ± 0.011	0.896 ± 0.020	1.1193 ± 0.0161
500 ± 17	1.095 ± 0.011	1.046 ± 0.020	1.0969 ± 0.0161
568 ± 20	1.081 ± 0.015	1.108 ± 0.020	1.1467 ± 0.0165
700 ± 20	1.100 ± 0.015	1.495 ± 0.034	1.1627 ± 0.0124
800 ± 20	1.132 ± 0.015	1.992 ± 0.030	1.2139 ± 0.0125
900 ± 20	1.141 ± 0.015	2.491 ± 0.028	1.2008 ± 0.0129
1042 ± 20	1.170 ± 0.016	2.990 ± 0.026	1.1586 ± 0.0164
1250 ± 50	1.149 ± 0.016	3.254 ± 0.047	1.1683 ± 0.0197
1450 ± 50	1.156 ± 0.019	3.490 ± 0.024	1.1601 ± 0.0163
1650 ± 50	1.170 ± 0.016	3.760 ± 0.044	1.1527 ± 0.0198
1850 ± 50	1.152 ± 0.017	3.964 ± 0.024	1.1704 ± 0.0165
		4.274 ± 0.041	1.1554 ± 0.0198
		4.514 ± 0.040	1.1738 ± 0.0197
		5.19 ± 0.140	1.1531 ± 0.0253
		5.48 ± 0.130	1.1743 ± 0.0232
		5.76 ± 0.11	1.1554 ± 0.0224
		6.04 ± 0.10	1.1675 ± 0.0213
		6.31 ± 0.09	1.2431 ± 0.0197
		6.58 ± 0.08	1.3743 ± 0.0351
		6.84 ± 0.08	1.3764 ± 0.0320
		7.10 ± 0.08	1.3642 ± 0.0312
		7.36 ± 0.08	1.2963 ± 0.0237
		7.61 ± 0.08	1.3952 ± 0.0275
		7.86 ± 0.07	1.3348 ± 0.0273
		8.12 ± 0.07	1.3791 ± 0.0273
		8.36 ± 0.07	1.3533 ± 0.0277
		8.58 ± 0.07	1.4013 ± 0.0284
		8.83 ± 0.07	1.3798 ± 0.0271

variance of the assumed Gaussian distribution of K) versus the saddle point excitation energy E_x, as shown in Fig.3. This behaviour exhibits the expected feature (18) that K_0^2 is closer to the value for the second barrier at low excitation energies, going over smoothly to that for the liquid drop model barrier at higher energies.

In view of the scatter in the data points of the different measurements (Figs 1 and 2), and our present inadequate knowledge of the K_0^2 versus E_x curve, it is difficult to arrive at a set of the anisotropy values which one could recommend as the best set. For the present, the solid line in Fig.1 can serve as a recommended set of anisotropies, particularly in the energy range $1 < E_n < 5$ MeV where the statistical theory is applicable and the uncertainties due to direct interaction effects and second chance corrections are minimal.

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THE ^{238}U FISSION CROSS SECTION

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May 1981

This cross section is a useful reference standard in fast neutron flux determinations, relative fission cross section measurements and dosimetry applications. The threshold nature of the process makes it reasonably free of low-energy neutron perturbations, the fissile material is easily obtainable and the product fragments are readily detected. The cross section is known to display a micro-structure well into the few-MeV range with a periodicity of a few tens of keV and a relative magnitude fluctuation of several percent (1). Care should be taken to avoid perturbations due to such structure.

Status

The contemporary status is reasonably well defined in Ref. (2). The following summary is taken from this reference.

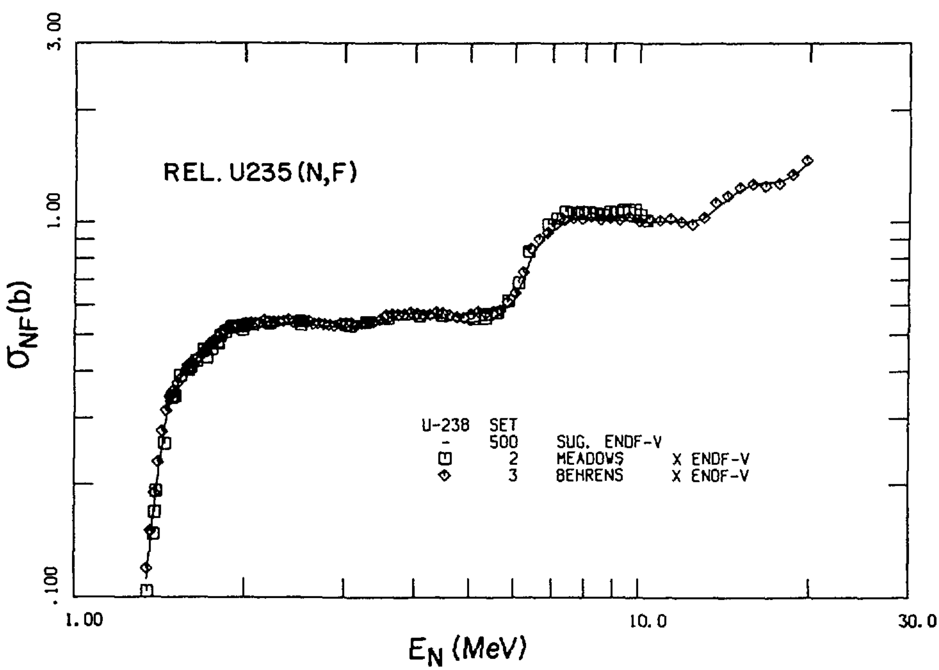

FIG.1. Comparison of the ENDF/B–V evaluated data with values implied by the measurements of Refs (4) and (5).

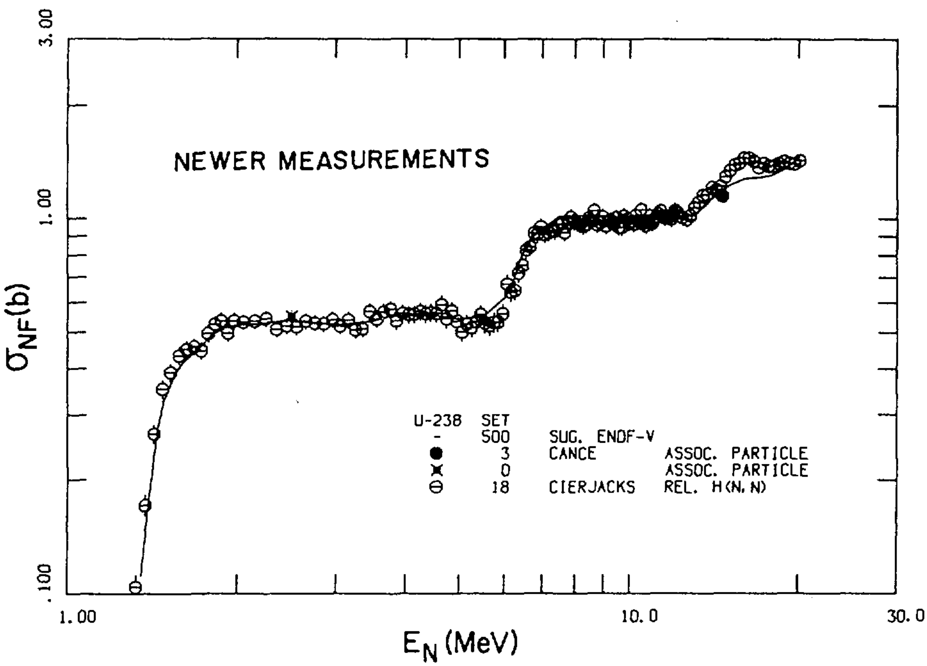

FIG.2. Comparison of the ENDF/B–V evaluated data with the experimental results of Refs (1) and (6).

The majority of the experimental information is available in the form of fission cross section ratios relative to the ^{235}U fission cross section. A minority of the information comes from measurements employing absolute flux determinations based upon the H(n,n) reaction or using the associated particle method. The two types of information were separately evaluated in Ref. (2) to obtain the cross section from ratio and absolute measured values. The evaluation methods (3) employed in Ref. (2) were rigorous, including detailed attention to renormalization (where justified) and the propogation of the respective uncertainties. The two evaluated results were combined to obtain the final ^{238}U values. The combination step followed the recommended ENDF/B-V procedures which were not entirely consistent with the rigorous methods employed in the derivation of the two components. The final numerical results are given in the tabulation below.

Illustrative comparisons of the evaluated result with some measured values are given in Figs 1, 2 and 3. Figure 1 compares the evaluation with the cross section results implied by the ratio measurements of Refs (4) and (5). Some newer absolute experimental results, taken from Refs (1) and (6), are compared with the relevant evaluated quantities in Fig. 2. Figure 3 shows a detailed comparison with experimental values (7) in the threshold region. These and similar comparisons (2) are generally consistent within the respective evaluation and experimental uncertainties though there remain systematic discrepancies in certain energy regions and with respect to some data sets.

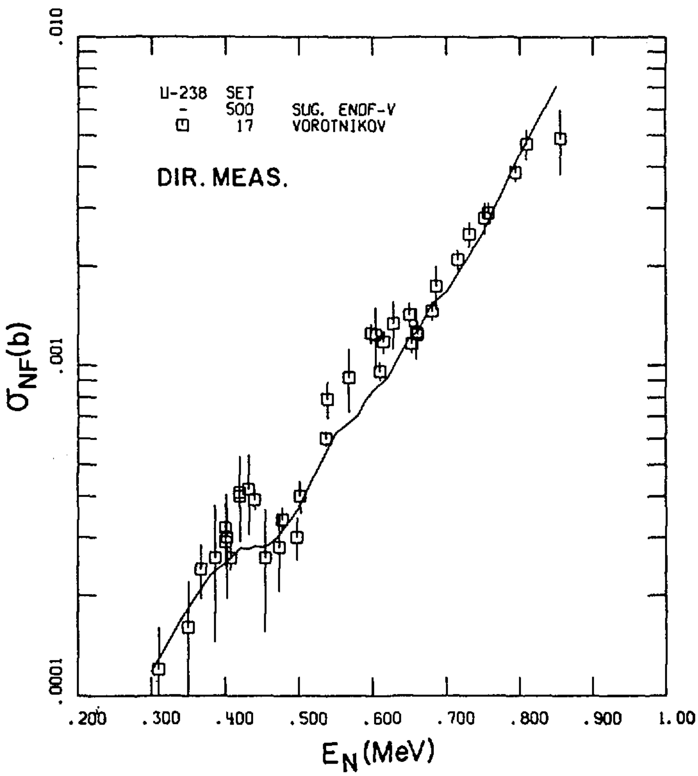

FIG.3. Comparison of the ENDF/B–V evaluated data with the measured values of Ref. (7).

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^{238}U FISSION CROSS SECTIONS - Recommended Reference Data

NUMERICAL VALUES FROM ENDF/B-V, MAT-6398.
APPLICABLE ENERGY RANGE THRESHOLD TO 20.0 MeV.
LINEAR-LINEAR INTERPOLATION.

Cross Section Values

E (keV)	XSEC (b)	E (keV)	XSEC (b)	E (keV)	XSEC (b)
0.5000E+01	0.2500E-04	0.6000E+01	0.5500E-04	0.8500E+01	0.9500E-04
0.1000E+02	0.1050E-03	0.2000E+02	0.9000E-04	0.4000E+02	0.6500E-04
0.8000E+02	0.5500E-04	0.1000E+03	0.6500E-04	0.3000E+03	0.1139E-03
0.3500E+03	0.1862E-03	0.3800E+03	0.2342E-03	0.4000E+03	0.2527E-03
0.4200E+03	0.2773E-03	0.4300E+03	0.2773E-03	0.4400E+03	0.2846E-03
0.4500E+03	0.2865E-03	0.4600E+03	0.2924E-03	0.4700E+03	0.3054E-03
0.5000E+03	0.3785E-03	0.5500E+03	0.6330E-03	0.5800E+03	0.6946E-03
0.5900E+03	0.7630E-03	0.6000E+03	0.8271E-03	0.6200E+03	0.9328E-03
0.6400E+03	0.1134E-02	0.6500E+03	0.1246E-02	0.6600E+03	0.1301E-02
0.6800E+03	0.1583E-02	0.7000E+03	0.1726E-02	0.7500E+03	0.2588E-02
0.7800E+03	0.3598E-02	0.8000E+03	0.4495E-02	0.8500E+03	0.7208E-02
0.8800E+03	0.1083E-01	0.9000E+03	0.1370E-01	0.9200E+03	0.1558E-01
0.9500E+03	0.1663E-01	0.9700E+03	0.1591E-01	0.1000E+04	0.1712E-01
0.1020E+04	0.1665E-01	0.1030E+04	0.1702E-01	0.1050E+04	0.1955E-01
0.1080E+04	0.2480E-01	0.1100E+04	0.2885E-01	0.1130E+04	0.3389E-01
0.1140E+04	0.3564E-01	0.1150E+04	0.3763E-01	0.1170E+04	0.4047E-01
0.1200E+04	0.4232E-01	0.1230E+04	0.4158E-01	0.1240E+04	0.4297E-01
0.1250E+04	0.4581E-01	0.1280E+04	0.5916E-01	0.1300E+04	0.7059E-01
0.1350E+04	0.1125E+00	0.1400E+04	0.1889E+00	0.1450E+04	0.2838E+00
0.1480E+04	0.3299E+00	0.1500E+04	0.3467E+00	0.1550E+04	0.3802E+00
0.1600E+04	0.4063E+00	0.1700E+04	0.4474E+00	0.1800E+04	0.4891E+00
0.1900E+04	0.5189E+00	0.2000E+04	0.5337E+00	0.2100E+04	0.5388E+00
0.2200E+04	0.5417E+00	0.2250E+04	0.5413E+00	0.2300E+04	0.5409E+00
0.2309E+04	0.5408E+00	0.2400E+04	0.5400E+00	0.2500E+04	0.5390E+00
0.2502E+04	0.5389E+00	0.2600E+04	0.5364E+00	0.2700E+04	0.5338E+00
0.2750E+04	0.5325E+00	0.2800E+04	0.5312E+00	0.3000E+04	0.5226E+00
0.3100E+04	0.5228E+00	0.3500E+04	0.5327E+00	0.3700E+04	0.5439E+00
0.4000E+04	0.5457E+00	0.4200E+04	0.5478E+00	0.4500E+04	0.5492E+00
0.5000E+04	0.5334E+00	0.5500E+04	0.5474E+00	0.6000E+04	0.6126E+00
0.6200E+04	0.6864E+00	0.6400E+04	0.7736E+00	0.6500E+04	0.8091E+00
0.6600E+04	0.8398E+00	0.6800E+04	0.8935E+00	0.7000E+04	0.9218E+00
0.7500E+04	0.9871E+00	0.8000E+04	0.9910E+00	0.9000E+04	0.9984E+00
0.1000E+05	0.9820E+00	0.1100E+05	0.9867E+00	0.1150E+05	0.9873E+00
0.1200E+05	0.9848E+00	0.1300E+05	0.1020E+01	0.1350E+05	0.1067E+01
0.1400E+05	0.1120E+01	0.1450E+05	0.1172E+01	0.1500E+05	0.1216E+01
0.1600E+05	0.1272E+01	0.1700E+05	0.1274E+01	0.1800E+05	0.1288E+01
0.1900E+05	0.1336E+01	0.2000E+05	0.1418E+01		

Uncertainties

ENERGY (MeV)	UNCERTAINTY (PERCENT)
0.3	8.9
0.4	10.0
0.5	12.0
0.6	11.3
0.7	11.0
0.8	8.3
0.9	7.7
1.0	7.9
1.2	6.1
1.4	7.4
1.6	1.3
2.0	1.3
2.5	2.9
3.0	2.4
4.0	2.3
5.0	2.6
6.0	3.9
8.0	3.2
10.0	2.9
12.0	3.7
14.0	4.3
20.0	8.4

THE ^{27}Al(n,α) CROSS SECTION

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May 1981

This activation reaction is recommended as a Category-I dosimetry reference and is widely employed as a standard in dosimetry and activation measurements. The previous report (INDC-30/L+SP) pointed out that the desired accuracies of 5 percent had not been generally achieved. Since that time (1978) there have been additional precision measurements and a comprehensive re-evaluation. Both the measurement status and the evaluation are defined in a paper by Tagesen and Vonach (1). The results of this recent work, given in the numerical table below, generally define the cross section to better than few-percent accuracies from 7 to 20 MeV. These new results are compared with the previous evaluation (ENDF/B-V) in

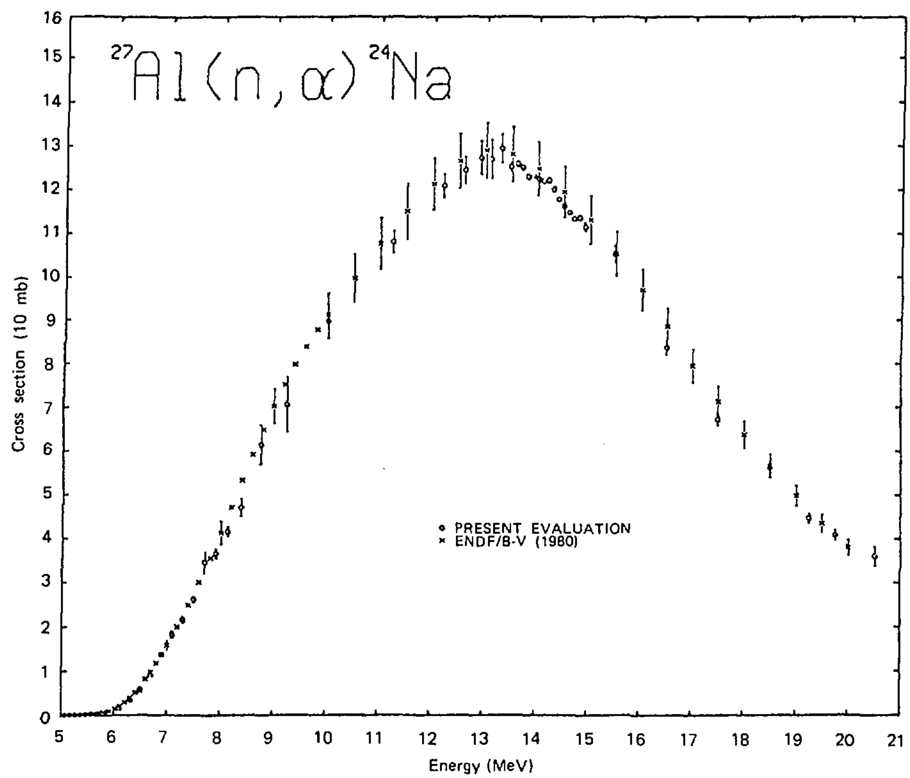

FIG.1. Comparison of the present evaluation of the cross section for the $^{27}Al(n,\alpha)^{24}Na$ reaction with those given in ENDF/B–V.

Fig. 1. The two evaluated cross section sets are very similar in magnitude throughout the energy range of appreciable magnitude but the later work carries a greatly improved accuracy that is now consistent with the 5 percent uncertainties usually associated with a Category-I dosimetry reference standard. Indeed, the quoted evaluated accuracies in the region around 14 MeV make this a very well known standard suitable for a wide spectrum of measurement applications.

Statement of Status

The abstract of the paper by Tagesen and Vonach summarizes the present status as follows:

The cross sections for the important dosimetry reaction $^{27}Al(n,\alpha)^{24}Na$ were evaluated in the neutron energy range: threshold to 20 MeV. All reported measured data sets were critically reviewed and obviously erroneous sets were disregarded. If necessary, the data were renormalized in order to take account of adjustments in relevant standard cross sections and decay schemes. Cross sections were evaluated in energy groups with widths of 0.1 to 1.5 MeV, the selected widths depending upon the slope of the excitation function and the density of available data points. For each of the evaluated cross sections an uncertainty (1σ confidence level) was derived taking into account the errors given by the experimentalists and the general consistency of the experimental data. In addition, relative correlation matrices were derived from the evaluated excitation function describing the uncertainties of the cross sections at different energies. The results of the present evaluation agree with those of ENDF/B-V to within the uncertainty limits associated with the two evaluations. However, owing to a considerably extended data base, the uncertainties associated with the present evaluation are much smaller than those given in the ENDF/B-V covariance file. Strong arguments are presented that, in the energy range 13.5-14.7 MeV, the $^{27}Al(n,\alpha)^{24}Na$ cross section is known to an accuracy of about 0.5 percent. Therefore, it can be recommended as the best cross section standard in this energy range.

Editor's Comment:

The above, and the comparable section dealing with ^{235}U, suggest that the ratio $^{235}U(n,f)/^{27}Al(n,\alpha)$ should be known to approximately 1 percent near 14 MeV. If this could be experimentally verified it could reasonably show that the desired accuracies of these two cross sections at this important energy have been achieved.

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5/81.

REFERENCE

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$^{27}Al(n,\alpha)$ CROSS SECTIONS - Recommended Reference Data

NUMERICAL VALUES FROM S.TAGESEN AND H.VONACH, Physics Data 13-1 (1981).
LINEAR-LINEAR INTERPOLATION.

Cross Section Values

GROUP-ENERGY (MeV) to (MeV)	XSEC (mb)	ERROR (PERCENT)
5.40 - 6.00	0.395	11.4
6.00 - 6.20	1.622	11.7
6.20 - 6.40	3.502	7.4
6.40 - 6.60	5.916	3.2
6.60 - 6.80	9.171	3.5
6.80 - 7.00	13.807	4.3
7.00 - 7.20	18.253	4.9
7.20 - 7.40	21.652	3.9
7.40 - 7.60	26.180	2.7
7.60 - 7.80	34.562	7.1
7.80 - 8.00	36.539	3.2
8.00 - 8.25	41.589	3.1
8.25 - 8.50	47.059	4.6
8.50 - 9.00	61.431	7.6
9.00 - 9.50	70.566	8.9
9.50 - 10.50	89.611	4.5
10.50 - 12.00	107.928	2.4
12.00 - 12.40	120.788	2.3
12.40 - 12.80	124.288	2.6
12.80 - 13.00	127.145	3.1
13.00 - 13.20	126.843	3.6
13.20 - 13.40	129.252	2.6
13.40 - 13.55	125.069	0.8
13.55 - 13.65	125.774	0.5
13.65 - 13.75	124.856	0.6
13.75 - 13.85	122.725	0.6
13.85 - 13.95	123.020	0.5
13.95 - 14.05	122.245	0.5
14.05 - 14.15	121.907	0.5
14.15 - 14.25	121.998	0.6
14.25 - 14.35	119.970	0.5
14.35 - 14.45	117.540	0.3
14.45 - 14.55	116.046	0.6
14.55 - 14.65	114.530	0.5
14.65 - 14.75	113.100	0.4
14.75 - 14.85	112.307	0.6
14.85 - 14.95	111.292	1.0
14.95 - 16.00	105.081	1.9
16.00 - 17.00	83.555	2.1
17.00 - 18.00	67.127	2.1
18.00 - 19.00	56.136	2.2
19.00 - 19.50	44.604	2.8
19.50 - 20.00	40.753	3.2
20.00 - 21.00	35.969	3.4

Correlation Matrix (percent, 44 X 44 array)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	E (MeV)
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
2		100	0	13	12	10	14	11	13	17	0	9	18	14	11	10	15	7	6	5	0	6	5.40
3			100	28	25	22	39	29	28	26	42	32	37	28	0	0	0	0	0	0	0	0	6.00
4				100	52	46	28	51	56	43	32	49	44	48	27	25	17	18	13	11	0	15	6.20
5					100	59	24	47	51	52	29	59	40	46	44	41	28	31	13	11	0	14	6.40
6						100	24	41	46	53	27	57	40	36	48	47	28	31	11	9	0	12	6.60
7							100	27	29	29	37	30	30	16	0	0	5	0	0	0	0	0	6.80
8								100	50	39	33	45	39	45	22	21	14	15	17	10	0	13	7.00
9									100	43	33	49	44	47	26	24	17	17	13	11	0	14	7.20
10										100	29	52	31	30	42	41	36	36	9	8	0	11	7.40
11											100	36	28	25	5	7	0	0	0	0	0	0	7.60
12												100	39	42	48	35	24	27	10	8	0	11	7.80
13													100	30	26	28	15	12	9	8	0	10	8.00
14														100	29	28	19	20	15	13	0	17	8.25
15															100	64	30	34	12	10	0	13	8.50
16																100	28	31	11	9	0	12	9.00
17																	100	48	7	6	0	8	9.50
18																		100	9	7	0	11	10.50
19																			100	26	19	20	12.00
20																				100	25	18	12.40
21																					100	16	12.80
22																						100	13.00

	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
2	0	0	1	0	0	1	0	1	2	0	0	2	0	1	2	0	0	6	4	5	6	8	5.40
3	13	3	0	0	0	0	0	0	0	0	0	0	0	0	3	0	7	9	7	9	11	0	6.00
4	0	0	3	0	0	4	0	0	4	0	0	4	0	3	5	0	0	13	9	11	13	19	6.20
5	0	0	3	0	0	3	0	0	4	0	0	4	0	3	5	0	0	13	9	11	13	18	6.40
6	0	0	3	0	0	3	0	1	3	0	0	3	0	2	4	0	0	11	7	9	11	15	6.60
7	0	0	0	0	0	0	0	1	0	0	0	0	0	0	7	0	0	0	0	0	0	0	6.80
8	0	0	3	0	0	3	0	0	3	0	0	4	0	3	5	0	0	18	11	9	11	26	7.00
9	0	0	3	0	0	3	0	0	4	0	0	4	0	3	5	0	0	13	9	11	13	18	7.20
10	0	0	2	0	0	2	0	2	3	0	0	3	0	2	4	0	0	9	6	8	9	13	7.40
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	7.60
12	0	0	2	0	0	3	0	0	3	0	0	3	0	2	5	0	0	10	6	8	10	13	7.80
13	9	2	2	0	0	2	0	2	3	0	0	3	0	2	4	0	6	15	11	14	17	13	8.00
14	0	0	4	0	0	4	0	0	4	0	0	5	0	3	7	0	0	15	10	12	15	21	8.25
15	0	0	3	0	0	3	0	2	3	0	0	4	0	3	3	0	0	11	8	9	11	16	8.50
16	0	0	3	0	0	3	0	3	3	0	0	3	0	2	3	0	0	11	7	9	11	15	9.00
17	0	0	2	0	0	2	0	0	2	0	0	2	0	2	2	0	0	7	5	6	7	10	9.50
18	0	0	2	0	0	2	0	0	3	0	0	2	0	2	3	0	2	8	6	7	8	11	10.50
19	16	14	12	9	4	5	3	0	6	4	6	5	10	5	14	0	2	20	14	6	7	15	12.00
20	20	15	11	9	5	4	3	2	5	4	6	5	9	5	13	2	7	27	15	15	11	24	12.40
21	34	8	4	4	7	5	5	2	5	5	4	5	5	6	6	0	9	10	7	9	11	16	12.80
22	16	4	5	3	4	5	3	0	6	4	2	6	3	5	7	1	6	9	6	7	7	9	13.00

	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	
23	100	9	3	4	6	4	4	2	4	5	3	4	4	6	5	0	14	13	10	12	15	12	13.20
24		100	19	19	11	11	10	11	8	12	11	13	18	10	23	19	4	15	11	3	4	4	13.40
25			100	38	36	35	35	34	35	35	23	38	39	30	17	15	6	10	7	2	2	1	13.55
26				100	38	37	38	37	37	38	24	30	30	28	14	15	5	7	5	0	0	0	13.65
27					100	41	42	42	42	42	24	38	34	31	10	15	8	2	2	2	2	3	13.75
28						100	41	41	41	41	23	39	33	31	12	17	5	2	1	1	2	2	13.85
29							100	41	42	42	23	39	34	31	11	16	5	0	0	0	0	0	13.95
30								100	41	42	23	38	33	31	11	17	6	3	1	2	2	4	14.05
31									100	41	23	38	34	31	10	13	6	2	1	2	2	2	14.15
32										100	23	39	34	31	12	18	6	0	0	0	0	0	14.25
33											100	22	22	17	10	9	4	5	4	1	1	2	14.35
34												100	36	34	14	19	6	2	1	1	2	3	14.45
35													100	29	17	16	5	7	6	0	0	0	14.55
36														100	11	14	6	3	14	15	16	4	14.65
37															100	20	7	10	8	2	2	2	14.75
38																100	10	2	0	1	0	1	14.85
39																	100	12	9	10	12	10	14.95
40																		100	23	21	18	15	16.00
41																			100	41	41	17	17.00
42																				100	49	23	18.00
43																					100	29	19.00
44																						100	19.50

NEUTRON ENERGY STANDARDS

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Neutron energy standards are required to help ensure that all neutron spectrometers produce data on energy scales that agree within the estimated errors of measurement. Discrepancies in neutron energy scales present additional problems for evaluators, compilers, data analysts and other users of neutron data. The work required to revise and correct energy scales would be greatly reduced if a set of accurately measured resonance energies became available. These could then be checked on each spectrometer, preferably during each experiment. Such a set of energy resonances would be particularly valuable in standardizing the energy scales of spectrometers which are either not capable of the highest precision in neutron energy measurements or for which the work required to establish an absolute energy scale has not been undertaken. Instruments capable of the highest precision in neutron energy measurement could have their energy scales compared for resonances, selected in advance, for which the available data have been conveniently gathered and assessed.

As the energy resolution of spectrometers improves, the list of resonances selected as standards will change so as to match the resolution capability.

Status and Recent Results

The table of narrow resonances suitable for use as energy standards set up by James (1) in consultation with members of an INDC Sub-Group on Neutron Energy Calibration has been revised and is listed below. The data used to revise this table are referenced in the notes to the table. For forty selected narrow resonances, the tabulation lists either the most accurately quoted resonance energy or an average of published values. The tabulated energies are not to be regarded as an evaluated data set. The method of averaging is wrong for correlated data. Perey (2) has clearly demonstrated how, especially when combining data measured on the same spectrometer, the covariances must be taken into account. These recommendations have not yet been implemented, partly because the time required for this work has not been made available, and partly because the recommendations disregard the fact that in some experiments (notably the $\Delta L/\Delta t$ method) the errors are assigned by statistical methods and represent standard deviations, whereas, for other experiments, substantial components of the error assignment are made from a basic understanding of the physics of the experiment, and are not strictly standard deviations.

Conclusions and Recommendations

Problems arising in the evaluation and use of neutron data from discrepant energy scales will be alleviated if experimenters are able to standardize their neutron energy scales. A list of suitable narrow resonances, most of which have well measured energies, is presented below. For some of the resonances listed, measurements are sparse and not of high accuracy. Experimenters should be encouraged to provide energy measurements of the highest attainable accuracy and precision for these poorly measured resonances. The table should be extended to provide the ratio of the resonance width to the resonance energy so that the suitability of a given resonance for accurate standardization can be quickly judged. A proper evaluation of the data available should be carried out taking into account the work of Perey and the comments made above. The table should be reviewed at suitable intervals so as to incorporate even narrower resonances which will be more suitable for use as spectrometer resolution improves.

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1. G.D. James, Neutron Energy Standards, NBS Special Publication 493, Washington (1977) 319.

2. F.G. Perey, Covariance Matrices of Experimental Data, Neutron Physics and Nuclear Data, OECD/NEA, Paris (1978) 104.

Notes to the Tabulated Energy Standards

1. P. Fischer, U. Harz and H.G. Priesmeyer, Gesellschaft fuer Kernenergieverwertung in Schiffbau und Schiffahrt mbH Report GKSS 81/E/17.

2. D.K. Olsen, G. de Saussure, R.B. Perez, F.C. Difilippo and R.W. Ingle, Nucl. Sci. Eng. 66 (1978) 141. Olsen et al. give a statistical error and a systematic error. For this resonance the systematic error is dominant and is the error quoted in the table.

3. Five resonances are covered by this note. The values quoted are derived as described by James in Table 5 of his paper (1) with the following changes: (a) the data from Geel were slightly revised to the values 145.66, 463.53, 708.44, 1420.72 and 2489.7 eV; (b) the Olsen et al. values 145.63, 463.14 and 708.27 eV were included in the Oak Ridge data. Perey (2) has demonstrated that the procedure used to derive a best value from several measurements must take proper account of measurement covariances. An application of this procedure to all the data quoted by James has not been carried out; partly because it disregards the fact that the error on the Harwell values derived by the $\Delta L/\Delta t$ method is different in nature from the errors on the 100 m and 50 m results. Briefly, errors on the $\Delta L/\Delta t$ method are derived by statistical methods whereas a component of the error on the 100 m and 50 m data are assessed from an understanding of the physics of the experiment - an assessment which the $\Delta L/\Delta t$ method is designed to overcome. Further resolution of this problem awaits a proper evaluation.

4. For three sulphur resonances, unweighted average values of the data of Halperin et al. (note 5) and Olsen et al. (note 2) are given. These data, measured at Oak Ridge on flight-paths of length 200 m and 150 m respectively, agree to a small fraction of the quoted errors.

An error based on the difference between the two data sets is probably too optimistic and the error quoted is that given by Halperin et al.

5. J. Halperin, G.H. Johnson, R.R. Winters and R.L. Macklin, Phys. Rev. C21 (1980) 545.

6. Data of Olsen et al. (note 2). The statistical and systematic errors quoted are comparable and have been combined to provide the error given.

7. J.A. Harvey, private communication and Oak Ridge National Lab. Report ORNL/TM-5618.

8. Revised result from the Harwell synchrocyclotron.

9. S.F. Mughabghab and D.I. Gerber, Brookhaven National Lab. Report BNL325 Third Ed. Vol. 1 (1973).

10. The value derived by James (1) from data from seven laboratories is given but the work of Perey (2) and comments on the $\Delta L/\Delta t$ method made in note 3 must be taken into account.

11. S. Cierjacks et al., INDC-30 (March 1980).

NEUTRON ENERGY STANDARDS - Recommended Reference Data

Neutron resonances to be used as energy standards

ISOTOPE	E (eV)		ΔE (eV)	NOTE
Ir-191	6.52800E-01	±	5E-04	1
U -238	6.67200E 00	±	2E-03	2
U -238	1.02360E 01	±	3E-03	2
U -238	2.08640E 01	±	6E-03	2
U -238	3.66710E 01	±	1.1E-02	2
U -238	6.60150E 01	±	2E-02	2
U -238	8.07290E 01	±	2.5E-02	2
U -238	1.45616E 02	±	1.9E-02	3
U -238	1.89640E 02	±	4E-02	2
U -238	3.11280E 02	±	7E-02	2
U -238	3.97580E 02	±	1.2E-01	2
U -238	4.63150E 02	±	1.5E-01	3
U -238	6.19950E 02	±	1.9E-01	2
U -238	7.08200E 02	±	1.1E-01	3
U -238	9.05030E 02	±	1.9E-01	2
U -238	1.41976E 03	±	2.1E-01	3
U -238	1.47382E 03	±	3.1E-01	2
U -238	2.48919E 03	±	2.9E-01	3
U -238	2.67222E 03	±	5.6E-01	2
Pb-206	3.35740E 03	±	7E-01	2
U -238	3.45814E 03	±	7.3E-01	2
U -238	4.51230E 03	±	1E 00	2
U -238	5.65060E 03	±	1.2E 00	2
Al- 27	5.90350E 03	±	1.2E 00	2
S - 32	3.03790E 04	±	5.0E 00	4
Na- 23	5.31910E 04	±	2.9E 01	6
Si- 28	6.77300E 04	±	2.0E 01	7
Pb-206	7.11910E 04	±	2.1E 01	6
Fe- 56	9.02360E 04	±	1.6E 01	8
S - 32	9.75060E 04	±	1.1E 01	4
S - 32	1.12183E 05	±	2.0E 01	4
Fe- 56	2.66766E 05	±	3.3E 01	8
S - 32	4.12330E 05	±	6.0E 01	5
S - 32	8.18720E 05	±	1.3E 02	5
O - 16	1.65100E 06	±	2.0E 03	9
C - 12	2.07805E 06	±	3.2E 02	10
C - 12	2.81800E 06	±	4.0E 03	9
O - 16	3.21170E 06	±	2.0E 02	11
C - 12	6.29300E 06	±	5.0E 03	9
C - 12	1.21000E 07	±	1.0E 05	9

ACTINIDE HALF-LIVES

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As actinide half-lives enter as major parameters in the correction for sample decay in the precision measurement of fission cross sections of fissile isotopes, as well as in the mass determination of samples, they are considered as important standards.

A co-ordinated research programme on the measurement and evaluation of transactinium isotope decay data has been pursued under IAEA auspices for several years. Participants in this programme, composed of a number of specialists active in this field, produce updated lists of recommended actinide decay properties. The most recent of these lists, which is to be published in INDC(NDS)-139/NE (December 1982), represents the current status of heavy element radionuclide half-lives. The standard-relevant numerical values given below were taken from this compilation. The complete listing given in INDC(NDS)-139/NE includes a wide range of heavy elements of broader interest than that of nuclear standards. The data have been drawn from the following existing decay data files:

- ENSDF, the Evaluated Nuclear Structure and Decay Data File maintained by the United States National Nuclear Data Center, at Brookhaven,
- the actinide data file of the Idaho National Engineering Laboratory (INEL) which serves as the source file for the decay data part of the ENDF/B compilation, and
- the UK Chemical Nuclear Data Committee Heavy Element Decay Data File, compiled at the AEE Winfrith laboratory.

Whenever warranted, the half-life data are supplemented or superseded by the latest known measured and/or evaluated values. The master-file is kept at the IAEA Nuclear Data Section.

ACTINIDE HALF-LIVES - Recommended Reference Data

NUCLIDE	DECAY MODE	HALF-LIFE	UNCERTAINTY (PERCENT)
U-233	Alpha	1.592E 05 Y	0.13
	Spontaneous fission	1.200E 17 Y	25.0
U-234	Alpha	2.454E 05 Y	0.24
	Spontaneous fission	1.420E 16 Y	5.6
U-235	Alpha	7.037E 08 Y	0.15
	Spontaneous fission	9.800E 18 Y	28.6
U-238	Alpha	4.468E 09 Y	0.11
	Spontaneous fission	8.190E 15 Y	1.1
Np-237	Alpha	2.140E 06 Y	0.47
	Spontaneous fission	1.000E 18 Y	----
Pu-239	Alpha	2.411E 04 Y	0.12
	Spontaneous fission	5.500E 15 Y	----
Pu-240	Alpha	6.550E 03 Y	0.31
	Spontaneous fission	1.150E 11 Y	3.5
Pu-241	Alpha	6.000E 05 Y	4.2
	Beta	1.440E 01 Y	1.4
Pu-242	Alpha	3.760E 05 Y	0.53
	Spontaneous fission	6.840E 10 Y	1.2
Pu-244	Alpha	8.200E 07 Y	1.2
	Spontaneous fission	6.560E 10 Y	4.9
Cf-252	Total	2.640E 00 Y	0.38
	Alpha	2.720E 00 Y	0.37
	Spontaneous fission	8.538E 01 Y	0.46

REFERENCE: INDC(NDS)-139/NE (1982).

THERMAL PARAMETERS FOR ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu

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Status of the Data

The thermal cross sections of ^{235}U are considered as standard reference data for cross section measurements of other nuclides. The thermal neutron data of ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu are correlated, because cross section ratios between these nuclides have been measured in addition to some accurate absolute values. The values for 2200 m/s neutrons (0.0253 eV) are used for normalization of cross section curves at thermal and higher energies.

The fission cross sections are strongly dependent on the half-life values of ^{233}U, ^{234}U and ^{239}Pu. During the past years there have been significant changes in the knowledge of these half-lives; consequently, earlier values of the fission cross sections must be considered to be superseded. The fission neutron yield data ν depend strongly on ν for the spontaneous fission of ^{252}Cf for which several new measurements

Table I. ^{235}U standard cross sections for 2200 m/s neutrons

(cross sections in barns)

	Recommended Values from ENDF/B-V Standards File (4) 1979	Evaluation by NNDC group (1) 1983	Evaluation by Axton (3) 1983
σ_T	696.7	694.9 ± 1.1	
σ_S	14.8	14.0 ± 0.5	
σ_A	681.9	680.9 ± 1.1	681.5 ± 1.7
σ_f	583.5	582.6 ± 1.1	584.7 ± 1.7
σ_γ	98.4	98.3 ± 0.8	96.8 ± 1.8
α	0.169	0.169 ± 0.002	0.166 ± 0.003
η	2.0845	2.075 ± 0.003	2.083 ± 0.006
ν_t	2.436	2.425 ± 0.003	2.427 ± 0.005
ν_t (Cf-252)	3.766	3.767 ± 0.004	3.766 ± 0.005

Table II. 2200 m/s cross sections for ^{233}U, ^{239}Pu, ^{241}Pu

(cross sections in barns)

		ENDF/B-V (5) 1979	Evaluation by NNDC group (1) 1983	Evaluation by Axton (3) 1983
^{233}U	σ_A	574.2	574.7 ± 1.0	574.1 ± 1.8
	σ_f	528.4	529.1 ± 1.2	531.9 ± 2.4
	σ_γ	45.8	45.5 ± 0.7	42.2 ± 1.8
	α	0.0866	0.086 ± 0.002	0.079 ± 0.004
	η	2.296	2.296 ± 0.004	2.305 ± 0.006
	ν_t	2.495	2.493 ± 0.004	2.488 ± 0.006
^{239}Pu	σ_A	1011.9	1017.3 ± 2.9	1017.7 ± 3.8
	σ_f	741.7	748.1 ± 2.0	748.3 ± 2.4
	σ_γ	270.2	269.3 ± 2.2	269.4 ± 3.4
	α	0.3643	0.360 ± 0.003	0.360 ± 0.005
	η	2.119	2.115 ± 0.005	2.115 ± 0.007
	ν_t	2.891	2.877 ± 0.006	2.876 ± 0.007
^{241}Pu	σ_A	1376.4	1369.4 ± 7.7	1378.9 ± 12.7
	σ_f	1015.0	1011.1 ± 6.2	1018.0 ± 10.0
	σ_γ	361.4	358.2 ± 5.1	360.9 ± 5.6
	α	0.356	0.354 ± 0.006	0.355 ± 0.006
	η	2.178	2.169 ± 0.008	2.169 ± 0.008
	ν_t	2.953	2.937 ± 0.007	2.937 ± 0.007

have been completed recently; their mean value, as evaluated up to 1980 (1), is in good agreement with the value adopted previously for ENDF/B-V.

The fission and capture cross sections of ^{235}U used to show unresolved discrepancies between σ_0, measured with monoenergetic neutrons of 0.0253 eV (2200 m/s), and $\langle\sigma\rangle$ measured in a thermal Maxwellian neutron spectrum. If the neutron spectrum is a pure Maxwellian of temperature T, then $\langle\sigma\rangle = g(T)\ \sigma_0$. The Westcott g-factor g(T) depends only on the cross section curve $\sigma(E)$ in the neutron energy range significant to the Maxwellian spectrum (about 0.001 eV to 1 eV). A new evaluation performed at the US National Nuclear Data Center (NNDC) (1) suggests that these discrepancies have now disappeared owing to revised values of half-lives (2), ν and g-factors. Another recent evaluation by Axton (3) was obtained from the experimental cross section data with monoenergetic 0.0253 eV neutrons together with the neutron yield data. Excluding the thermal Maxwellian cross section data, Axton's evaluation is less comprehensive than that of the NNDC group, but it used a more sophisticated analysis of correlated uncertainties. In the tables the recommended values from both evaluations are presented without giving preference to the one or the other. Data users are invited to enquire with one of the nuclear data centres whether internationally recommended values have been adopted in the meantime.

The first column of Table I lists for ^{235}U the recommended values of ENDF/B-V (4). The second column lists the values obtained by the NNDC group 1983 (1). The third column contains the results of Axton's evaluation 1983 (3). Table II shows the data for ^{233}U, ^{239}Pu and ^{241}Pu.

In addition, recommended values for Westcott g-factors for T = 20°C can be found in reference (1). A correlation matrix for the 0.0253 eV cross sections and neutron yields can be found in reference (3).

REFERENCES

1. J.R. Stehn, M. Divadeenam and N.E. Holden, Evaluation of the thermal neutron constants for ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu, Paper presented at the Conference on Nuclear Data for Science and Technology, Antwerp, 6-10 September, 1982, Proceedings edited by K.H. Boeckhoff (1983) p. 685. The Antwerp values are preliminary. The Tables I and II contain final values as of August 1983, to be published. The release of these values by M. Divadeenam before publication is gratefully acknowledged.

2. A. Lorenz, (Ed.), Proposed recommended list of heavy element radionuclide decay data, Report INDC(NDS)-127 (December 1981) (see preceding section).

3. E.J. Axton, Evaluation of the thermal neutron constants of ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu and the fission neutron yield of ^{252}Cf. Manuscript (1983). To be published. The release of the values before publication is gratefully acknowledged.

4. ENDF/B-V MAT 1395 for ^{235}U, US National Nuclear Data Center; evaluation by M.R. Bhat, Brookhaven National Lab. Report BNL-NCS-51184 (March 1980); see also document IAEA-NDS-15 Rev. 1.

5. ENDF/B-V files for ^{233}U, ^{239}Pu and ^{241}Pu not released; values quoted from Ref. (1).

PROMPT FISSION NEUTRON SPECTRUM OF ^{252}Cf

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This fission neutron spectrum is employed as a basic reference in both microscopic and macroscopic measurements (1). The energy distribution impacts upon the determination of the essential nu-bar ^{252}Cf standard (see comments in article on "Nu-bar ^{252}Cf", p.84). The spectrum is also used as a relative flux standard in instrument calibrations (2).

Status

This spectrum has been measured with varying accuracies over a period of approximately 25 years. The history, as summarized by Blinov (3) is outlined in Table I. Despite this wealth of information, neither the shape nor average energy is known to an accuracy warranted by the importance of this standard spectrum.

Reviewing the available information, Blinov (3) concluded that the spectrum is Maxwellian in shape. The conclusion was enforced by the results of a measurement also performed by Blinov (4). The observed spectrum was described by a Maxwellian with kT = 1.42 MeV, with no significant deviation from this Maxwellian in the range from 1 keV to 3 MeV. The accuracy of the shape of the spectrum obtained in this work is essentially higher than that known from literature, especially for the region around 10 keV, where a 14 percent (1σ) error is quoted (compared to 50-70 percent in other measurements). The accuracy in the region from 100 keV to 4 MeV is better than ±3 percent.

Other recent experimental results of Boldeman (5) illustrated in Fig. 1, and of Bensch and Jansicek (6) are in agreement with the conclusions by Blinov.

The experimental definition of the spectrum is less accurate at low (<0.1 MeV) and at high energies (5 MeV) and in those regions uncertainties persist.

Starostov et al. (7) measured the ^{252}Cf spectrum from 10 keV to 10 MeV. Contrary to the results of Blinov they obtained pronounced deviations from the Maxwellian form between 50 and 500 keV. Similar deviations have been reported in some earlier work (8).

Mon Jiangshen et al. (9) measured the ^{252}Cf spectrum between 450 keV and 15 MeV. The observed spectrum was described by a Maxwellian with kT = 1.416 ± 0.023 MeV. At the high energy end between 11 and 15 MeV, the measured spectrum shows a structure exceeding the Maxwellian by a factor of 2. Similar deviations have been reported by Bensch and Jansicek (6) and by Maerten et al. (10). Neither a Maxwellian nor a Watt spectrum seem to fit the data perfectly, but the deviations from a Maxwellian are small.

Table I. Summary of Data on Fission Neutron Spectrum of ^{252}Cf up to 1979: compiled by Blinov (3)
(Detailed references in (3))

Year	Authors	Neutron Energy Range (MeV)	Method of Neutron Detection	Results	
				T_{maxw} (MeV)[a]	$\bar{E}$ (MeV)
1955	Hjalmar et al.	2	Photoemulsion	1.40 ± 0.09	-
1957	Smith et al.	0.2 - 7.0	TOF, plastic scintillator		
			photoemulsion	-	2.36
1961	Bonner	4	Integral (Bramblett counter)	1.367 ± 0.030	-
1962	Bowman et al.	0.5 - 6.0	TOF, plastic scintillator	-	2.34 ± 0.05
1965	Condé, During	0.07 - 7.5	TOF, ^{6}Li-glass, plastic		
			scintillator	1.39 ± 0.04	(2.09)
1967	Meadows	0.003 - 15	TOF, ^{6}Li-glass, liquid		
			scintillator	1.52	2.348
1969	Green	-	Integral (Mn-bath)	1.39	(2.09)
1970	Zamyatnin et al.	0.005 - 6.0	TOF, ^{6}Li-glass, plastic	1.48 ± 0.03	(2.22 ± 0.05)
			scintillator		
1972	Jeki et al.	0.002 - 1.0	TOF, ^{6}Li-glass	1.57(1.3)	-
1972	Smith, Koster		Review	-	-
1976	Knitter		Review	-	-
1972	Werle, Bluhm	0.2 - 8.0	^{3}He-spectrometer,		2.155 ± 0.024
			proportional counter	(1.42 ± 0.015)	2.130 ± 0.022
1973	Green et al.	0.5 - 13	TOF, organic scintillator	1.406 ± 0.015	2.105 ± 0.014
1973	Knitter et al.	0.15 - 15	TOF, organic scintillator	1.42 ± 0.05	2.13 ± 0.08
1974	Spiegel	-	Integral ("age")	-	2.21 ± 0.05
1974	Alexandrova et al.	2.04 - 13.2	Single-crystal spectrometer	1.42 ± 0.03	(2.13 ± 0.045)
1975	Kotelnikova et al.	0.5 - 7.0	TOF, liquid scintillator	1.46 ± 0.02	(2.19 ± 0.03)
1975	Johnson	2.6 - 15	Single-crystal spectrometer	(1.42 ± 0.02)	2.13 ± 0.03)

Table I. Summary of Data on Fission Neutron Spectrum of ^{252}Cf up to 1979: compiled by Blinov (3) (Contd.)

Year	Authors	Neutron Energy Range (MeV)	Method of Neutron Detection	Results: T_{maxw} (MeV)[a]	Results: $\bar{E}$ (MeV)
1976	Csikai, Dezsoe	2.5 - 15	Activation detector (threshold reactions);	1.41 ± 0.02	(2.12 ± 0.03)
			"age" - method	1.48 ± 0.03	(2.22 ± 0.05)
1976	Batenkov et al.	0.02 - 2.0	TOF, ^{6}LiI-crystal	1.40	-
1976	Stewart et al.	-	Review	-	-
1975	Grundl et al.	0.25 - 8.0	Evaluation	(1.42)	2.13
1977	Blinov et al.	0.01 - 7.0	TOF, ^{6}LiI-crystal, ^{235}U-chamber	1.41 ± 0.03	2.12
1977	Djachenko et al.	<2	Amplitude, reaction $^{6}Li(n,\alpha)T$	1.18	-
1977	Nefedov et al.	0.01 - 10	TOF, metallic ^{235}U; ^{235}U - chamber	1.28	(1.92)
1978	Bertin	1 - 10	TOF, liquid scintillator	(1.51)	2.27 ± 0.02
1978	Nefedov et al.	0.01 - 10	TOF, metallic ^{235}U, ^{235}U - chamber	1.43 ± 0.02	(2.15 ± 0.03)
1979	Blinov et al.	0.001 - 1	TOF, ^{6}LiI-crystal	1.42	-
1979	Boldeman et al.	0.6 - 15	TOF, plastic scintillator	1.424 ± 0.013	2.136 ± 0.020

[a]The values of T_{maxw} and $\bar{E}$ in brackets are not taken from the reference works but calculated according to their data.

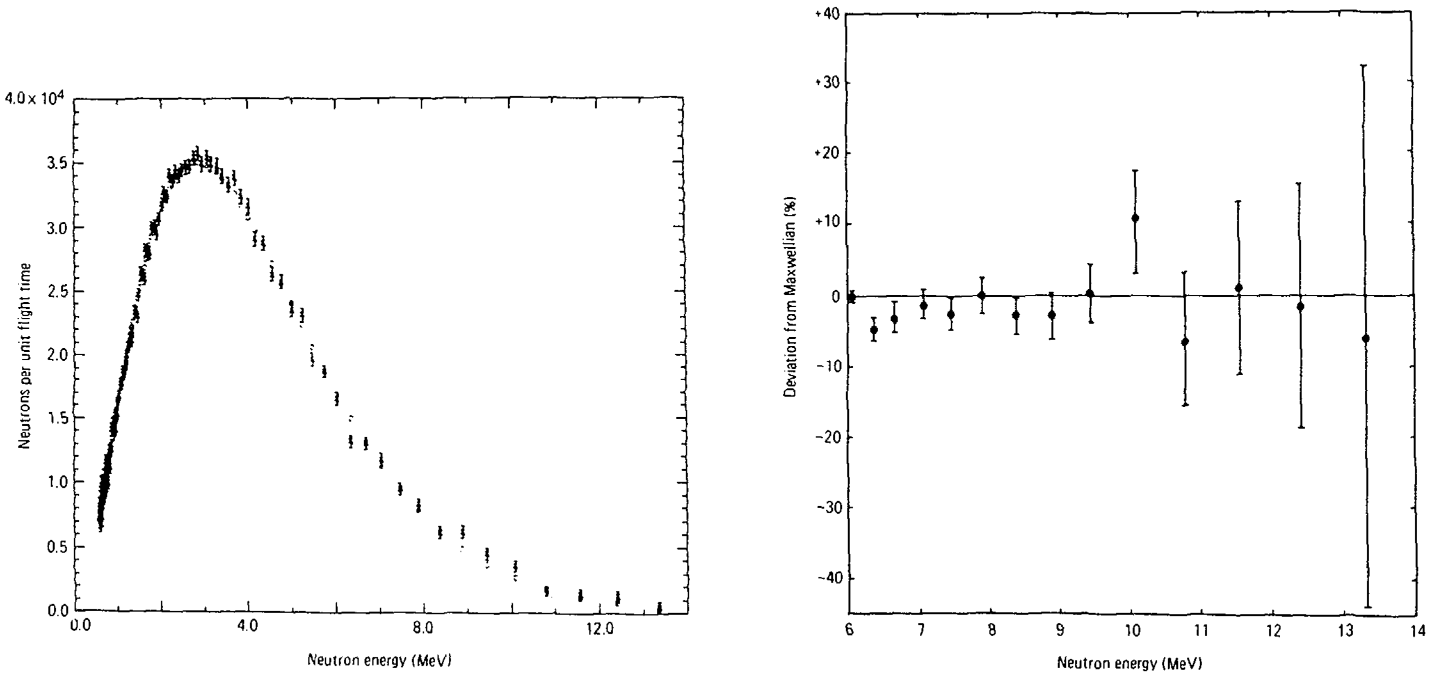

FIG. 1. Illustrative measured ^{252}Cf spectrum of Boldeman (5) and percentage deviation of measured-spectrum values from Maxwellian having T = 1.424 MeV as given by Boldeman (5).

Table II: Recent Data (after 1979) on the Fission Neutron Spectrum of ^{252}Cf

					Results	
Year	Authors	Ref.	Neutron Energy (MeV)	Comments	T_{maxw} (MeV)	$\bar{E}$ (MeV)
1979	Bensch et al.	(6)	0.9-10	small deviations from Maxwellian	1.409 ± 0.05	(2.114)
1981	Mon Jiangshen et al.	(9)	0.45-15	small deviations from Maxwellian, excess neutrons above 11 MeV	1.416 ± 0.023	(2.124)
1982	Blinov et al.	(12)	0.01-7	Maxwellian	1.418 ± 0.024	(2.127)
1982	Lajtai et al.	(13)	0.025-1.2	(result not yet known)	?	?
1982	Poenitz et al.	(12)	0.2-10	black neutron detector, small deviations from Maxwellian	1.439 ± 0.010	(2.159)
1982	Boettger et al.	(12)	2-14	Maxwellian in the range 3-13 MeV	1.355	
1982	Maerten et al.	(10,12)	above 10	excess neutrons above 20 MeV		

A measurement of the ^{252}Cf spetrum is in progress at ORNL by Spencer and Olsen. Semi-empirical calculation of the spetrum based on nuclear evaporation theory has been reported by Madland and Nix (11); the results slightly overestimate the high-energy part of the spectrum compared to experiments.

Several important new experiments were reported at the International Conference on Nuclear Data for Science and Technology, Antwerp, September 1982 (12); see Table II. These data require a comprehensive review and evaluation.

Recommendation

It is recommended that the Maxwellian form of the ^{252}Cf spectrum with a temperature T = 1.42 MeV be accepted as a contemporary reference. This should be considered an interim status until the evaluation of the recent experiments becomes available.

Note added in proof:

The IAEA Consultants' Meeting on the Californium-252 Fission Neutron Spectrum (Smolenice, CSSR, 28 March - 1 April 1983) concluded:

- The spectrum shape cannot be described by a simple parameterization (such as a Maxwellian or Watt spectrum). Recent experimental data still require evaluation.
- In the meantime a Maxwellian distribution with T = 1.42 MeV can be used as an approximation up to 6 MeV. For the energy range from 1 MeV to 20 MeV the NBS spectrum evaluation (available on magnetic tape from IAEA Nuclear Data Section) is preferable.

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12. Papers presented at the Int. Conf. on Nuclear Data for Science and Technology, Antwerp, 6-10 September 1982.

13. A. Lajtai et al., An absolute measurement of the ^{252}Cf prompt fission-neutron spectrum 25 keV - 1.2 MeV, private communication, to be published.

NU-BAR OF ^{252}Cf

A.B. Smith
Argonne National Laboratory, USA
July 1981

ν-bar of ^{252}Cf (number of neutrons emitted per spontaneous fission of ^{252}Cf) is the basic reference standard for the majority of ν-bar measurements. In addition, the neutron-emission rate (and associated emission spectrum) is a useful experimental calibration reference in a number of measurement systems.

Summary Status

This topic was the subject of a comprehensive review at a workshop held in Washington on 21 November 1980. The following remarks were abstracted from the summary of that workshop prepared by A. Carlson (NBS).

The workshop undertook a comprehensive review of the contemporary status of ν-bar ^{252}Cf. The ν-bar values considered in these discussions are summarized in Table I.

Table I. ^{252}Cf Total ν-bar Summary

Measurement	ν-bar (Total)
Liquid Scintillator	
Spencer	3.782 ± 0.008
Boldeman	3.755 ± 0.016
Asplund, Nilsson	3.792 ± 0.040
Hopkins, Diven	3.777 ± 0.031
Zhang, Liu	3.752 ± 0.018
Manganese Bath	
Axton	3.744 ± 0.019*
De Volpi	3.747 ± 0.019*
Bozorgmanesh	3.744 ± 0.023*
White, Axton	3.815 ± 0.040*
Aleksandrov	3.747 ± 0.036*
Smith	3.764 ± 0.014
Gilliam	3.789 ± 0.037*
Boron Pile	
Colvin	3.739 ± 0.037*

*Values may not include a large enough uncertainty in the sulphur absorption cross section.

Some of the values in Table I are very old. In these cases concern was expressed as to the experimental techniques employed and the associated correction procedures. Thus, continued and extensive evaluations and interpretations of some of this older data may be, at this late date, primarily of historical interest.

Smith et al. (1) have recently completed a new manganese-bath measurement. The result is ν-bar = 3.764 ± 0.014. Primary reliance was placed upon neutron fission coincidence counting for determining the fission rate. The largest contribution to the uncertainty is attributable to sulphur absorption (0.2 percent) and leakage corrections remain a concern (0.1-0.2 percent level). H Bozorgmanesh (University of Michigan) reported a manganese-bath result, referenced to NBS-II, of 3.744 ± 0.023. A similar measurement by D. Gilliam (NBS), referenced to NBS-I, gave a result of 3.789 ± 0.037. These two experiments, very similar in nature, employed the same ^{252}Cf source but gave somewhat different results. This may be due to migration of the source material during the approximately five years separating the two measurements. H. Goldstein (Columbia University) described analytical corrections for bath measurements including sensitivity coefficients. These correction factors will soon be available as an EPRI report. A major uncertainty in the bath technique is associated with the absorption cross section of sulphur. C. Robertson plans to directly measure the effect.

R. Spencer outlined the recent refinements in the ORNL scintillation tank measurements. The newest result for prompt nu-bar is 3.773 ± 0.008. Particular consideration has been given to multiple event corrections in the organic scintillators employed in monitoring the experiment. The prompt fission neutron spectrum also remains a concern, with a potential uncertainty contribution of 0.4 percent. Zhang-Huan-Qiao and Liu Zu-Hua (2) have reported a scintillation-tank result of 3.743 ± 0.018 (prompt). It is not clear that the requisite corrections are entirely consistent with those applied to the ORNL measurements.

Lemmel suggested that the comprehensive thermal constants (NBS-425) and the measured ^{235}U/^{252}Cf ratio reported by Boldeman (NBS-594) imply a ^{252}Cf ν-bar = 3.738 ± 0.025 percent (based upon monoenergetic ^{235}U data) or 3.824 ± 0.8 percent (based upon thermal Maxwellian ^{235}U data). These implications are not entirely consistent with some of the values of Table I.

There was some consideration of possible dineutron effects; they were felt to be negligible.

Editor's Comments:

Aleksandrov et al. have reinvestigated their earlier manganese-bath measurement resulting in a value of total ν-bar = 3.758 ± 0.015, which is 0.3 percent higher than the old value (Table I).

Jurney et al. (3) measured the absorption cross section at thermal energies for sulphur (513 ± 15 b). They concluded that this value cannot describe the discrepancy between $MnSO_4$-bath and liquid scintillator measurements of ^{252}Cf. A measurement is also under way by Robertson

(University of Arizona) of the absorption cross section for sulphur at thermal energies.

H. Condé
FOA,
Sweden
5/82.

Note added in proof: Two recent evaluations by E.J. Axton (private communication, December 1982, to be published) and by the United States National Nuclear Data Center (private communication, March 1983, preliminary) both give a value of total ν-bar = 3.766 with estimated uncertainties of ±0.005 (Axton) and ±0.005 (NNDC). H.D. Lemmel, IAEA, 4/83.

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NEUTRON FLUX COMPARISONS

G. Grenier
Centre d'Etudes de Bruyères-le-Chatel, France
December 1981

In addition to the first campaign of intercomparisons made between December 1973 and February 1978, a second series of intercomparisons is under way, under the sponsorship of the "Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants" (BIPM).

The methods, the neutron energies and the co-ordinating laboratories are summarized in Table I.

Table I.

Neutron energy (MeV)	Transfer methods			
	Fission chamber	$^{115}In(n,\gamma)^{116}In$	$^{115}In(n,n')^{115m}In$	$^{93}Nb(n,2n)$ $^{90}Zr(n,2n)$
0.144	X	X		
0.565	X	X		
2.5	X		X	
5.0	X		X	
14.8	X		X	X
Co-ordinator	AERE (D. Gayther) NPL (E.J. Axton)	NPL (T.B. Ryves)	CBNM (H. Liskien)	NPL (V.E. Lewis)

The following comments can be made about the various methods:

a) Fission chambers

The ^{235}U fission chamber will be used at all energies.

The ^{238}U fission chamber will be used at 2.5 MeV, 5.0 MeV and 14.8 MeV only.

The following laboratories have given their approval to participate in this intercomparison: NBS, BIPM, PTB, CEN, NRC, ETL, NPL and CBNM.

Measurements are expected to start in 1981-1982 and to be finished at the end of 1984.

It was suggested that an additional energy (25 keV) should be added as an option.

b) $^{115}In(n,\gamma)^{116}In$

The following laboratories have agreed to participate: NPL, NBS, PTB, BARC, NRC, ETL, CBMN.

Measurements have started this year. The analysis will be made in the spring of 1984.

c) $^{115}In(n,n')^{115m}In$

Indium samples and ^{52}Cr sources for checking have been distributed to the participants in May 1981.

Participant laboratories include CBMN, BIPM, IMM, NBS, PTB, BARC, NFL (Sweden), NPL, AERE (UK) and AEIP (People's Republic of China).

The comparisons should be completed and analysed during the period 1981-1983.

d) $^{93}Nb(n,2n)$ and $^{90}Zr(n,2n)$

This transfer method will provide a check on the In(n,n') results at 14.8 MeV.

Niobium and zirconium samples were distributed by NPL to all participants in May 1981.

The analysis should be finished early in 1982.

Participant laboratories include BIPM, NBS, PTB, BARC, CBMN, AEIP, NPL, University of Vienna.

Neutron Flux Measurements at BIPM

Besides the series of intercomparisons, the BIPM is also engaged in:

- measurement of the sensitivity of the BIPM precision long counter at 14.61 MeV. This is part of a study on the possibility of using this instrument to measure fluence rate for D-T neutrons;

- measurement of the response to neutrons of the Geiger-Mueller counter used to measure gamma-ray dose in mixed neutron-gamma radiation fields;

- comparison of fluence rate measurements with NPL testing the Nb/Zr transfer method near 14.6 MeV, yielding a result NPL/BIPM of 1.025.

Studies have also been made of the Exradin Model T2 tissue-equivalent ionization chamber as a possible transfer instrument for neutron dosimetry intercomparisons.

DECAY DATA FOR RADIONUCLIDES USED AS CALIBRATION STANDARDS

A. Lorenz
IAEA, Vienna
1982

The calibration of gamma detectors is of fundamental importance for the accurate measurement of energies and intensities of gamma rays, as well as for the intercomparison of measurements made by different experimentalists.

This compilation of decay data for radionuclides used as calibration standards consists of current "best" values which have been drawn from a number of sources. It is our intent to update these calibration data as new evaluations are performed, in co-operation with the efforts of the ICRM Working Group on α-, β- and γ-ray Spectroscopy.

Selection of Standards Included in File

The radionuclides chosen to be included in this tabulation were selected on the basis of their inclusion in the following compilations:

The 1980 INDC/NEANDC Standard File (1)

The 1979 list of standards for gamma ray energy calibration recommended by IUPAC (2)

The 1980 report by the AECL Radioisotope Standardization Group to the Spectrometry Working Group of the ICRM (3).

Selection of Recommended Half-Life Values

The half-life values of the radionuclides chosen to be recommended as standards were selected from the following compilations of evaluated data:

The LMRI Table of Radionuclides (4), including private communications from LMRI in 1981

The Nuclear Data Sheets Journal

The report of the AECL Radioisotope Standardization Group to the Spectrometry Working Group of the ICRM (3)

The 1980 report by Y. Yoshizawa et al., "Evaluation of Gamma Ray Intensities" (5)

The 7th Edition of the Table of Isotopes (6)

The 1981 edition of the IAEA-proposed recommended list of trans-actinium isotope half-lives. (7).

Most selected values consist of half-lives evaluated since 1977 as part of the international nuclear structure data evaluation effort (published in the Nuclear Data Sheets and compiled in the ENDSF data library).

Selection of Recommended Gamma-ray Energies and Emission Probabilities

All gamma-ray energy standards recommended by the IUPAP Commission on Atomic Masses and Fundamental Constants (2) were adopted for those radionuclides included in this file.

Beyond this initial criterion, the recommended values of E_γ and I_γ were selected from the following publications and compilations of evaluated data:

1. The LMRI Table of Radionuclides (4), including private communication from LMRI in 1982
2. The 1980 report by Y. Yoshizawa et al., "Evaluation of Gamma-Ray Intensities" (5)
3. The nuclear spectroscopy standards listed in the 7th Edition of the Table of Isotopes (6)
4. The report of the AECL Radioisotope Standardization Group to the α-, β - and γ-Ray Spectrometry Group of the ICRM (3)
5. The Nuclear Data Sheets Journal
6. The 7th Edition of the Table of Isotopes (6)

The last reference was used primarily in those cases where the radionuclide had not been evaluated since before 1976

All gamma-ray intensity values are given as absolute intensities per decay.

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GAMMA-RAY STANDARDS - Recommended Reference Data

Half-Lives

NUCLIDE	DECAY-MODE	HALF-LIFE	
4-Be- 7	EC	53.29 ± 0.07	(D)
9-F - 18	B+	109.77 ± 0.05	(M)
11-Na- 22	T (B+,EC)	2.602 ± 0.001	(Y)
11-Na- 24	B-	14.960 ± 0.006	(H)
19-K - 42	B-	12.359 ± 0.006	(H)
21-Sc- 46	B-	83.83 ± 0.02	(D)
24-Cr- 51	EC	27.703 ± 0.004	(D)
25-Mn- 54	EC	312.2 ± 0.1	(D)
25-Mn- 56	B-	2.5785 ± 0.0006	(H)
26-Fe- 59	B-	45.54 ± 0.05	(D)
27-Co- 56	T (B+,EC)	77.12 ± 0.10	(D)
27-Co- 57	EC	271.73 ± 0.14	(D)
27-Co- 58	T (B+,EC)	70.78 ± 0.10	(D)
27-Co- 60	EC	5.271 ± 0.001	(Y)
28-Ni- 65	B-	2.520 ± 0.001	(H)
29-Cu- 64	T (B-,B+,EC)	12.701 ± 0.002	(H)
30-Zn- 65	T (B+,EC)	244.0 ± 0.2	(D)
34-Se- 75	EC	119.78 ± 0.01	(D)
35-Br- 82	B-	35.30 ± 0.03	(H)
36-Kr- 85	B-	10.72 ± 0.02	(Y)
38-Sr- 85	EC	64.85 ± 0.02	(D)
39-Y - 88	EC	106.6 ± 0.2	(D)
40-Zr- 95	B-	63.98 ± 0.06	(D)
41-Nb- 94	B-	(2.03 ± 0.16)E+04	(Y)
41-Nb- 95	B-	35.05 ± 0.10	(D)
43-Tc- 99	B-	(2.14 ± 0.05)E+05	(Y)
43-Tc- 99m	IT	6.007 ± 0.002	(H)
47-Ag-108m	T (IT,EC)	127.0 ± 21.0	(Y)
47-Ag-110m	B-	249.8 ± 0.10	(D)
48-Cd-109	EC	463.1 ± 0.8	(D)
49-In-111	EC	2.802 ± 0.003	(D)
49-In-113m	IT	99.49 ± 0.06	(H)
49-In-115m	T (B-,IT)	4.486 ± 0.004	(H)
50-Sn-113	EC	115.10 ± 0.17	(D)
51-Sb-124	B-	60.20 ± 0.03	(D)
53-I -125	EC	59.90 ± 0.11	(D)
54-Xe-133	B-	5.244 ± 0.007	(D)
55-Cs-131	EC	9.68 ± 0.06	(D)
55-Cs-134	B-	2.066 ± 0.001	(Y)
55-Cs-134m	IT	2.91 ± 0.02	(H)
55-Cs-137	B-	30.18 ± 0.05	(Y)
56-Ba-133	EC	10.6 ± 0.2	(Y)
56-Ba-137m	IT	2.554 ± 0.002	(M)
58-Ce-139	EC	137.65 ± 0.03	(D)
58-Ce-141	B-	32.50 ± 0.01	(D)
58-Ce-144	B-	284.9 ± 0.2	(D)
63-Eu-152	T (B-,B+)	13.33 ± 0.04	(Y)
64-Gd-153	EC	241.6 ± 0.2	(D)
69-Tm-170	B-	128.6 ± 0.3	(D)
70-Yb-169	EC	32.022 ± 0.008	(D)
73-Ta-182	B-	114.8 ± 0.2	(D)

77-Ir-192	B-	74.1 ± 0.2	(D)
79-Au-198	B-	2.695 ± 0.002	(D)
80-Hg-203	B-	46.585 ± 0.008	(D)
83-Bi-207	EC	33.4 ± 0.8	(Y)
90-Th-228	A	1.913 ± 0.002	(Y)
95-Aa-241	A	432.6 ± 0.6	(Y)

Abbreviations used above

A	=	Alpha decay	M	=	minutes
B^+	=	Positron beta decay	H	=	hours
B^-	=	Beta decay	D	=	days
EC	=	Electron capture	Y	=	years
IT	=	Internal transition			
T	=	Total			

Gamma-ray Standards, Energies and Intensities

NUCLIDE	ENERGY(keV)	EMISSION PROBABILITY
4-Be- 7	477.605 ± 0.003	0.1030 ± 0.0004
11-Na- 22	1274.542 ± 0.007	0.9995 ± 0.0002
11-Na- 24	1368.633 ± 0.006	0.99994 ± 0.00002
	2754.030 ± 0.014	0.99881 ± 0.00008
19-K - 42	1524.665 ± 0.020	0.179 ± 0.005
21-Sc- 46	889.277 ± 0.003	0.999836 ± 0.000016
	1120.545 ± 0.004	0.999871 ± 0.000012
24-Cr- 51	320.0842 ± 0.0009	0.0985 ± 0.0009
25-Mn- 54	834.843 ± 0.006	0.99976 ± 0.00002
25-Mn- 56	846.754 ± 0.020	1.000 ± 0.003
	1810.72 ± 0.04	0.275 ± 0.008
	2113.05 ± 0.04	0.145 ± 0.004
	2522.88 ± 0.06	0.0100 ± 0.0003
	2657.45 ± 0.05	0.0066 ± 0.0002
	2959.77 ± 0.06	0.0031 ± 0.0001
	3369.60 ± 0.07	0.0017 ± 0.0001
26-Fe- 59	142.652 ± 0.002	0.0098 ± 0.0004
	192.349 ± 0.005	0.0295 ± 0.0008
	334.99 ± 0.05	0.0027 ± 0.0001
	382.5 ± 0.2	0.00021 ± 0.00003
	1099.251 ± 0.004	0.561 ± 0.010
	1291.596 ± 0.007	0.436 ± 0.008
	1481.7 ± 0.1	0.00061 ± 0.00004

27-Co- 56	846.764 ± 0.006	0.99923 ± 0.00007
	1037.844 ± 0.004	0.1409 ± 0.0006
	1175.099 ± 0.008	0.0227 ± 0.0002
	1238.287 ± 0.006	0.670 ± 0.007
	1360.206 ± 0.006	0.0426 ± 0.0002
	1771.350 ± 0.015	0.1549 ± 0.0005
	1810.722 ± 0.017	
	1963.714 ± 0.012	
	2015.179 ± 0.011	0.0303 ± 0.0004
	2034.759 ± 0.011	0.0778 ± 0.0012
	2112.921 ± 0.010	
	2113.117 ± 0.012	
	2598.460 ± 0.010	0.1695 ± 0.0006
	3009.596 ± 0.017	
	3201.954 ± 0.014	0.0318 ± 0.0008
	3253.417 ± 0.014	0.0764 ± 0.0020
	3272.998 ± 0.014	0.018 ± 0.001
	3451.154 ± 0.013	0.0093 ± 0.0003
	3548.18 ± 0.12	0.0019 ± 0.0001
27-Co- 57	122.06135 ± 0.00030	0.8568 ± 0.0013
	136.4743 ± 0.0005	0.1067 ± 0.0013
27-Co- 58	810.775 ± 0.009	0.99445 ± 0.00010
	863.959 ± 0.009	0.0069 ± 0.0002
	1674.730 ± 0.010	0.00519 ± 0.00004
27-Co- 60	1173.238 ± 0.004	0.9989 ± 0.0002
	1332.502 ± 0.005	0.999816 ± 0.000015
28-Ni- 65	1482.	0.235 ± 0.004
29-Cu- 64	1345.77 ± 0.06	0.0077 ± 0.0006
30-Zn- 65	1115.546 ± 0.004	0.5075 ± 0.0010
34-Se- 75	24.38 ± 0.03	0.0030 ± 0.0006
	66.060 ± 0.0007	0.0113 ± 0.0002
	80.92 ± 0.02	0.00008 ± 0.00002
	96.734 ± 0.002	0.0349 ± 0.0007
	121.119 ± 0.003	0.176 ± 0.002
	136.002 ± 0.003	0.596 ± 0.005
	198.596 ± 0.006	0.0151 ± 0.0002
	264.656 ± 0.004	0.596 ± 0.003
	279.538 ± 0.003	0.253 ± 0.003
	303.924 ± 0.003	0.0134 ± 0.0002
	400.657 ± 0.002	0.1160 ± 0.0015
	419.0 ± 0.2	0.00012 ± 0.00002
	572.5 ± 0.2	0.00038 ± 0.00002
35-Br- 82	92.184 ± 0.007	0.0072 ± 0.0003
	137.23 ± 0.04	0.0012 ± 0.0005
	221.48 ± 0.03	0.0227 ± 0.0005
	273.47 ± 0.03	0.0081 ± 0.0003
	554.348 ± 0.003	0.706 ± 0.003
	606.33 ± 0.02	0.0125 ± 0.0007
	619.106 ± 0.004	0.433 ± 0.003
	698.374 ± 0.005	0.284 ± 0.004
	776.517 ± 0.003	0.834 ± 0.002

	827.828 ± 0.006	0.241 ± 0.003
	951.95 ± 0.04	0.0038 ± 0.0002
	1007.54 ± 0.03	0.0127 ± 0.0006
	1044.002 ± 0.007	0.275 ± 0.006
	1081.3 ± 0.1	0.0063 ± 0.0004
	1317.476 ± 0.006	0.27 ± 0.008
	1426.	0.0011 ± 0.0005
	1474.884 ± 0.006	0.164 ± 0.002
	1650.339 ± 0.008	0.0075 ± 0.0002
	1779.58 ± 0.05	0.00116 ± 0.00003
36-Kr- 85	514.009 ± 0.012	0.00437 ± 0.00011
38-Sr- 85	514.009 ± 0.012	0.9929 ± 0.0004
39-Y- 88	898.042 ± 0.004	0.937 ± 0.004
	1836.063 ± 0.013	0.9934 ± 0.0007
	2734.087 ± 0.087	0.0072 ± 0.0007
40-Zr- 95	204.12 ± 0.02	0.0003 ± 0.0001
	235.69 ± 0.02	0.0029 ± 0.0005
	561.66 ± 0.02	0.00010 ± 0.00004
	724.199 ± 0.005	0.4425 ± 0.0040
	756.729 ± 0.012	0.5444 ± 0.0040
41-Nb- 94	702.645 ± 0.006	0.998
	871.119 ± 0.004	0.999
41-Nb- 95	765.807 ± 0.006	0.9980 ± 0.0002
43-Tc- 99	140.511 ± 0.001	0.890 ± 0.002
43-Tc- 99M1	141.	0.8875 ± 0.0014
47-Ag-108M1	433.936 ± 0.004	0.905 ± 0.007
	614.281 ± 0.004	0.910 ± 0.007
	722.929 ± 0.004	0.907 ± 0.008
47-Ag-110M1	446.811 ± 0.003	0.0368 ± 0.002
	620.360 ± 0.003	0.0279 ± 0.002
	657.7622 ± 0.0020	0.9437 ± 0.0010
	677.623 ± 0.002	0.1048 ± 0.0010
	687.015 ± 0.003	0.0644 ± 0.0003
	706.682 ± 0.003	0.162 ± 0.002
	744.277 ± 0.003	0.0466 ± 0.0006
	763.944 ± 0.003	0.2225 ± 0.0007
	818.031 ± 0.004	0.0730 ± 0.0004
	884.685 ± 0.003	0.727 ± 0.003
	937.493 ± 0.004	0.3426 ± 0.0012
	1384.300 ± 0.004	0.258 ± 0.005
	1475.788 ± 0.006	0.0398 ± 0.0003
	1505.040 ± 0.005	0.1305 ± 0.0006
	1562.302 ± 0.005	0.0118 ± 0.0001
48-Cd-109	88.0341 ± 0.0011	0.0365 ± 0.0006
49-In-111	171.28 ± 0.03	0.902 ± 0.003
	245.35 ± 0.04	0.940 ± 0.002
	537.1 ± 1.	0.87

49-In-113M1	391.702 ± 0.004	0.6489 ± 0.0017
49-In-115M1	336.	0.459 ± 0.003
50-Sn-113	255.115 ± 0.015	0.0182 ± 0.0004
51-Sb-124	602.730 ± 0.003	0.9792 ± 0.0029
	645.855 ± 0.002	0.0739 ± 0.0005
	709.320 ± 0.013	0.0135 ± 0.0002
	713.781 ± 0.005	0.0227 ± 0.0003
	722.786 ± 0.004	0.1077 ± 0.0010
	790.712 ± 0.007	0.0074 ± 0.0001
	968.201 ± 0.004	0.0189 ± 0.0002
	1045.131 ± 0.004	0.0184 ± 0.0004
	1325.512 ± 0.006	0.0163 ± 0.0004
	1355.175 ± 0.022	0.0104 ± 0.0004
	1368.164 ± 0.007	0.0262 ± 0.0005
	1436.563 ± 0.007	0.0123 ± 0.0005
	1690.980 ± 0.006	0.474 ± 0.006
	2090.942 ± 0.008	0.056 ± 0.001
53-I -125	35.4919 ± 0.0005	0.0667 ± 0.0013
54-Xe-133	79.623 ± 0.010	0.0027 ± 0.0003
	80.997 ± 0.003	0.380 ± 0.007
	160.613 ± 0.008	0.00066 ± 0.00005
	223.234 ± 0.012	0.0000012 ± 0.0000002
	302.853 ± 0.001	0.000048 ± 0.000003
	383.851 ± 0.003	0.000024 ± 0.000002
55-Cs-131	355. ± 6.	1.0
55-Cs-134	475.34 ± 0.02	0.0150 ± 0.0002
	563.23 ± 0.02	0.0838 ± 0.0003
	569.32 ± 0.02	0.1539 ± 0.0005
	604.69 ± 0.02	0.9763 ± 0.0003
	795.84 ± 0.01	0.8552 ± 0.0003
	801.93 ± 0.02	0.0870 ± 0.0002
	1038.555 ± 0.020	0.00991 ± 0.00004
	1167.92 ± 0.02	0.01792 ± 0.00008
	1365.16 ± 0.02	0.03015 ± 0.00013
55-Cs-134M1	11.28 ± 0.02	0.0094 ± 0.0009
	127.42 ± 0.06	0.126 ± 0.004
	138.70 ± 0.03	0.00004 ± 0.00001
55-Cs-137	32.1	0.0557 ± 0.0016
	36.4	0.0107 ± 0.0004
	37.3	0.0025 ± 0.0001
	661.660 ± 0.003	0.847 ± 0.003
56-Ba-133	53.161 ± 0.001	0.0220 ± 0.0006
	79.623 ± 0.010	0.0264 ± 0.0012
	80.997 ± 0.003	0.343 ± 0.006
	160.613 ± 0.008	0.0062 ± 0.0002
	223.234 ± 0.012	0.00447 ± 0.00020
	276.398 ± 0.002	0.0712 ± 0.0007
	302.853 ± 0.001	0.183 ± 0.002
	356.017 ± 0.002	0.621 ± 0.007
	383.851 ± 0.003	0.0892 ± 0.0009

56-Ba-137M1	661.660 ± 0.003	0.9007 ± 0.0004
58-Ce-139	165.857 ± 0.006	0.7999 ± 0.0010
58-Ce-141	145.4442 ± 0.0014	0.488 ± 0.004
58-Ce-144	33.622 ± 0.010	0.0029 ± 0.0002
	40.89 ± 0.05	0.0039 ± 0.0006
	53.432 ± 0.010	0.00095 ± 0.00005
	59.03 ± 0.03	0.000012 ± 0.000002
	80.106 ± 0.005	0.0112 ± 0.0013
	99.963 ± 0.020	0.00039 ± 0.00003
	133.544 ± 0.005	0.110 ± 0.002
63-Eu-152	121.7824 ± 0.0004	0.2837 ± 0.0024
	244.6989 ± 0.0010	0.0751 ± 0.0005
	344.2811 ± 0.0019	0.2658 ± 0.0018
	411.115 ± 0.005	0.02234 ± 0.00013
	443.976 ± 0.005	0.0312 ± 0.00018
	778.903 ± 0.006	0.1296 ± 0.0007
	964.131 ± 0.009	0.1462 ± 0.0006
	1085.914 ± 0.013	0.1016 ± 0.0005
	1112.116 ± 0.017	0.1356 ± 0.0006
	1408.011 ± 0.014	0.2085 ± 0.0008
64-Gd-153	69.6734 ± 0.0020	0.0242 ± 0.0012
	83.367 ± 0.003	0.00206 ± 0.00022
	97.4316 ± 0.0030	0.295 ± 0.009
	103.1807 ± 0.0030	0.211 ± 0.008
69-Tm-170	84.25510 ± 0.00030	0.0326 ± 0.0016
70-Yb-169	63.1208 ± 0.00002	0.43695 ± 0.01500
	93.6151 ± 0.00004	0.02656 ± 0.00087
	109.7802 ± 0.0003	0.17345 ± 0.00506
	118.1901 ± 0.0010	0.01878 ± 0.00053
	130.5239 ± 0.0004	0.11098 ± 0.00490
	177.2144 ± 0.0005	0.21429 ± 0.00602
	197.9581 ± 0.0006	0.349 ± 0.008
	261.0788 ± 0.0007	0.01895 ± 0.00050
	307.7382 ± 0.0008	0.10784 ± 0.00160
73-Ta-182	31.7378 ± 0.004	0.00892 ± 0.00021
	42.7154 ± 0.006	0.00266 ± 0.00008
	57.98	0.2802 ± 0.0052
	65.72247 ± 0.00014	
	67.75001 ± 0.00020	0.571 ± 0.013
	84.6808 ± 0.0003	0.0263 ± 0.0010
	100.10653 ± 0.00030	0.1423 ± 0.0042
	113.6723 ± 0.0004	0.0187 ± 0.0006
	116.4186 ± 0.0007	0.00445 ± 0.00015
	152.4308 ± 0.0005	0.0695 ± 0.0009
	156.3874 ± 0.0005	0.0263 ± 0.0005
	179.3948 ± 0.0005	0.0309 ± 0.0004
	198.3530 ± 0.0006	0.0144 ± 0.0002
	222.1099 ± 0.0006	0.0750 ± 0.0010
	229.3220 ± 0.0009	0.0364 ± 0.0005
	264.0755 ± 0.0008	0.0362 ± 0.0006
	1121.301 ± 0.005	0.3530 ± 0.0032

	1189.050 ± 0.005	0.1644 ± 0.0015
	1221.408 ± 0.005	0.2717 ± 0.0025
	1231.016 ± 0.005	0.1158 ± 0.0011
	1257.418 ± 0.005	0.0150 ± 0.0002
	1289.156 ± 0.005	0.0136 ± 0.0002
77-Ir-192	136.3434 ± 0.0005	0.0018 ± 0.0001
	205.7955 ± 0.0005	0.0331 ± 0.0006
	295.95821 ± 0.0008	0.287 ± 0.002
	308.45685 ± 0.0008	0.297 ± 0.003
	316.50800 ± 0.0008	0.830 ± 0.003
	468.0715 ± 0.0012	0.478 ± 0.003
	484.5779 ± 0.0013	0.0316 ± 0.0003
	588.5851 ± 0.0016	0.0448 ± 0.0004
	604.41455 ± 0.0016	0.0807 ± 0.0006
	612.46569 ± 0.0016	0.0527 ± 0.0005
	884.5423 ± 0.0020	0.0029 ± 0.0001
79-Au-198	411.8044 ± 0.0011	0.9556 ± 0.0007
	675.8875 ± 0.0019	0.0082 ± 0.0003
	1087.6905 ± 0.0029	0.00167 ± 0.00009
80-Hg-203	70.8319 ± 0.0008	0.038 ± 0.001
	72.8715 ± 0.0009	0.0064 ± 0.002
	82.4	0.022 ± 0.001
	85.2	0.0063 ± 0.0003
	279.1967 ± 0.0012	0.816 ± 0.0002
83-Bi-207	569.702 ± 0.002	0.9774 ± 0.0003
	1063.662 ± 0.004	0.740 ± 0.003
	1770.237 ± 0.010	0.0687 ± 0.0004
90-Th-228	84.371 ± 0.003	0.0121 ± 0.0006
	131.610 ± 0.004	0.00123 ± 0.00006
	166.407 ± 0.004	0.000956 ± 0.000048
	205.93 ± 0.05	0.000184 ± 0.000008
	215.979 ± 0.005	0.00238 ± 0.00013
95-Am-241	26.345 ± 0.001	0.024 ± 0.001
	33.195 ± 0.011	0.00103 ± 0.00011
	43.423 ± 0.020	0.00057 ± 0.00018
	59.537 ± 0.001	0.3582 ± 0.0012

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