International Atomic Energy Agency

INDC-36/LN

INDC

INTERNATIONAL NUCLEAR DATA COMMITTEE

INDC/NEANDC

Nuclear Standards File

1980 Version

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INDC/NEANDC
NUCLEAR STANDARDS FILE, Version '80

Argonne National Laboratory, 5/'81
Subcommittee Chairman: A. B. Smith
Subcommittee Executive Secretary: W. P. Poenitz

INDC/NEANDC
NUCLEAR STANDARDS FILE, Version '80

PREFACE

This working document of the Nuclear Standards Subcommittee of the International Nuclear Data Committee (INDC) summarizes the status of nuclear standards as of the 11th INDC meeting (6/'80) with selective updating to ≈5/'81. This version of the file is presented in two sections as per the following.

The first section (A) consists of numerical tabulations of the respective quantities generally including quantitative definition of the uncertainties. Most of these numerical values are taken from the ENDF/B-V file which is available on a world-wide basis through the 4-Center network. Some guidelines as to appropriate usage are also given. The objective is the provision of a concise and readily used reference guide to essential standard-nuclear quantities useful for a diversity of basic and applied endeavors.

The second section (B) briefly summarizes the contemporary status of each of the standards tabulated in Section A and additional items, including recent relevant work and areas of continuing uncertainty. These brief reviews were prepared under the auspices of the Committee by outstanding specialists in the respective fields. In many instances they are new statements but, where review indicates that the previous statement (see INDC-30/L+sp) remains appropriate, the previous summaries were retained; often with additional remarks by the editor.

It remains the intent to revise and update this file at periodic intervals correlated with the meetings of the INDC and NEANDC. Comment is encouraged, particularly where it provides a feedback mechanism resulting in the improvement of the file.

Argonne National Laboratory, 5/'81

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INDC REFERENCE-DATA-TYPE AND REVIEW RESPONSIBILITIES (1980)

	Reference-Data-Type	Responsibility	
		National	Current Personnel
I.	$H(n;n)H$	U. K.	C. Uttley
II.	$^{6}Li(n;t)^{4}He$	U. S.	A. Smith/H. Motz
III.	$^{10}B(n;\alpha)^{7}Li$	EEC	E. Wattecamps
IV.	$C(n;n)C$	U. S.	A. Smith
V.	$^{197}Au(n;\gamma)^{198}Au$	U. S.	A. Smith
VI.	$^{235}U(\sigma_f)$	USSR	G. Yankov
VII.	^{252}Cf Fission Spec	IAEA/USSR	H. Lemmel/G. Yankov
VIII.	$\bar{\nu}$ of ^{252}Cf	U. S.	A. Smith
IX.	$\tau_{1/2}$; ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu	IAEA	A. Lorenz/H. Lemmel
X.	Thermal Constants: ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu	U. S.	~~A. Smith~~ H.D.L
XI.	γ-ray Standards	IAEA	A. Lorenz
XII.	Neutron Flux Comparisons	France	A. Michaudon/G. Grenier
XIII.	Neutron Energy Standards	U. K.	D. James
XIV.	$^{27}Al(n;\alpha)$	Austria	H. Vonach
XV.	$^{238}U(\sigma_f)$	U. S.	A. Smith
XVI.	Remarks on Monoenergetic Sources	U.S./IAEA	A. Smith/H. Lemmel

INDC SUBCOMMITTEE MEMBERSHIP (1980)[a]

Name	Representation
H. Conde'	Sweden
J. Csikai*	Hungary
A. Ferguson	United Kingdom
Y. Gur*	Israel
S. Kapoor	India
H. Lemmel*	NDS
H. Liskien	EEC
A. Lorenz*	NDS
S. Rapeanu*	Romania
J. Schmidt*	NDS
D. Seeliger	German Democratic Republic
A. Smith	United States -- Chairman
H. Vonach*	Austria
G. Yankov	Union of Soviet Socialist Republics

[a]Referenced to the 11th INDC Meeting.
*Observer-attendees for the 11th Meeting.
NEANDC Subcommittee Chairman: F. Perey

SECTION A: NUMERICAL REFERENCE TABLES*

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 referencable and easily available. The INDC/NEANDC reference file provides such standard-reference quantities in a manner not otherwise available. This Section tabulates the explicit numerical reference values, generally with associated uncertainties, and with guidelines as to their use. The tabulations are provided when the values are judged to be reasonably well defined. Certain important standard values are omitted from this tabulation as the contemporary situation is judged to be in a state of flux (e.g. nu-bar of ^{252}Cf) or the relevant quantities are of a specialized and/or extensive nature (e.g. gamma-ray standards).

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

--- standards tabulated in this Section be adopted for all measurements

and

--- that when converting relative observables 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.

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

H(N,N) CRØSS SECTIØNS

NUMERICAL VALUES FRØM ENDF/B-V, MAT-1301,
APPLICABLE ENERGY RANGE 0.001 TØ 20.0 MEV,
LINEAR-LINEAR INTERPØLATIØN,

CRØSS SECTIØN 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
1,60E 02	1,0140E 01	1,90E 02	9,8980E 00	2,00E 02	9,6710E 00
2,20E 02	9,2580E 00	2,40E 02	8,8920E 00	2,60E 02	8,5620E 00
2,80E 02	8,2620E 00	3,00E 02	7,9870E 00	3,20E 02	7,7340E 00
3,40E 02	7,5010E 00	3,60E 02	7,2840E 00	3,80E 02	7,0830E 00
4,00E 02	6,8970E 00	4,20E 02	6,7250E 00	4,40E 02	6,5650E 00
4,60E 02	6,4150E 00	4,80E 02	6,2750E 00	5,00E 02	6,1430E 00
5,50E 02	5,8450E 00	6,00E 02	5,5840E 00	6,50E 02	5,3540E 00
7,00E 02	5,1480E 00	7,50E 02	4,9640E 00	8,00E 02	4,7970E 00
8,50E 02	4,6450E 00	9,00E 02	4,5060E 00	9,50E 02	4,3780E 00
1,00E 03	4,2610E 00	1,10E 03	4,0510E 00	1,20E 03	3,8680E 00
1,30E 03	3,7060E 00	1,40E 03	3,5610E 00	1,50E 03	3,4290E 00
1,60E 03	3,3090E 00	1,70E 03	3,1980E 00	1,80E 03	3,0970E 00
1,90E 03	3,0030E 00	2,00E 03	2,9150E 00	2,20E 03	2,7590E 00
2,40E 03	2,6220E 00	2,60E 03	2,5010E 00	2,80E 03	2,3920E 00
3,00E 03	2,2930E 00	3,20E 03	2,2030E 00	3,40E 03	2,1200E 00
3,60E 03	2,0430E 00	3,80E 03	1,9730E 00	4,00E 03	1,9070E 00
4,20E 03	1,8450E 00	4,40E 03	1,7880E 00	4,60E 03	1,7340E 00
4,80E 03	1,6830E 00	5,00E 03	1,6350E 00	5,20E 03	1,5890E 00
5,40E 03	1,5470E 00	5,60E 03	1,5060E 00	5,80E 03	1,4670E 00
6,00E 03	1,4300E 00	6,20E 03	1,3950E 00	6,40E 03	1,3620E 00
6,60E 03	1,3290E 00	6,80E 03	1,2990E 00	7,00E 03	1,2690E 00
7,50E 03	1,2010E 00	8,00E 03	1,1390E 00	8,50E 03	1,0830E 00
9,00E 03	1,0320E 00	9,50E 03	9,8590E-01	1,00E 04	9,4320E-01
1,05E 04	9,0350E-01	1,10E 04	8,6650E-01	1,15E 04	8,3230E-01
1,20E 04	8,0050E-01	1,25E 04	7,7100E-01	1,30E 04	7,4330E-01
1,35E 04	7,1730E-01	1,40E 04	6,9290E-01	1,45E 04	6,6980E-01
1,50E 04	6,4800E-01	1,55E 04	6,2740E-01	1,60E 04	6,0780E-01
1,65E 04	5,8930E-01	1,70E 04	5,7170E-01	1,75E 04	5,5490E-01
1,80E 04	5,3900E-01	1,85E 04	5,2380E-01	1,90E 04	5,0930E-01
1,95E 04	4,9550E-01	2,00E 04	4,8230E-01		

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
1,0E+03 TØ 1,0E+05(EV)	0,5
1,0E+05 TØ 1,0E+06	0,7
1,0E+06 TØ 1,4E+07	0,9
1,4E+07 TØ 2,0E+07	1,0

CØRRELATIØN MATRIX

+1,000			
+0,339	+1,000		
-0,110	+0,330	+1,000	
-0,040	-0,110	+0,335	+1,00

RELATIVE CENTER-ØF-MASS NEUTRØN ANGULAR DISTRIBUTIØNS,
FØRM--- SUM ØVER A(I)*P(I), I=0,1,2,3 AND 4, A(0)=1,0,
LINEAR-LINEAR INTERPØLATIØN,

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

SUPPLEMENTAL HIGH-ENERGY H(N,N) CRØSS SECTIØNS,
VALUES FRØM J, HØPKINS AND G, BREIT, NUCL, DATA, 9A, 137 (1971),

CRØSS SECTIØN VALUES

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
2,00E 04	4,8230E-01	2,20E 04	4,3500E-01	2,40E 04	3,9490E-01
2,60E 04	3,6050E-01	2,80E 04	3,3070E-01	3,00E 04	3,0470E-01

LI-6(N,T)HE-4 CRØSS SECTIØNS

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

CRØSS SECTIØN VALUES

E(KEV)	XSEC(B)	E(KEV)	XSEC(B)	E(KEV)	XSEC(B)
LØG-LØG INTERPØLATIØN.					
1,00E-08	4,7075E 04	1,00E-05	1,4886E 03	2,53E-05	9,3599E 02
1,00E-04	4,7073E 02	1,00E-03	1,4884E 02	1,00E-02	4,7052E 01
1,00E-01	1,4865E 01	4,00E-01	1,4248E 00	1,00E 00	4,6924E 00
2,00E 00	3,3175E 00	4,00E 00	2,3481E 00	6,50E 00	1,8462E 00
1,00E 01	1,4949E 00	1,50E 01	1,2297E 00	2,00E 01	1,0743E 00
2,50E 01	9,7026E-01	3,00E 01	8,9531E-01		
LINEAR-LINEAR INTERPØLATIØN.					
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	6,5061E-01	9,00E 01	6,4679E-01
1,00E 02	6,5235E-01				

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
1,0E-05 TØ 2,0E 02(EV)	0,4
2,0E 02 TØ 2,0E 03	0,5
2,0E 03 TØ 1,0E 04	0,5
1,0E 04 TØ 3,0E 04	1,0
3,0E 04 TØ 1,0E 05	2,0

CØRRELATIØN MATRIX

+1,00				
+0,99	+1,00			
+0,93	+0,96	+1,00		
+0,67	+0,72	+0,88	+1,00	
+0,30	+0,35	+0,58	+0,89	+1.00

RELATIVE CENTER-ØF-MASS TRITØN ANGULAR DISTRIBUTIØNS,
FØRM--- SUM ØVER A(I)*P(I), I=0,1 AND 2, A(0)=1.0,

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

B-10(N,ALPHA-0) CRØSS SECTIØNS

NUMERICAL VALUES FRØM ENDF/B-V, MAT-1305,
APPLICABLE ENERGY RANGE THERMAL TØ 200 KEV,
LØG-LØG INTERPØLATIØN,

CRØSS SECTIØN 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	2,7164E-01	3,00E 01	2,2520E-01	4,00E 01	1,9802E-01
5,00E 01	1,7988E-01	6,00E 01	1,6680E-01	7,00E 01	1,5690E-01
8,00E 01	1,4919E-01	9,00E 01	1,4307E-01	1,00E 02	1,3819E-01
1,20E 02	1,3121E-01	1,40E 02	1,2707E-01	1,60E 02	1,2506E-01
1,80E 02	1,2458E-01	2,00E 02	1,2495E-01		

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
1,0E-08 TØ 4,0E 01(KEV)	2,2
4,0E 01 TØ 1,0E 02	2,0
1,0E 02 TØ 1,8E 02	1,2
1,8E 02 TØ 2,0E 02	1,6

CØRRELATIØN MATRIX

+1,000			
+0,924	+1,000		
+0,055	+0,323	+1,000	
+0,316	+0,302	+0,627	+1.000

B-10(N,ALPHA-1) CRØSS SECTIØNS

NUMERICAL VALUES FRØM ENDF/B-V,MAT-1305,
APPLICABLE ENERGY RANGE THERMAL TØ 200 KEV,
LØG-LØG INTERPØLATIØN

CRØSS SECTIØN 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	3,6717E 00	3,00E 01	3,1664E 00	4,00E 01	2,7524E 00
5,00E 01	2,4736E 00	6,00E 01	2,2697E 00	7,00E 01	2,1124E 00
8,00E 01	1,9859E 00	9,00E 01	1,8812E 00	1,00E 02	1,7922E 00
1,20E 02	1,6471E 00	1,40E 02	1,5307E 00	1,60E 02	1,4320E 00
1,80E 02	1,3442E 00	2,00E 02	1,2626E 00		

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
1,0E-08 TØ 4,0E 01(KEV)	0,3
4,0E 01 TØ 1,0E 02	0,7
1,0E 02 TØ 1,8E 02	0,8
1,8E 02 TØ 2,0E 02	1,2

CØRRELATIØN MATRIX

+1,000			
+0,981	+1,000		
+0,861	+0,928	+1,000	
+0,729	+0,810	+0,921	+1,000

NATURAL CARBØN, ELASTIC SCATTERING

NUMERICAL VALUES FRØM ENDF/B-V,MAT-1306,
APPLICABLE ENERGY RANGE 10**-5 EV TØ 2 MEV,
LINEAR-LINEAR INTERPØLATIØN,

CRØSS SECTIØN 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	.1075E 04	.2509E 01
.1075E 04	.2481E 01	.1100E 04	.2450E 01	.1125E 04	.2420E 01
.1150E 04	.2390E 01	.1175E 04	.2361E 01	.1200E 04	.2333E 01
.1225E 04	.2305E 01	.1250E 04	.2278E 01	.1275E 04	.2251E 01
.1300E 04	.2225E 01	.1325E 04	.2199E 01	.1350E 04	.2174E 01
.1375E 04	.2149E 01	.1400E 04	.2125E 01	.1425E 04	.2101E 01
.1450E 04	.2078E 01	.1475E 04	.2055E 01	.1500E 04	.2033E 01
.1525E 04	.2011E 01	.1550E 04	.1989E 01	.1553E 04	.1987E 01
.1575E 04	.1968E 01	.1600E 04	.1948E 01	.1625E 04	.1928E 01
.1650E 04	.1908E 01	.1675E 04	.1889E 01	.1700E 04	.1870E 01
.1725E 04	.1851E 01	.1750E 04	.1833E 01	.1775E 04	.1815E 01
.1800E 04	.1798E 01	.1825E 04	.1781E 01	.1850E 04	.1764E 01
.1875E 04	.1748E 01	.1900E 04	.1732E 01	.1925E 04	.1716E 01
.1950E 04	.1701E 01	.1975E 04	.1685E 01	.2000E 04	.1670E 01
.2025E 04	.1659E 01	.2050E 04	.1685E 01	.2052E 04	.1695E 01
.2053E 04	.1702E 01	.2054E 04	.1709E 01	.2056E 04	.1728E 01
.2058E 04	.1754E 01	.2060E 04	.1792E 01	.2061E 04	.1816E 01
.2062E 04	.1847E 01	.2063E 04	.1884E 01	.2064E 04	.1929E 01
.2065E 04	.1987E 01	.2066E 04	.2059E 01	.2067E 04	.2152E 01
.2068E 04	.2274E 01	.2069E 04	.2433E 01	.2070E 04	.2645E 01
.2071E 04	.2930E 01	.2072E 04	.3312E 01	.2073E 04	.3818E 01
.2074E 04	.4451E 01	.2075E 04	.5156E 01	.2076E 04	.5766E 01
.2077E 04	.6043E 01	.2078E 04	.5872E 01	.2079E 04	.5373E 01

.2080E 04	.4765E 01	.2081E 04	.4199E 01	.2082E 04	.3728E 01
.2083E 04	.3356E 01	.2084E 04	.3066E 01	.2085E 04	.2840E 01
.2086E 04	.2663E 01	.2087E 04	.2522E 01	.2088E 04	.2408E 01
.2089E 04	.2317E 01	.2090E 04	.2241E 01	.2091E 04	.2178E 01
.2092E 04	.2124E 01	.2093E 04	.2079E 01	.2094E 04	.2041E 01
.2095E 04	.2007E 01	.2096E 04	.1976E 01	.2097E 04	.1953E 01
.2098E 04	.1930E 01	.2099E 04	.1910E 01	.2100E 04	.1893E 01
.2102E 04	.1862E 01	.2104E 04	.1838E 01	.2106E 04	.1817E 01
.2108E 04	.1800E 01	.2110E 04	.1785E 01	.2112E 04	.1772E 01
.2114E 04	.1761E 01	.2116E 04	.1751E 01	.2118E 04	.1742E 01
.2120E 04	.1735E 01	.2140E 04	.1686E 01	.2160E 04	.1661E 01
.2180E 04	.1644E 01	.2200E 04	.1632E 01	.2220E 04	.1622E 01
.2240E 04	.1614E 01	.2260E 04	.1606E 01	.2280E 04	.1600E 01
.2300E 04	.1595E 01	.2320E 04	.1591E 01	.2340E 04	.1588E 01
.2360E 04	.1585E 01	.2380E 04	.1584E 01	.2400E 04	.1583E 01
.2420E 04	.1583E 01	.2440E 04	.1584E 01	.2460E 04	.1587E 01
.2480E 04	.1590E 01	.2500E 04	.1594E 01	.2520E 04	.1600E 01
.2540E 04	.1608E 01	.2553E 04	.1613E 01	.2560E 04	.1616E 01
.2580E 04	.1627E 01	.2600E 04	.1639E 01	.2620E 04	.1654E 01
.2640E 04	.1671E 01	.2660E 04	.1690E 01	.2680E 04	.1713E 01
.2700E 04	.1740E 01	.2720E 04	.1770E 01	.2740E 04	.1806E 01
.2760E 04	.1848E 01	.2780E 04	.1898E 01	.2785E 04	.1912E 01
.2790E 04	.1927E 01	.2795E 04	.1943E 01	.2800E 04	.1961E 01
.2802E 04	.1969E 01	.2804E 04	.1979E 01	.2806E 04	.1990E 01
.2808E 04	.2007E 01	.2810E 04	.2039E 01	.2811E 04	.2072E 01
.2812E 04	.2140E 01	.2813E 04	.2326E 01	.2814E 04	.3160E 01
.2815E 04	.5071E 01	.2816E 04	.2776E 01	.2817E 04	.2289E 01
.2818E 04	.2159E 01	.2819E 04	.2109E 01	.2820E 04	.2086E 01
.2822E 04	.2070E 01	.2824E 04	.2067E 01	.2826E 04	.2070E 01
.2828E 04	.2076E 01	.2830E 04	.2082E 01	.2835E 04	.2103E 01
.2840E 04	.2126E 01	.2845E 04	.2152E 01	.2850E 04	.2180E 01
.2855E 04	.2210E 01	.2860E 04	.2242E 01	.2865E 04	.2277E 01
.2870E 04	.2315E 01	.2875E 04	.2355E 01	.2880E 04	.2399E 01
.2885E 04	.2447E 01	.2890E 04	.2499E 01	.2895E 04	.2555E 01
.2900E 04	.2616E 01	.2905E 04	.2682E 01	.2910E 04	.2753E 01
.2915E 04	.2830E 01	.2920E 04	.2910E 01	.2924E 04	.2977E 01
.2928E 04	.3043E 01	.2932E 04	.3107E 01	.2936E 04	.3163E 01
.2940E 04	.3207E 01	.2944E 04	.3230E 01	.2948E 04	.3221E 01
.2952E 04	.3171E 01	.2956E 04	.3069E 01	.2960E 04	.2911E 01
.2964E 04	.2701E 01	.2968E 04	.2456E 01	.2972E 04	.2196E 01
.2976E 04	.1946E 01	.2980E 04	.1723E 01	.2984E 04	.1539E 01
.2988E 04	.1396E 01	.2992E 04	.1291E 01	.2996E 04	.1218E 01
.3000E 04	.1170E 01	.3010E 04	.1129E 01	.3020E 04	.1150E 01
.3030E 04	.1198E 01	.3040E 04	.1255E 01	.3050E 04	.1314E 01
.3053E 04	.1332E 01	.3060E 04	.1372E 01	.3080E 04	.1482E 01
.3100E 04	.1583E 01	.3120E 04	.1674E 01	.3140E 04	.1760E 01
.3160E 04	.1840E 01	.3180E 04	.1917E 01	.3200E 04	.1990E 01
.3220E 04	.2061E 01	.3240E 04	.2128E 01	.3260E 04	.2193E 01
.3280E 04	.2255E 01	.3300E 04	.2313E 01	.3320E 04	.2368E 01
.3340E 04	.2418E 01	.3360E 04	.2464E 01	.3380E 04	.2506E 01
.3400E 04	.2542E 01	.3420E 04	.2573E 01	.3440E 04	.2598E 01
.3460E 04	.2616E 01	.3480E 04	.2632E 01	.3500E 04	.2641E 01
.3520E 04	.2644E 01	.3540E 04	.2642E 01	.3553E 04	.2638E 01
.3560E 04	.2635E 01	.3580E 04	.2624E 01	.3600E 04	.2608E 01
.3620E 04	.2588E 01	.3640E 04	.2565E 01	.3660E 04	.2539E 01
.3680E 04	.2510E 01	.3700E 04	.2479E 01	.3720E 04	.2446E 01

.3740E 04	.2412E 01	.3760E 04	.2376E 01	.3780E 04	.2339E 01
.3800E 04	.2302E 01	.3820E 04	.2264E 01	.3840E 04	.2226E 01
.3860E 04	.2187E 01	.3880E 04	.2149E 01	.3900E 04	.2111E 01
.3920E 04	.2074E 01	.3940E 04	.2037E 01	.3960E 04	.2001E 01
.3980E 04	.1966E 01	.4000E 04	.1932E 01	.4010E 04	.1916E 01
.4020E 04	.1900E 01	.4030E 04	.1885E 01	.4040E 04	.1871E 01
.4050E 04	.1858E 01	.4053E 04	.1854E 01	.4060E 04	.1846E 01
.4070E 04	.1835E 01	.4080E 04	.1825E 01	.4090E 04	.1818E 01
.4100E 04	.1813E 01	.4110E 04	.1810E 01	.4120E 04	.1810E 01
.4130E 04	.1814E 01	.4140E 04	.1823E 01	.4150E 04	.1837E 01
.4160E 04	.1857E 01	.4170E 04	.1884E 01	.4180E 04	.1917E 01
.4190E 04	.1958E 01	.4200E 04	.2004E 01	.4210E 04	.2055E 01
.4220E 04	.2107E 01	.4230E 04	.2156E 01	.4240E 04	.2199E 01
.4250E 04	.2232E 01	.4260E 04	.2253E 01	.4270E 04	.2261E 01
.4280E 04	.2257E 01	.4290E 04	.2242E 01	.4300E 04	.2219E 01
.4310E 04	.2191E 01	.4320E 04	.2158E 01	.4330E 04	.2124E 01
.4340E 04	.2089E 01	.4350E 04	.2053E 01	.4360E 04	.2019E 01
.4370E 04	.1985E 01	.4380E 04	.1953E 01	.4390E 04	.1923E 01
.4400E 04	.1893E 01	.4420E 04	.1839E 01	.4440E 04	.1790E 01
.4460E 04	.1745E 01	.4480E 04	.1705E 01	.4500E 04	.1668E 01

UNCERTAINTIES

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

CØRRELATIØN MATRIX
(IN PERCENT)

100				
38	100			
33	33	100		
33	33	71	100	
33	33	71	71	100

```
 33  33  29  29  57 100
 33  33  29  29  29  71 100
 33  33  29  29  29  71  71 100
 33  33  29  29  29  29  29  29 100
 33  33  29  29  29  29  29  29  71 100
 33  33  29  29  29  29  29  29  71  71 100
 33  33  29  29  29  29  29  29  29  29  57 100
 33  33  29  29  29  29  29  29  29  29  29  71 100
 33  33  29  29  29  29  29  29  29  29  29  71  71 100
 29  29  25  25  25  25  25  25  25  25  25  25  25  25 100
 29  29  25  25  25  25  25  25  25  25  25  25  25  25  77 100
 29  29  25  25  25  25  25  25  25  25  25  25  25  25  77  77 100
 29  29  25  25  25  25  25  25  25  25  25  25  25  25  22  22  67 100
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CENTER-ØF-MASS LEGENDRE CØEF,

FØRM---

DXSEC=(XSEC/4PI)*SUM((2L+1)*A(L)*P(L))

TABLE GIVES---

ENERGY AND NUMBER ØF CØEF,(N)

FØLLØWED BY CØEF, A(1) TØ A(N), ASSUMING A(0)=1,

```
 E(KEV)= ,1000E 01     NØ, CØEF,=  1
,1401E-03
 E(KEV)= ,5000E 01     NØ, CØEF,=  1
,6982E-03
 E(KEV)= ,1000E 02     NØ, CØEF,=  1
,1391E-02
 E(KEV)= ,5000E 02     NØ, CØEF,=  2
,6728E-02 ,7499E-04
 E(KEV)= ,1000E 03     NØ, CØEF,=  2
,1292E-01 ,2793E-03
 E(KEV)= ,2000E 03     NØ, CØEF,=  2
,2388E-01 ,9736E-03
 E(KEV)= ,3000E 03     NØ, CØEF,=  3
,3316E-01 ,1917E-02 ,6338E-04
 E(KEV)= ,4000E 03     NØ, CØEF,=  3
,4099E-01 ,2995E-02 ,1285E-03
 E(KEV)= ,5000E 03     NØ, CØEF,=  3
,4753E-01 ,4130E-02 ,2241E-03
 E(KEV)= ,6000E 03     NØ, CØEF,=  3
,5292E-01 ,5271E-02 ,3492E-03
 E(KEV)= ,7000E 03     NØ, CØEF,=  4
,5725E-01 ,6392E-02 ,4997E-03-,5711E-04
 E(KEV)= ,8000E 03     NØ, CØEF,=  4
,6062E-01 ,7483E-02 ,6684E-03-,1026E-03
 E(KEV)= ,9000E 03     NØ, CØEF,=  4
,6306E-01 ,8550E-02 ,8446E-03-,1721E-03
 E(KEV)= ,1000E 04     NØ, CØEF,=  4
,6464E-01 ,9614E-02 ,1013E-02-,2737E-03
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 E(KEV)= ,1100E 04      NØ, CØEF,=  4
,6535E-01 ,1071E-01 ,1156E-02-,4167E-03
 E(KEV)= ,1200E 04      NØ, CØEF,=  4
,6522E-01 ,1189E-01 ,1248E-02-,6122E-03
 E(KEV)= ,1300E 04      NØ, CØEF,=  4
,6422E-01 ,1321E-01 ,1256E-02-,8722E-03
 E(KEV)= ,1400E 04      NØ, CØEF,=  5
,6231E-01 ,1477E-01 ,1139E-02-,1209E-02 ,6183E-04
 E(KEV)= ,1500E 04      NØ, CØEF,=  5
,5945E-01 ,1668E-01 ,8418E-03-,1634E-02 ,8928E-04
 E(KEV)= ,1600E 04      NØ, CØEF,=  5
,5553E-01 ,1906E-01 ,2826E-03-,2154E-02 ,1262E-03
 E(KEV)= ,1700E 04      NØ, CØEF,=  5
,5038E-01 ,2208E-01-,6674E-03-,2753E-02 ,1748E-03
 E(KEV)= ,1800E 04      NØ, CØEF,=  5
,4370E-01 ,2590E-01-,2261E-02-,3358E-02 ,2367E-03
 E(KEV)= ,1850E 04      NØ, CØEF,=  5
,3956E-01 ,2814E-01-,3475E-02-,3583E-02 ,2725E-03
 E(KEV)= ,1900E 04      NØ, CØEF,=  5
,3459E-01 ,3061E-01-,5202E-02-,3630E-02 ,3100E-03
 E(KEV)= ,1925E 04      NØ, CØEF,=  5
,3162E-01 ,3192E-01-,6391E-02-,3505E-02 ,3282E-03
 E(KEV)= ,1950E 04      NØ, CØEF,=  5
,2815E-01 ,3329E-01-,7950E-02-,3184E-02 ,3445E-03
 E(KEV)= ,1960E 04      NØ, CØEF,=  5
,2655E-01 ,3386E-01-,8727E-02-,2967E-02 ,3500E-03
 E(KEV)= ,1970E 04      NØ, CØEF,=  5
,2479E-01 ,3445E-01-,9625E-02-,2675E-02 ,3545E-03
 E(KEV)= ,1980E 04      NØ, CØEF,=  5
,2282E-01 ,3508E-01-,1068E-01-,2281E-02 ,3576E-03
 E(KEV)= ,1990E 04      NØ, CØEF,=  5
,2057E-01 ,3576E-01-,1195E-01-,1746E-02 ,3588E-03
 E(KEV)= ,2000E 04      NØ, CØEF,=  5
,1795E-01 ,3654E-01-,1351E-01-,1006E-02 ,3570E-03
 E(KEV)= ,2020E 04      NØ, CØEF,=  5
,1080E-01 ,3894E-01-,1806E-01 ,1571E-02 ,3379E-03
 E(KEV)= ,2040E 04      NØ, CØEF,=  5
,2063E-02 ,4600E-01-,2688E-01 ,7934E-02 ,2678E-03
 E(KEV)= ,2060E 04      NØ, CØEF,=  4
,3518E-01 ,9691E-01-,4969E-01 ,3288E-01
 E(KEV)= ,2070E 04      NØ, CØEF,=  5
,6030E-01 ,2756E 00-,6113E-01 ,7791E-01-,3519E-03
 E(KEV)= ,2080E 04      NØ, CØEF,=  5
,5407E-01 ,4256E 00 ,3582E-01 ,4467E-01 ,5298E-03
 E(KEV)= ,2090E 04      NØ, CØEF,=  5
,7744E-01 ,1978E 00 ,4476E-01-,1026E-01 ,9477E-03
 E(KEV)= ,2100E 04      NØ, CØEF,=  5
,6315E-01 ,1232E 00 ,3079E-01-,1741E-01 ,9142E-03
 E(KEV)= ,2110E 04      NØ, CØEF,=  5
,5284E-01 ,9624E-01 ,2203E-01-,1790E-01 ,8753E-03
 E(KEV)= ,2120E 04      NØ, CØEF,=  5
,4583E-01 ,8401E-01 ,1651E-01-,1744E-01 ,8529E-03
 E(KEV)= ,2130E 04      NØ, CØEF,=  5
,4073E-01 ,7768E-01 ,1276E-01-,1691E-01 ,8426E-03
 E(KEV)= ,2140E 04      NØ, CØEF,=  5
,3677E-01 ,7418E-01 ,1002E-01-,1648E-01 ,8402E-03
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 E(KEV)= ,2150E 04      NØ, CØEF,=  5
,3352E-01 ,7224E-01 ,7924E-02-,1616E-01 ,8432E-03
 E(KEV)= ,2300E 04      NØ, CØEF,=  5
,6207E-02 ,8470E-01-,4603E-02-,1697E-01 ,1110E-02
 E(KEV)= ,2450E 04      NØ, CØEF,=  5
,1573E-01 ,1180E 00-,1183E-01-,2089E-01 ,1542E-02
 E(KEV)= ,2600E 04      NØ, CØEF,=  5
,3656E-01 ,1685E 00-,1863E-01-,2551E-01 ,2041E-02
 E(KEV)= ,2750E 04      NØ, CØEF,=  5
,4791E-01 ,2416E 00-,2207E-01-,2924E-01 ,2103E-02
 E(KEV)= ,2780E 04      NØ, CØEF,=  6
,4374E-01 ,2591E 00-,2020E-01-,3010E-01 ,1553E-02 ,6195E-04
 E(KEV)= ,2800E 04      NØ, CØEF,=  6
,2817E-01 ,2685E 00-,1353E-01-,3224E-01-,2144E-03 ,2082E-03
 E(KEV)= ,2805E 04      NØ, CØEF,=  6
,1393E-01 ,2683E 00-,7164E-02-,3402E-01-,1776E-02 ,3361E-03
 E(KEV)= ,2810E 04      NØ, CØEF,=  6
,3059E-01 ,2605E 00 ,1474E-01-,3815E-01-,6326E-02 ,7102E-03
 E(KEV)= ,2815E 04      NØ, CØEF,=  6
,1010E 00 ,2822E 00 ,1867E 00 ,6405E-01 ,1086E-01-,5477E-03
 E(KEV)= ,2820E 04      NØ, CØEF,=  6
,1161E 00 ,3100E 00-,4143E-01-,1114E-01 ,1161E-01-,7458E-03
 E(KEV)= ,2830E 04      NØ, CØEF,=  6
,7678E-01 ,3055E 00-,3155E-01-,2194E-01 ,5970E-02-,2935E-03
 E(KEV)= ,2840E 04      NØ, CØEF,=  6
,6629E-01 ,3109E 00-,2785E-01-,2349E-01 ,4736E-02-,1950E-03
 E(KEV)= ,2880E 04      NØ, CØEF,=  6
,4665E-01 ,3446E 00-,1940E-01-,2141E-01 ,3341E-02-,9901E-04
 E(KEV)= ,2900E 04      NØ, CØEF,=  6
,3385E-01 ,3644E 00-,1328E-01-,1772E-01 ,2856E-02-,8199E-04
 E(KEV)= ,2920E 04      NØ, CØEF,=  6
,1298E-01 ,3836E 00-,3016E-02-,1111E-01 ,2175E-02-,6937E-04
 E(KEV)= ,2940E 04      NØ, CØEF,=  6
,2403E-01 ,3919E 00 ,1578E-01 ,9419E-03 ,1039E-02-,6077E-04
 E(KEV)= ,2960E 04      NØ, CØEF,=  6
,8727E-01 ,3502E 00 ,4948E-01 ,2166E-01-,8155E-03-,6570E-04
 E(KEV)= ,2980E 04      NØ, CØEF,=  6
,1405E 00 ,1845E 00 ,8226E-01 ,3903E-01-,2168E-02-,1101E-03
 E(KEV)= ,3000E 04      NØ, CØEF,=  4
,7872E-01 ,4030E-01 ,5622E-01 ,1845E-01
 E(KEV)= ,3020E 04      NØ, CØEF,=  6
,4886E-02 ,6621E-01 ,1352E-01-,9095E-02 ,2606E-02-,1659E-03
 E(KEV)= ,3040E 04      NØ, CØEF,=  6
,4590E-01 ,1296E 00-,8942E-02-,2254E-01 ,3838E-02-,1537E-03
 E(KEV)= ,3080E 04      NØ, CØEF,=  6
,7010E-01 ,2193E 00-,2349E-01-,3037E-01 ,4577E-02-,1340E-03
 E(KEV)= ,3120E 04      NØ, CØEF,=  6
,7230E-01 ,2716E 00-,2572E-01-,3095E-01 ,4688E-02-,1233E-03
 E(KEV)= ,3200E 04      NØ, CØEF,=  6
,6205E-01 ,3310E 00-,2134E-01-,2723E-01 ,4487E-02-,1138E-03
 E(KEV)= ,3300E 04      NØ, CØEF,=  6
,4078E-01 ,3682E 00-,1015E-01-,1950E-01 ,3892E-02-,1115E-03
 E(KEV)= ,3400E 04      NØ, CØEF,=  6
,1657E-01 ,3823E 00 ,3931E-02-,1027E-01 ,3029E-02-,1163E-03
 E(KEV)= ,3500E 04      NØ, CØEF,=  6
,6739E-02 ,3803E 00 ,1911E-01-,5875E-03 ,1975E-02-,1286E-03
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 E(KEV)= ,3600E 04      NØ, CØEF,=  6
,2633E-01 ,3674E 00 ,3411E-01 ,8834E-02 ,8050E-03-,1495E-03
 E(KEV)= ,3700E 04      NØ, CØEF,=  6
,4017E-01 ,3475E 00 ,4802E-01 ,1759E-01-,4246E-03-,1803E-03
 E(KEV)= ,3800E 04      NØ, CØEF,=  6
,4670E-01 ,3233E 00 ,6022E-01 ,2559E-01-,1681E-02-,2222E-03
 E(KEV)= ,3900E 04      NØ, CØEF,=  6
,4448E-01 ,2958E 00 ,7001E-01 ,3297E-01-,2955E-02-,2766E-03
 E(KEV)= ,4000E 04      NØ, CØEF,=  6
,3361E-01 ,2627E 00 ,7576E-01 ,4010E-01-,4239E-02-,3441E-03
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AU-197 NEUTRØN CApTURE

NUMERICAL VALUES FRØM ENDF/B-V, MAT-6379,
APPLICABLE ENERGY RANGE 0,2 TØ 3,5 MEV,
LINEAR-LINEAR INTERPØLATIØN,

CRØSS SECTIØN VALUES

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

THERMAL VALUE(0,0253 EV)= 98,71+-0,3 B,

UNCERTAINTIES

ENERGY RANGE	UNCERTAINTY(PERCENT)
2,0E 02 TØ 5,0E 02(KEV)	6,1
5,0E 02 TØ 6,0E 02	4,1
6,0E 02 TØ 1,0E 03	4,1
1,0E 03 TØ 2,5E 03	20,0
2,5E 03 TØ 3,5E 03	20,0

CØRRELATIØN MATRIX

+1,000				
+0,040	+1,000			
+0,040	+0,060	+1,000		
+0,000	+0,000	+0,190	+1,000	
+0,000	+0,000	+0,000	+0,960	+1,000

U-235 FISSIØN CRØSS SECTIØNS

NUMERICAL VALUES FRØM ENDF/B-V, MAT-1395,
APPLICABLE ENERGY RANGE 0,1-20,0 MEV,
LINEAR-LINEAR INTERPØLATIØN,

CRØSS SECTIØN VALUES

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

UNCERTAINTIES

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

CØRRELATIØN 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

U-238 FISSIØN CRØSS SECTIØNS

NUMERICAL VALUES FRØM ENDF/B-V, MAT-6398.
APPLICABLE ENERGY RANGE THRESHØLD TØ 20.0 MEV.
LINEAR-LINEAR INTERPØLATIØN.

CRØSS SECTIØN 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

AL-27 (N,ALPHA) ACTIVATIØN CRØSS SECTIØNS,

NUMERICAL VALUES FRØM S,TAGESEN AND H,VØNACH,TØ BE PUBLISHED,
LINEAR-LINEAR INTERPØLATIØN,

GRØUP-ENERGY (MEV) TØ (MEV)	XSEC (MB)	ERRØR (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

COVARIANCE 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	23	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

NEUTRØN RESØNANCES TØ BE USED AS ENERGY STANDARDS

ISØTØPE	E(EV)	DE(EV)
IR-191	6,55100E-01	+- 1,4E-03
U -238	6,67200E 00	
U -238	1,02360E 01	
U -238	2,06640E 01	
U -238	3,66710E 01	
U -238	6,60150E 01	
U -238	8,07290E 01	
U -238	1,45617E 02	+- 3,3E-02
U -238	1,89640E 02	
U -238	3,11180E 02	+-2,5E-01
U -238	3,97580E 02	
U -238	4,63180E 02	+- 2,4E-01
U -238	6,19950E 02	
U -238	7,98220E 02	+- 2,0E-01
U -238	9,05030E 02	
U -238	1,41988E 03	+- 3,2E-01
U -238	1,47380E 03	
U -238	2,43947E 03	+- 5,0E-01
U -238	2,67220E 03	
PB-206	3,36000E 03	+- 1,0E-01
U -238	3,45810E 03	
U -238	4,51200E 03	
U -238	5,65060E 03	
AL- 27	5,90300E 03	+- 8,0E 00
S - 32	3,03780E 04	+- 6,0E 00
NA- 23	5,31910E 04	+- 2,7E 01
SI- 28	6,77300E 04	+- 2,0E 01
PB-206	7,11910E 04	+- 1,8E 01
FE- 56	9,01340E 04	+- 1,6E 01
S - 32	9,75120E 04	+- 2,8E 01
S - 32	1,12186E 05	+- 3,3E 01
FE- 56	2,66347E 05	+- 5,3E 01
S - 32	4,12300E 05	
S - 32	8,18700E 05	
Ø - 16	1,65100E 06	+- 2,0E 03
C - 12	2,07800E 06	
C - 12	2,81800E 06	+- 4,0E 03
Ø - 16	3,21110E 06	+- 1,5E 03
C - 12	6,29300E 06	+- 5,0E 03
C - 12	1,21000E 07	+- 1,0E 05

REFERENCE, G,D, JAMES, NBS-493 319(1977), SEE SECTIØN-B,

IMPØRTANT ACTINIDE HALF-LIVES

NUCLIDE	DECAY MØDE	HALF-LIFE	ERRØR(PERCENT)
U-233	ALPHA	1.952E 05 YR	0.126
	SPØN. FIS.	1.200E 17 YR	25.0
U-234	ALPHA	2.446E 05 YR	0.236
	SPØN. FIS.	2.000E 16 YR	50.0
U-235	ALPHA	7.038E 08 YR	0.099
	SPØN. FIS.	3.500E 17 YR	25.714
U-238	ALPHA	4.468E 09 YR	0.090
	SPØN. FIS.	8.190E 15 YR	1.099
NP-237	ALPHA	2.140E 06 YR	0.467
	SPØN. FIS.	1.000E 18 YR	----
PU-239	ALPHA	2.411E 04 YR	0.124
	SPØN. FIS.	5.500E 15 YR	9.091
PU-240	ALPHA	6.550E 03 YR	0.305
	SPØN. FIS.	1.200E 11 YR	8.333
PU-241	ALPHA	6.000E 05 YR	4.167
	BETA -	1.470E 01 YR	2.721
PU-242	ALPHA	3.760E 05 YR	0.532
	SPØN. FIS.	6.840E 10 YR	1.170

REFERENCE, INDC(NDS)-121/NE (1980).

SECTION B: NARRATIVE SUMMARIES

This Section provides concise and contemporary 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 numerical tabulations of Section A, above, and set forth other important nuclear standards not amenable to straightforward numerical tabulation.

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

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

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

A. Status

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

B. Accuracy of the Total Cross Section

A more detailed tabulation of the recommended Hopkins and Breit calculations is given in the Los Alamos report LA-4574. The estimated standard deviation in the total cross section is ±1% and is in agreement with the measurement of Davis and Barschall (Phys. Rev. C3, 1978(1971)) between 1.5 MeV and 27.5 MeV. A recent evaluation of the effective range parameters by Lomon and Wilson (Phys.

Rev., C9, 1329(1974)) gives total cross sections which do not differ significantly from the Hopkins and Breit values in the MeV region. A recent measurement of σ_T at 132 eV by Dilg (Phys. Rev., C11, 103(1975)) results in effective range parameters which disagree significantly with the evaluation of Lomon and Wilson, but a measurement at 24 keV by Fujita et al. (NEANDC(J)-42L) agrees with the cross section based on the evaluated parameters. These disagreements of a fraction of a percent in the low energy total cross section are unlikely to materially affect the recommended values in the region of practical interest.

C. Accuracy of the Differential Scattering Cross Section

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

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

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

Recent n-p polarization data at 21.1 MeV by Morris et al. (Phys. Rev., C9, 924(1974)) and by Jones and Brooks (Nucl. Phys., A222, 79(1974)) have been included with the Wisconsin data of Rothenberg, Burrows and Masterson in a phase shift analysis of nucleon-nucleon scattering data in the energy range 20-30 MeV by Bohannon et al. (Phys. Rev., C13, 1816(1976)). The relative differential scattering data at 25.8 MeV by Montgomery et al. (Phys. Rev., C16, 499(1977)) over a (C of M) angular range 20° to almost 180° has also been included in a phase shift analysis by Arndt et al. (Phys. Rev., C15, 1002 (1977)). In this work both a single energy analysis of data between 20 and 30 MeV has been carried out and an energy dependent analysis of all data between 0 and 425 MeV. The phase parameters obtained from the two recent analyses by Bohannon et al. and Arndt et al. at 25 MeV are in agreement but the large

uncertainties on the values of $\delta(^1P_1)$ of $-5.18 \pm 0.47°$ (Bohannon) and $-4.49 \pm 0.94°$ (Arndt) indicate that more differential-scattering data are needed over a wide angular range. These recent values of $\delta(^1P_1)$ are also in reasonable agreement with those of $-4.90 \pm 0.48°$ and $-4.61 \pm 0.08°$ obtained from the Yale and Livermore (constrained) analyses, respectively, on which the Hopkins and Breit analysis is based.

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

D. New Measurements

The relative cross section, $\sigma(\theta_c)/\sigma(\pi/2)$ from the angular distribution measurement at 27.3 MeV of Cookson et al. (Nucl. Phys. A299, 365(1978)) 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 (Phys. Rev. 10C, 19(1974)) based on phase calculated from the Bryan-Gersten one-boson-exchange model. The data favor 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. (Symp. on Neutron Cross Sections from 10 to 50 MeV, Brookhaven National Laboaratory, May 1980). Their data agree with the ENDF/B-V evaluation (up to 20 MeV) to within 1% and there is general agreement at higher energies with the data of Brady et al. (25 to 60 MeV; Phys. Rev. Lett., 25, 1628(1970), Grace and Sowerby (20 to 80 MeV; Nucl. Phys. 83, 199(1966)) Measday and Palmieri (90 to 150 MeV; Nucl. Phys. 85, 142(1966)). The semi-empirical fit of Gammel up to 40 MeV is also in good agreement with their total cross section.

The n-p analyzing power data of Tornow et al. have recently been discussed in detail (N.P. A340, 34(1980)). Their data for the analyzing power at 90° c.m. 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 c.m. 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. (N,P, A282, 189(1977)). The analysis by Fischer et al. yields the larger spin-orbit interaction in the nucleon-nucleon F states which is necessary to fit the analyzing power data at the larger c.m. scattering angles.

E. Comments and Recommendations

Differential n-p scattering cross section data below 30 MeV are not sufficiently accurate to distinguish between the calculation of Hopkin's 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 analyzing power data of Tornow et al. in a new analysis of all nucleon-nucleon scattering observables in the energy range 14 to 35 MeV, which could be used to extend the evaluated H(n,n)H cross section up to 40 MeV in accordance with the recommendation of the INDC Standards Subcommittee.

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6/81

Editor's Comments:

Some relatively recent results[1] suggested that the ENDF/B-V neutron total cross sections are in error in the energy range 23-29 MeV.[2] Corrections to the measured values removed this discrepancy.

Measured neutron total cross sections have recently been reported by Larson.[3] The experimental results are consistent with the analysis of Arndt[4] as shown in Fig. 1.

Poenitz and Whalen[5] have measured neutron total cross sections at 0.5, 1.0 and 2.0 MeV to accuracies of 0.2%, 0.2% and 0.4%, 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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5/81

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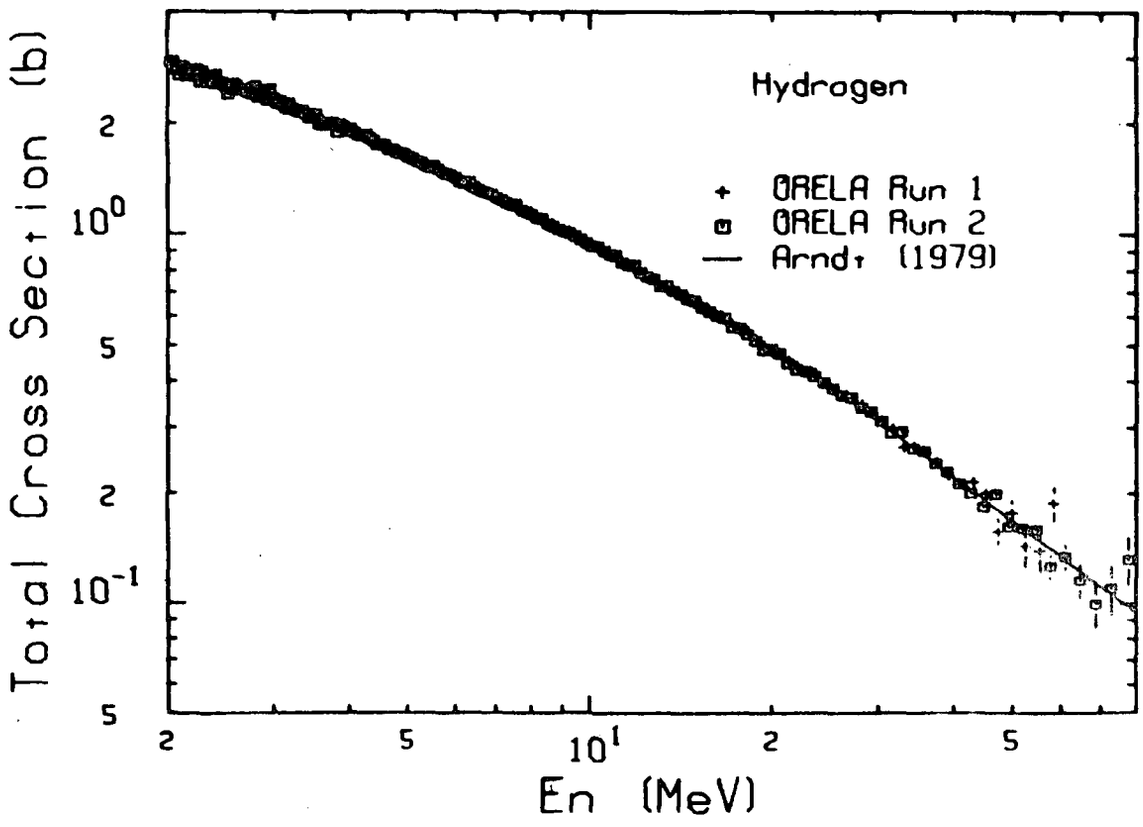

Fig. 1. Comparison of measured neutron total cross section of Larson[3] with the predictions of Arndt et al.[4]

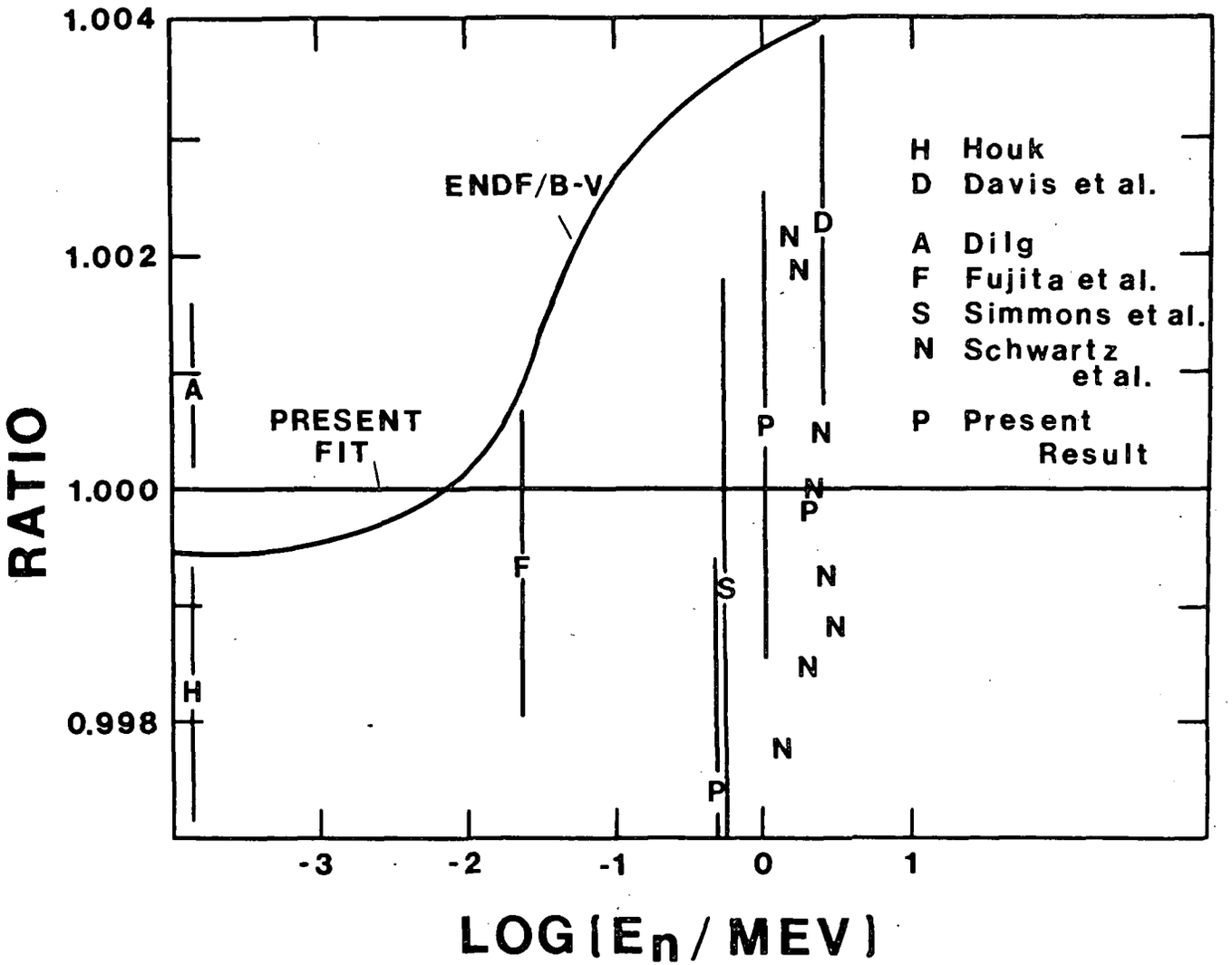

Fig. 2. Comparison of neutron total cross sections deduced by Poenitz and Whalen[7] with those given in ENDF/B-V.

B-II. THE $^{6}Li(n,t)^{4}He$ CROSS SECTION

A. Description

Because of its relatively high cross section and + Q-value and the convenience of counting the light triton and alpha products, this reaction is widely used as a standard. The recommended energy range for use as a standard is thermal -- 100 keV, a region in which the cross section begins to deviate substantially from 1/v behavior. However, applications in which the cross section is used as a standard at energies over the 240 keV resonance and up to a few MeV are not uncommon. The cross section is also of interest at energies up to several MeV 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.

B. Status

Measurements of the neutron cross sections for ^{6}Li 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 cross sections agree to the order of a few percent with each other 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 ^{6}Li (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 analyzing powers,[4] as well as the new measurements of the total cross section of Harvey[5] (ORNL) and of relative (n,t) cross sections of Lamaze[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 peak cross section of the total and (n,t) as predicted in the analysis agrees closely with the measurements of Harvey[5] and Lamaze,[6] without shifting either energy scale. The cross sections predicted at the peak, however, are ~2 and 5% higher, respectively, than these measurements indicate. At energies below 200 keV, the agreement of the calculated $\sigma_{n,t}$ cross section with Lamaze's relative data* is generally better than 2%, and the agreement of the calculated σ_{T} with Harvey's data is generally better than 1%, except for a region around 150 keV where the difference is ~5%. The predicted thermal value of the (n,t) cross section is in excellent agreement with the recommended value of 936 b.

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*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% in the low energy region.

Knitter[3] has reported measurements of σ_T between 80 keV and 3 MeV as well as an extension of his earlier ^{6}Li(n,n) angular distribution measurements down to 100 keV. Recent work by Smith[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. Knitter's (fitted) resolution-corrected value 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 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[6] data were replaced by the Renner[9] data.

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[13] has recently recalibrated his ^{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.

C. 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 Version V ENDF evaluation represent a considerable improvement in that situation, achieving generally good internal agreement and, perhaps more importantly, 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 ^{6}Li(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 version is close to that goal, they also point out discrepancies that should be resolved. Some of them are as follows.

1. Differences over the resonance between the $^{6}Li(n,t)$ measurements of Renner et al.[9] which appear to be supported by Macklin's recent flux determination,[13] and those of Lamaze et al.[6] at NBS.

2. 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 measurements[9] must be considered in conjunction with Harvey's measurement[5] of σ_T, since the target thickness in the former experiment was determined by the latter.

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.[1] Experiments are in progress at Uppsala[14] to measure $^{6}Li(n,\alpha)$ and $T(\alpha,^{6}Li)$ angular distributions in the vicinity of this anomaly.

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7/79
As given in Brookhaven National Lab. Report, BNL-300 (1979).

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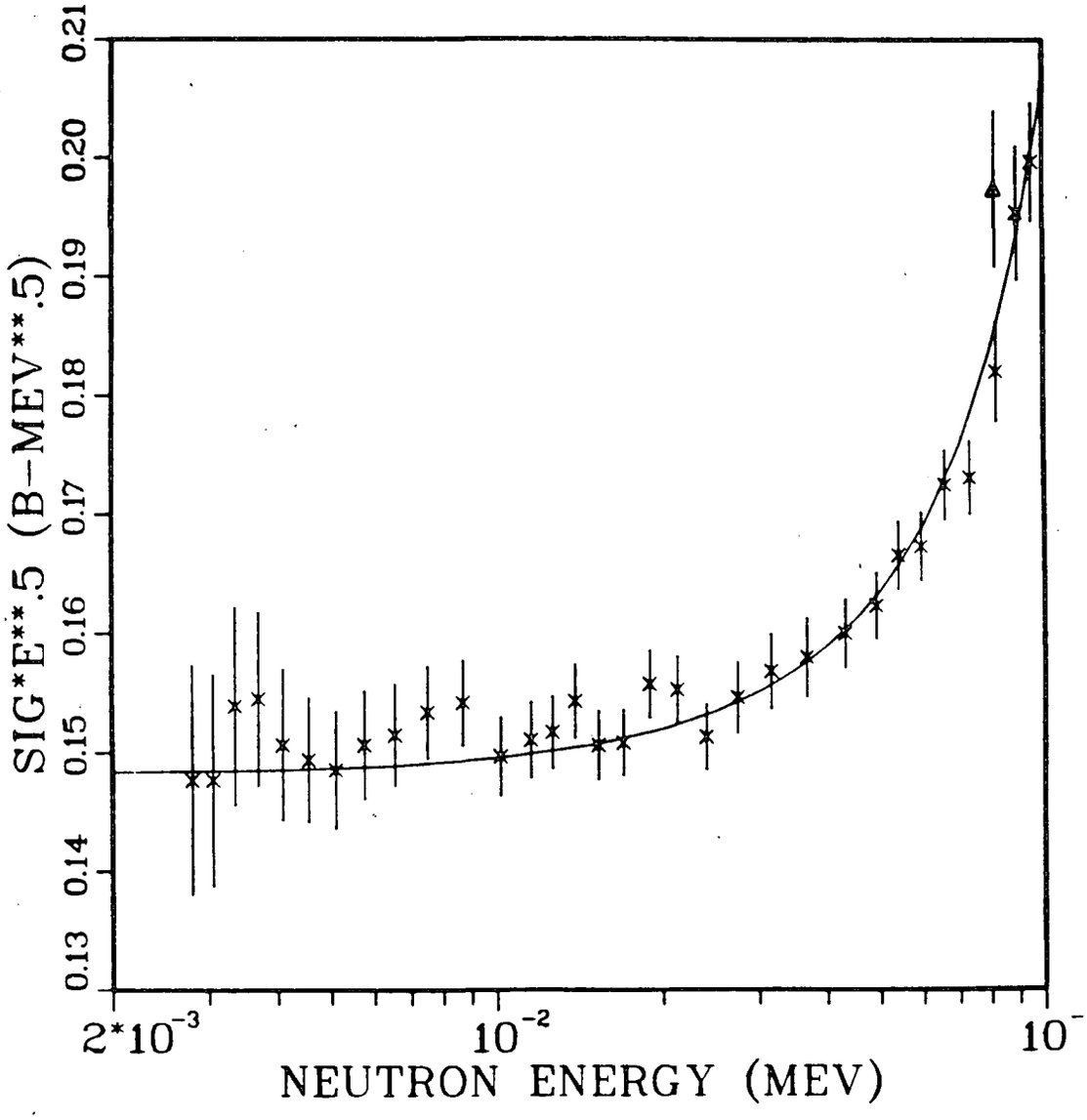

Fig. 1.
ENDF/B-V ^{6}Li(n,t) cross section (solid curve) compared with the measurements of Lamaze et al.[6] (x) and of Renner et al.[9] (Δ) at energies below 100 keV. The cross sections are scaled by $\sqrt{E}$ to remove the 1/v dependence at low energies.

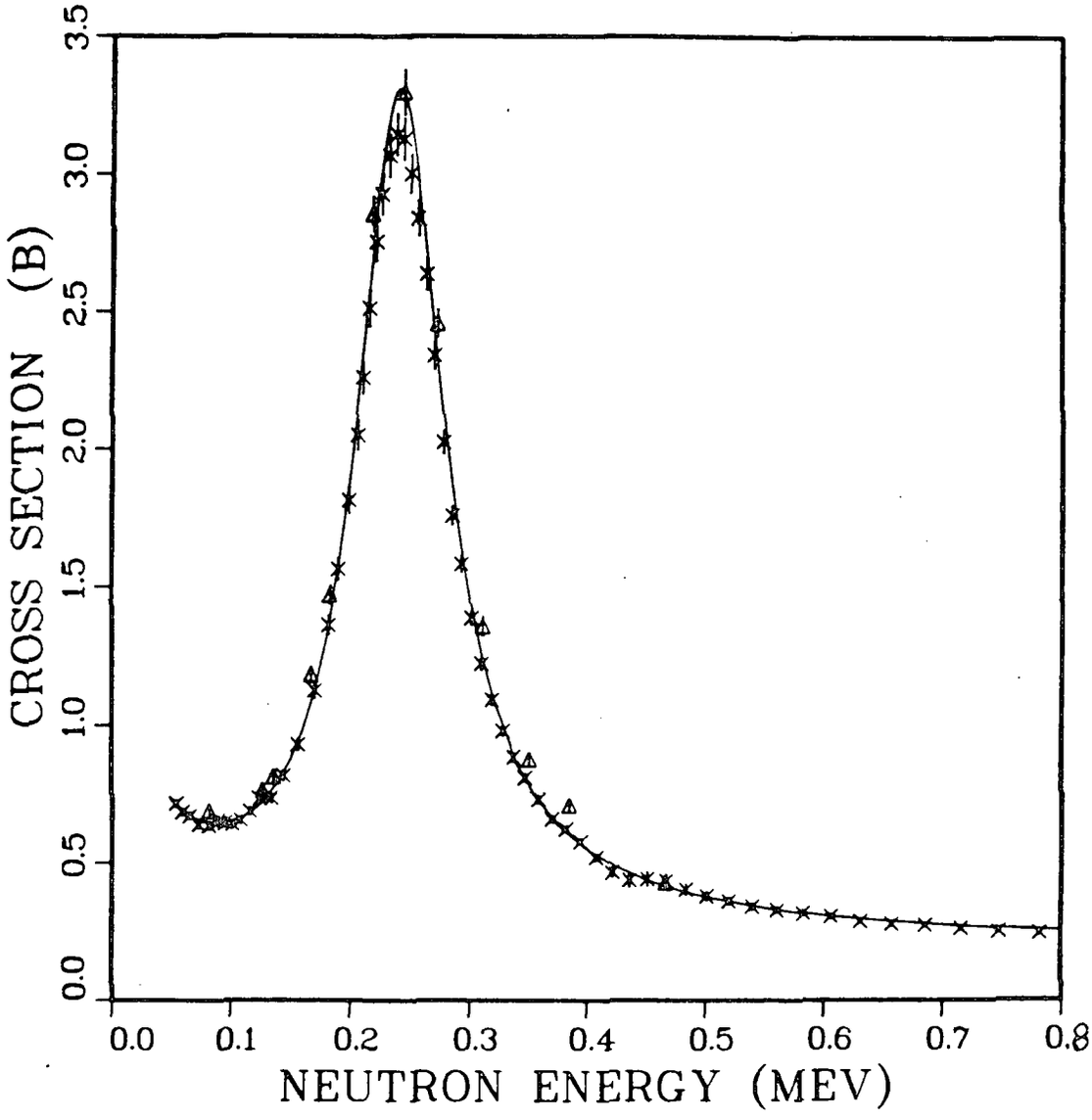

Fig. 2.
ENDF/B-V ^{6}Li(n,t) cross section (solid curve) compared with the measurements of Lamaze et al.[6] (x) and of Renner et al.[9] (Δ) at energies between 50 and 800 keV.

Editor's Comment:

The Committee commented on several aspects of this standard. It was noted that $^{10}B/^{6}Li$ 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 underway at Uppsala University corresponding to neutron energies of 0.2 to 3.5 MeV. W. Poenitz has initiated measurements designed to concurrently determine neutron total, elastic-scattering and n-alpha cross sections in the keV range. A relatively simple empirical expression has been developed at Obninsk that describes the $^{6}Li(n,t)$ cross section to 900 keV to average accuracies of 0.5%. Some concern was expressed for the apparent lack of correlation between standards (e.g. ^{6}Li, ^{10}B and ^{235}U) as expressed through the ENDF/B evaluation process. There was discussion of the reaction mechanism in the $n + {}^{6}Li$ process. A consistent problem is the postulated $l = 0$ resonance often employed in R-matrix interpretations in order to account for the low-energy cross-section behavior (e.g. the analysis involved in the ENDF/B-V evaluation). Such a resonance has not been directly observed in either ^{7}Li or the complimentary ^{7}Be system. An alternative deuteron-exchange mechanism has been suggested by Weigmann and Manakos (Z. Phys., A289 383(1979)). 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. (to be published) 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, particularly assuring unitarity.

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B-III. $^{10}B(n,\alpha)$ CROSS SECTIONS

A. Description and Usage

Natural boron or ^{10}B enriched samples are often used for neutron flux determination. A large variety of detectors is used, and the reaction underlying the detection systems is either $^{10}B(n,\alpha\gamma)^{7}Li$ or $^{10}B(n,\alpha)^{7}Li$, with α being α_0 or α_1. The α_0 refers to an α emission with α threshold energy of E_α = 1.7891 MeV, leaving the residual nucleus ^{7}Li in the ground state. The α_1 refers to an α emission with an energy of E_α = 1.4832 MeV, leaving the residual nucleus ^{7}Li in its first excited state which decays by prompt emission of a gamma ray of 478.5 keV.

B. Status

From thermal energy up to 10 keV the cross-sections $\sigma(n,\alpha_1)$ and $\sigma(n,\alpha)$ are known within 2%. From 10 keV to 1 MeV an accuracy of 2% is requested by eleven priority I requests in WRENDA 76-77.

The status of $\sigma(n,\alpha_1)$ and $\sigma(n,\alpha)$ data as well as $\sigma(n,n)$, σ_{tot}, branching ratio and $\sigma(n,\alpha)$ ratio of ^{10}B to ^{6}Li was reviewed and discussed at the International Symposium on Neutron Standards and Applications, held at the National Bureau for Standards in March 1977 (see NBS-425, pages 67-84). Since then the following measurements and/or evaluations were performed:

1. Molecular effects on $^{10}BF_3(n,\alpha)$ cross section by C. D. Bowman, J. W. Behrens, A. D. Carlson, J. Todd and R. Gwin; NEANDC (US)-205/U or BNL-NCS-26133 or DOE/NDC-15/U or INDC(USA)-81 U of April 1979 p. 155 and Comparison of ^{3}He and BF_3 cross section energy dependence by C. D. Bowman, J. W. Behrens and R. B. Schwartz same reference as above but page 157.

2. Best values for the cross-section of the neutron standard reaction $^{10}B(n,\alpha_1)^{7}Li$ in the range from 0.1 to 2.0 MeV by H. Liskien and E. Wattecamps, Nucl. Sci. and Eng., 68, 132 (1978).

3. The $^{10}B(n,\alpha\gamma)^{7}Li$ cross-section between 0.1 and 2.2 MeV by G. Viesti and H. Liskien, Annals of Nucl. Energy, 6, 13-18 (1978).

4. A measurement of the $^{10}B(n,\alpha\gamma)^{7}Li$ cross-section in the keV Energy Region by R. A. Schrack, G. P. Lamaze and O. A. Wasson, Nucl. Sci. and Eng., 68, 189-196 (1978).

5. The total neutron cross-section of ^{10}B between 90 and 420 keV by H. Beer and R. R. Spencer, Nucl. Sci. and Eng., 70, 98-101 (1979).

6. Neutron total cross-section measurements of ^{9}Be, $^{10,11}B$, and $^{12,13}C$ from 1 to 14 MeV using the $^{9}Be(d,n)^{10}B$ reaction as a "white" neutron source by G. F. Auchampaugh, S. Plattard and N. W. Hirr, Nucl. Sci. and Eng., 69, 30-38 (1979).

7. Angular distribution and branching ratio measurements at thermal, 2 keV and 24 keV by M. L. Stelts, R. E. Chrien, M. Goldhaber, M. Kenny and CM. Mc.Cullagh, Phy. Rev. C., 19, n° 4, 1159 (1979).

8. Differential elastic scattering cross sections of ^{10}B for neutrons of 4 to 8 MeV energy by H. D. Knox, R. M. White and R. O. Lane, Nucl. Sci. and Eng., 65, 65-90 (1978).

9. ENDF/B-version V is released, data and documentation are available.

Effects of atomic or molecular properties predict a difference between the (n,α) cross section for solid boron compared with a free molecule of $^{10}BF_3$. Time of flight measurements at NBS from 1 to 10^4eV demonstrate a cross section ratio for $^{10}BF_3(n,\alpha)$ to solid boron that is 0.980 ± 0.001 at 1 eV, steadily increasing with energy up to 1.000 ± 0.002 at 100 eV and remaining constant at higher energies. In the frame of these investigations the ratio of $^{10}BF_3(n,\alpha)$ to $^3He(n,p)$ was measured at 2 keV and at thermal, and it turned out to be 4.0 ± 0.5% higher at 2 keV than at thermal. It is claimed by the authors that 2% of this effect is due to a molecular effect whereas the remaining 2% is due to non 1/v nuclear effects in either $^{10}BF_3$, ^3He or both.

The paper of H. Liskien and E. Wattecamps essentially describes a renormalization between 0.1 and 2.0 MeV of existing $\sigma(n,\alpha_1)$ data by a least-squares method. At best an accuracy of 5% for one standard deviation seems to be achieved between 0.1 MeV and 0.5 MeV.

The measurements of E. Viesti and H. Liskien confirm the recommended values of H. Liskien and E. Wattecamps. An accuracy of one standard deviation of 4% is claimed below 1 MeV and an increasing error margin with energy reaching 7% at 2 MeV. The measurement of E. Viesti et al. furthermore yields a third data set above 1.2 MeV which helps to solve the discrepancy between the previously available data sets of Davis et al. (1961) and Nellis et al. (1970).

The $\sigma(n,\alpha_1)$ values of R. A. Schrack et al. have an estimated error of less than 3% between 8 and 400 keV, or less than 5% between 500 and 700 keV, and are well fit by an R-matrix analysis code. Presumably the data of R. A. Schrack et al. from 20 to 500 keV strongly determined the ENDF/B-V, which in turn, but independently, agree within 3% or better below 550 keV with the data of E. Viesti and H. Liskien. Above 550 keV there is no satisfactory agreement between the data of E. Viesti et al. and ENDF/B-V but rather close agreement is observed with ENDF/B-IV from 600 keV till 1.5 MeV. The $\sigma(n,\alpha_1)$ data of ENDF/B-V were decreased in general by several percent compared to ENDF/B-IV in the range of energy from 250 keV to 1.3 MeV. In particular a decrease of almost 9% around 450 keV and 13% around 850 keV is to be noted. The size of the changes is symptomatic of the moderate quality of the standard above 100 keV.

The Refs. (5), (6), (7) and (8) deal with the related cross section data such as σ_{tot}, $\sigma_{n,n}$, angular distribution of the α particles and branching ratio measurements.

The shape of the σ_{tot} measurements of A. Beer and R. R. Spencer is in good agreement with previous experimental results and no indication of narrow resonance structure is found. The broad bump in the total cross section was analyzed by an R-matrix analysis and associated with a 7/2 + s-wave resonance at 370 keV. The data of σ_{tot} of G. F. Auchampaugh et al. and the ENDF/B-IV data differ by about 10% at 1.7 MeV. This might indicate the need for a reevaluation but these data were not introduced in ENDF/B-V.

The measurements of R. Chrien et al. demonstrate a strong anisotropy for the $^{10}B(n,\alpha_0)^7Li$ reaction at 24 keV and less at 2 keV, which is confirmed by R-matrix analysis of G. Hale, whereas the $^{10}B(n,\alpha_1)^7Li$ reaction seems to be isotropic at 2 keV and slightly anisotropic at 24 keV.

The differential elastic scattering cross section measurements between 4 and 8 MeV of H. D. Knox et al. provide data in a region where only sparse data were previously available. The integrated elastic cross sections in this energy region are 6 to 9% lower than the ENDF/B-IV data and these new experimental data are not taken into account in ENDF/B-V.

The recent measurements listed above contain valuable data but only those of R. A. Schrack et al. have been taken into account in the recent evaluation of ENDF/B-V. An accuracy of 2% up to 1 MeV for $\sigma(n,\alpha_1)$ data has not been achieved. Rather optimistic estimates of one standard deviation at 100, 500 and 1000 keV are 3%, 5% and 7% respectively. Additional measurements and evaluations of $\sigma(n,\alpha_1)$ and related data are needed to confirm the accuracy claimed so far and evidently to satisfy the WRENDA-requests.

E. Wattecamps
C.B.N.M.
Geel, Belgium
9/79
Re-confirmed 7/80.

Editor's Comment:

There has been relatively little change in this standard over the past several years. This is reflected in the reviewers recommendation to retain his previous summary. There are some uncertainties at low energies associated with recent measurements of the $^{10}B/^{6}Li$ ratio as noted in Sec. II, above. Previous concerns as to molecular effects in gas and solid-film detection methods (see above) have not been supported by recent measurement (Bowman, NBS). Recent measurements of the $^{7}Li(\alpha,n)^{10}B$ angular distribution have been published by Sealock.

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B-IV. NATURAL-CARBON ELASTIC SCATTERING CROSS SECTIONS

A. Justification and Use

The primary use 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 application can be made to ≈4.8 MeV (i.e. to the inelastic-scattering threshold) if care is taken to avoid prominent resonance structure. High-purity samples are readily available and the target mass is sufficiently heavy to reduce center-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 minimia that are useful in experimental angle calibrations.

B. Status and Recent Results

A very extensive review, including new measurements and a R-matrix interpretation, has been completed by Fu and Perey.[1] This review is the basis of the ENDF/B-V file, relevant portions of which are given in the above tabulations. Concurrent with the work of Ref. 1, Holt, Smith and Whalen[2] have reported new neutron total and scattering measurements together with a R-matrix interpretation. The latter work is consistent with that of Ref. 1 and supports the ENDF/B-V evaluation to accuracies of ≲1%. 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. H. Knox and R. 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 and 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 expeirmental 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 2087 keV resonance is a valued energy-scale reference point. Contemporary knowledge of this resonance energy, as summarized by G. D. 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.

C. Conclusions and Recommendations

1. ENDF/B-V defines the neutron total cross section to accuracies of better than 1% 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 $\lesssim$1%. 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 $\approx$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 ± 0.004 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 $\approx$1%. 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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References

1. C. Fu and F. Perey, "Atomic Data and Nuclear Data Tables," 22 249(1978).

2. R. Holt, A. Smith and J. Whalen, Argonne National Lab. Report, ANL/NDM-43 (1978).

3. W. Poenitz et al., Nucl. Sci. and Eng., to be published; also Private Communication (1980).

4. H. Knox and R. Lane, To be published (1981).

5. F. G. Perey, Private Communication, as quoted in Ref. 4.

6. W. Galati et al., Phys. Rev., C5 1508(1969).

7. G. Auchampaugh, Los Alamos Scientific Lab. Report, LA-6761 (1977).

8. G. D. James, NBS Special Publication #493 (1977).

9. A. B. Smith, Private Communication (1981).

10. S. Cierjacks et al., NEANDC-192(U) (1979).

Table I. Measure 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	/77	2078.33 ± 0.89
(Average of above Harwell Results)		
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 references are given in Ref. 8.

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

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

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

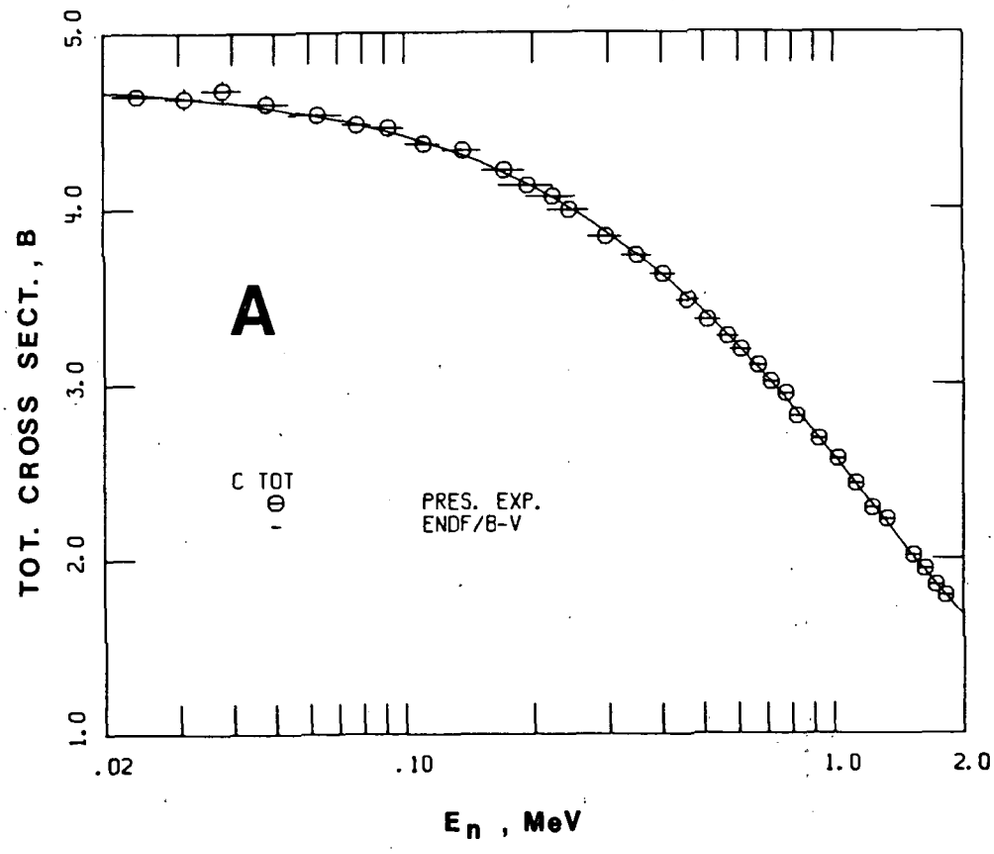

Fig. 1. Comparison of the neutron total cross sections of natural carbon measured by Poenitz et al.[3] with the corresponding values given in ENDF/B-V.

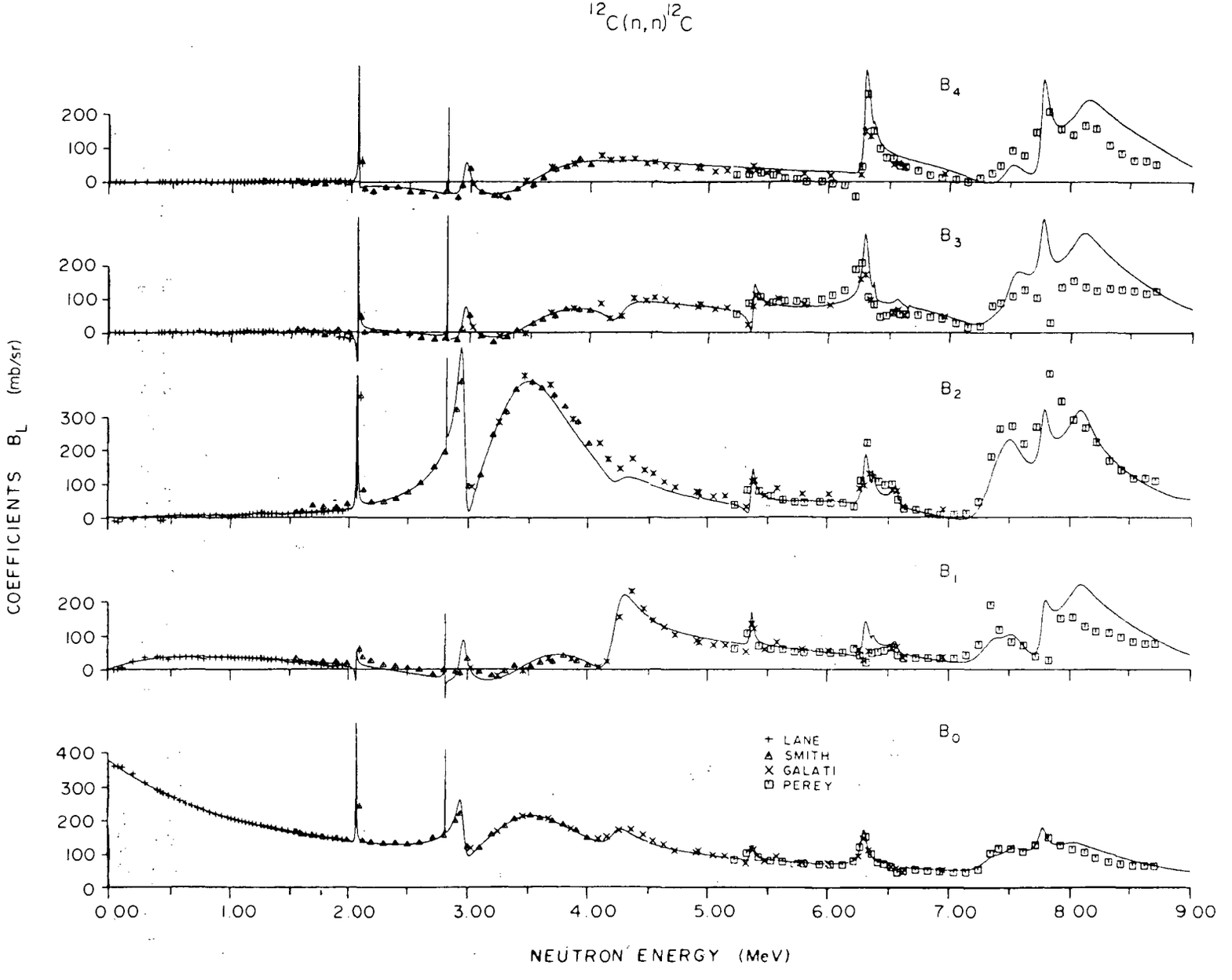

Fig. 2. Differential elastic-scattering cross sections of ^{12}C. Solid curves represent the result of an R-matrix interpretation by Knox and Lane.[4]

B-V. ^{197}Au RADIATIVE-NEUTRON-CAPTURE CROSS SECTIONS

A. Description

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.

B. Status

Measurements prior to 1975 have been incorporated into an ENDF/B-V evaluation.[1] Description of the data sets which thence appeared in the literature are the following.

1) The radiative capture cross section at 590 keV was measured[2] by the activation method. The neutron source is the T(p,n) ^{3}He reaction. The γ-ray activity was determined by a Ge-Li detector. The neutron flux was measured by two different types of hydrogen gas counters. The results are summarized in Table I. These results are to be compared with an ENDF/B-V value of 117 mb at 595 keV.

2) Konokov et al.,[3] measured the capture cross section of Au (Along with ^{115}In, ^{181}Ta, ^{147,149}Sm, Sm and ^{151,153}Eu, Eu) in the energy range 3-350 keV. The neutron source is the ^{7}Li(p,n) ^{7}Be reaction. The capture events were detected by a spherical liquid scintillator of diameter 32 cm, filled with heavy hydrogen-free scintillator. The relative flux was measured by a ^{10}B plate viewed by Na I(Tℓ) crystal. The capture cross section was normalized to a value of 596 ± 24 mb at 30 keV. The data are in the form of curves and are as yet unavailable. A total error of 5.75% is assigned[3] to the capture cross section. There is good agreement (within 5%) with the measurements of Macklin et al., LeRigoleur, and Poenitz over the entire energy range.[1]

3) Joly et al.[4], measured the capture cross section of Au in the energy range 0.5-2.5 MeV. The prompt capture γ-ray spectra were detected with a NaI spectrometer composed of a central and an annulus detector. The spectrometer is used in the anti-compton and first-escape modes simultaneously, thus reducing the background. The capture spectra were extrapolated to zero energy. The flux of th neutrons was monitored by a plastic scintillator, a calibrated directional long counter, and a proton recoil telescope.

The results of these measurements are summarized in Table II and are compared with the ENDF/B-V evaluation. In Figs. 1-2, a comparison is made between the present and previous measurements and the ENDF/B-V evaluation.

Using the same technique as above Drake et al.[4], reported at the 1977 Kiev Conference measurements at 0.720 and 3.00 MeV neutron energies. The preliminary value at 3.00 MeV is 21.4 ± 3.5 mb. It is not clear whether this value is withheld by the authors in their subsequent publication.[5]

4) Gupta et al.[6] employed a large Gd-loaded (0.5%) Liquid (NE 323) scintillator to measure the capture cross section of ^{197}Au as well as ^{238}U at three energy points: 1.68, 1.93, and 2.44 MeV. The prompt capture γ-rays were separated from the delayed γ-rays due to the thermalized neutrons by timing techniques. The relative neutrons produced by the $T(p,n)^3He$ reaction were monitored by a directional counter. Since the efficiencies of both the neutron flux monitor and the liquid scintillator were not determined, the authors[6] normalized the sum of the cross sections to those of Lindner et al.[1], in the same energy region. It is felt by the present reviewer that this procedure is not totally justifiable. The results of the measurements are indicated in Table III and are compared with other measurements as well as those of the ENDF/B-V evaluation in Fig. 2.

5) More recently Macklin[7] remeasured the capture cross sections of gold with an attempt to extend the energy region up to 2.0 MeV (not yet analyzed).

C. Conclusions and Recommendations

The recent published Au capture measurements are summarized in Tables I, II, III, and compared with the ENDF/B-V evaluation in Figs. 1 and 2. As shown, particularly in Fig. 2, the recent measurements agree with the ENDF/B-V evaluation within the error limits. It will be of interest in the future to incorporate the Macklin data when they become available for the purpose of resolving the discrepancy between the Liskien and the Poenitz data sets (Fig. 2).

References

1. ENDF/B data file for Au (MAT 1379) and references therein. Evaluation by S. F. Mughabghab. See also BNL-NCS-21774.

2. M. B. Pasechnik, 1977 Kiev Conference, 4, 99.

3. V. N. Kononov, B. D. Hurlov, E. D. Poletaev, and V. M. Timokhav, Yad. Fiz. 26, 947(1977).

4. D. Drake, G. Greneir, S. Joly, L. Nilsson, J. Voignier, National Soviet Conference on Neutron Physics, Part 21, 175(1975).

5. S. Joly, J. Voignier, A. Grenier, D. M. Drake, and L. Nilsson, Nucl. Inst. Meth., 153, 493, 78.

6. S. K. Gupta, J. Frehaut and R. Bois, Nuclear Instruments and Methods 148, 77(1978).

7. R. Macklin, private communication (1979).

Table I.

Counter Type	Neutron Energy (keV)	Cross Section (mb)	Total Error %	Neutron Flux Error %	Error in Determining Activity %
1	597 ± 16	125.5 ± 4.1	3.3	2.2	1.4
2	590 ± 23	121.2 ± 4.1	3.4	2.2	1.2

Table II.

Neutron energy (MeV)	Neutron energy spread (MeV)	Detection mode	Cross Section (mb)	Cross Section (weighted mean) (mb)	ENDF/B-V (mb)
0.52	± 0.08	FE	132 ± 10	132 ± 11	130.0
		AC	132 ± 9		
0.72	± 0.08	FE	100 ± 9	101 ± 9	98.7
		AC	102 ± 7		
0.94	± 0.07	FE	71 ± 11	77 ± 8	84.5
		AC	79 ± 7		
2.50	± 0.06	FE	42 ± 6	41 ± 6	37.5
		AC	41 ± 4		

AC = Anti-Compton mode
FE = First Escape mode

Table III.

E_n(MeV	$\sigma_{n\gamma}$(mb) Ref. 5	$\sigma_{n\gamma}$(mb) ENDF/B-V
1.68 ± 0.03	59 ± 4	63.4
1.93 ± 0.03	55 ± 4	58.9
2.44 ± 0.03	45 ± 4	39.0

S. F. Mughabghab
4/79
Taken from Brookhaven Natl. Lab. Report, ENDF-300 (12/79).

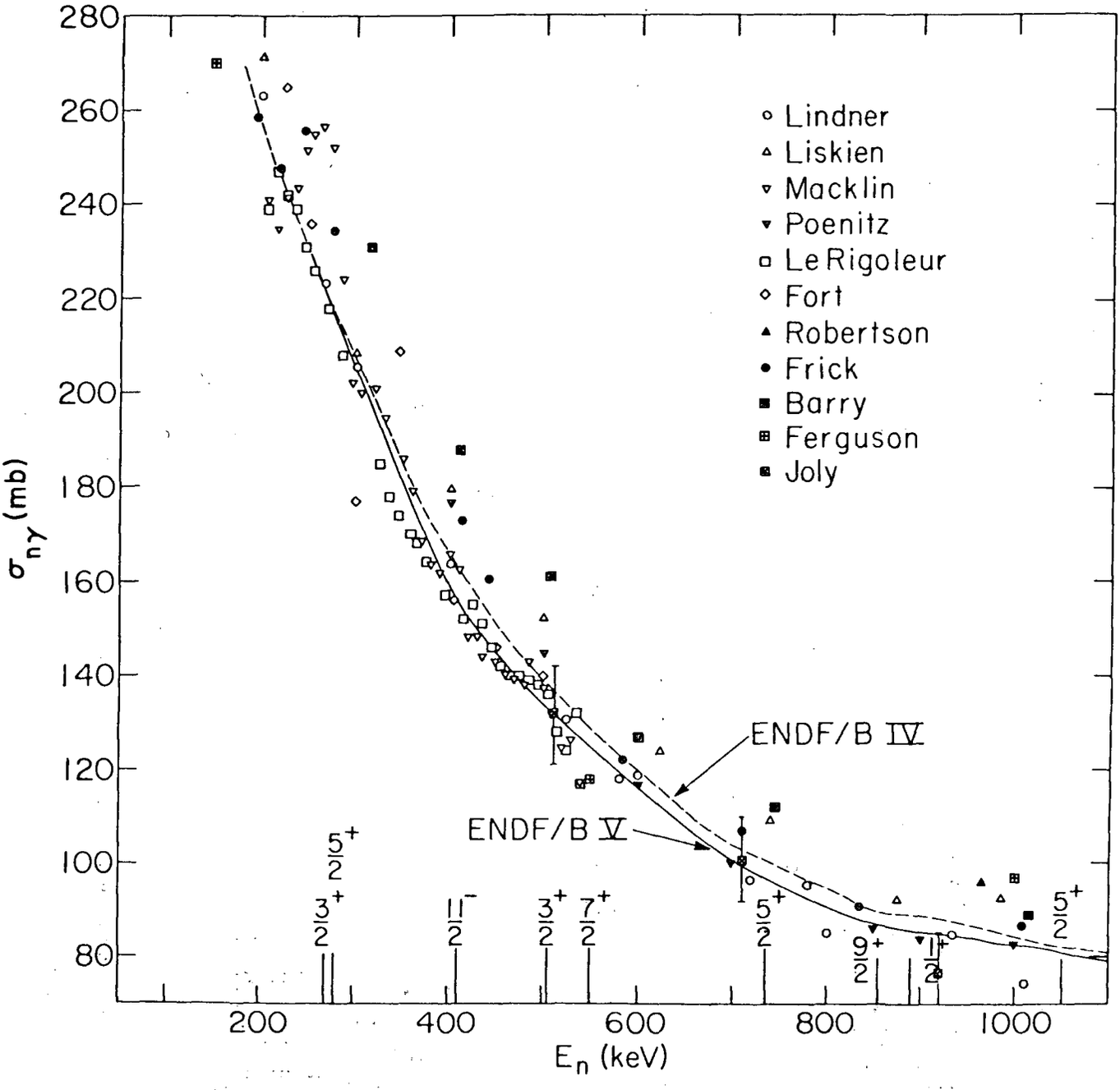

Fig. 1. The Capture Cross Section of Au in the Energy Region 200-1000 keV. The Vertical Lines Represent the Thresholds for the Inelastic Channels.

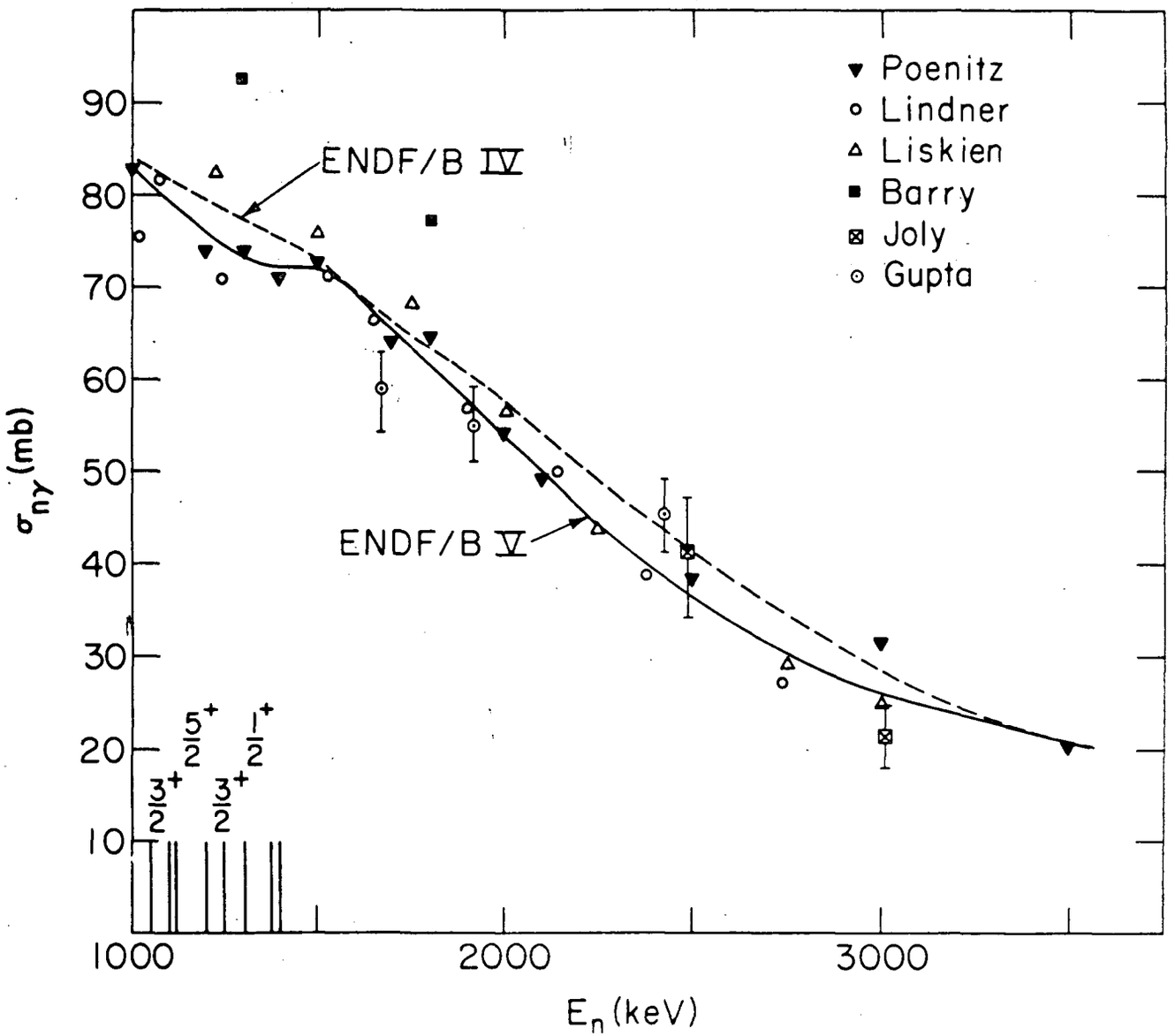

Fig. 2. Comparison of the ENDF/B-V Evaluation of the Capture Cross Section of Gold with Experimental Data.

Editor's Comment:

Davletshin and co-workers (A. N. Davletshin et al., At. Energy 48, 2, 87(1980) have measured the activation cross section from 0.35 to 1.4 MeV relative to H(n,n) to accuracies of 2.5 - 4.0%. Measurements are underway from 1.0 to 10.0 MeV at Lund University (Bergqvist et al.). The Committee expressed concern for the ^{198}Au half life as given in the ENSDF files and thus recommends the values given in Section XI, below.

New gold capture measurements have been reported by Zhu Sheng Yun that agree well with Version V. Macklin has recently completed high resolution gold capture measurements from 100 keV to 2 MeV. These data show prominent cusps just above the thresholds for inelastic scattering for many levels. The data are generally lower than Version V by many percent.

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B-VI. ^{235}U FISSION CROSS SECTION

A. Introductory Remark

This resumé is a statement of contemporary status. Information prior to 1978 is reasonably summarized in the previous distrbution of file (INDC-30/L+SP) and is the basis of the numerical standard file of ENDF/B-V, noted above.* The recommended range of application is 0.1 to 20.0 MeV though new results (below) improve definition at lower energies.

B. Reviewer's Comments

The major relevant meeting during the period was the 5th All-Union Conference on Nuclear Physics, Kiev, 15-19 September 1980. Several precise determinations of the ^{235}U fission cross section were reported.

In the first experiment of Biriukov et al.[1] the fission cross section was measured using the time-of-flight method over the energy range 0.1-100 keV to accuracies of 1.5-2.0%. The results are given in Table 1. They span an energy range that has long been uncertain.

The second experiment of Arlt et al.[2] consists of absolute measurement of the fission cross sections at 2.6 and 8.2 MeV. The experimental values are 1.215 ± 0.024 b and 1.741 ± 0.057 b, respectively.

The third experiment by Zhagrov et al.[3] measured the fission cross section at 46 ± 7 keV and 120 ± 9 keV yielding the values 2.08 ± 0.08 b and 1.51 ± 0.06 b, respectively.

A fourth experiment by Bergman et al.[4] consisted of a measurement of the fission cross section using a neutron spectrometer based upon the slowing-down technique over the energy range 0.1 to 50.0 keV to average accuracies of 1.5% to 2.0%.

An additional measurement of the cross sections at 14.7 MeV has been reported by Petrzhak et al.;[5] the result is 2.073 ± 0.023 b.
Reviewer .

G. Yankov
Kurchatov Institute of Atomic Energy
USSR, 12/80

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*It is believed that the previous report and ENDF/B-V were cognizant of data reported at the Conf. on Nuclear Cross Sections for Technology, Knoxville (1979), at least in preliminary form.

100 keV - 20 MeV
100 eV - 100 keV
} $10^2 - 2 \cdot 10^7$ eV

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

E_1-E_2 KeV	σ_f barn	E_1-E_2 KeV	σ_f barn	E_1-E_2 KeV	σ_f barn
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

C. Additional Comment (Editor's remark)

The INDC Subcommittee was informed that M. Cance´ and G. Grenier[6] (Bureyes-le-Chatel) have measured the ^{235}U fission cross section at 2.5 ± 0.04 MeV and 4.45 ± 0.1 MeV. The cross-section values are 1.26 ± 0.03 b and 1.13 ± 0.03 b, respectively.

O. Wasson, A. Carlson and K. Durvall[7] (Natl. Bureau of Stds.) have completed measurements at 14.1 ± 0.1 MeV with a result of 2.080 ± 0.30 b. This precise value compares very well with ENDF/B-V as shown in Figs. 1A, 1B and 1C. These same figures cite some previously reported values at similar energies. An inspection of the figures suggests that this standard may be known to better than 1% near 14 MeV.

2.6 MeV cross-section values recently reported by Arlt et al.[8] (Technische Universität Dresden) are compared with previous values report at similar energies in Fig. 1D. These results appear similar to (or identical with) those of Ref. 2 cited by the reviewer, above.

A precision measurement program over the energy range ≈0.1 to 1.0 MeV is in progress at the National Bureau of Standards (USA). It is hoped that 1% to 1-1/2% accuracies will be achieved. With these measurements, those noted above, and previously reported values the major energy region of remaining uncertainty is probably in the range 3.0 to 6.0 MeV.

Two international intercomparisons relevant to the ^{235}U fission cross section are in progress. Arrangements are being made, via the IAEA, to inter-compare precision references foils of the USSR and the USA. The intent is to ship one or more reference standard USSR foils to the USA where Argonne National Laboratory; National Bureau of Standards, and other institutions will make precise comparisons with USA standards using a variety of techniques. A second intercomparison involves the UK transfer

chamber (see INDC-30/L+SP). It is planned to independently audit this device at the National Bureau of Standards, USA. The Status of this chamber as of 5/80 was defined by D. B. Gayther (UK) as follows:

Standard Fission Chamber for Flux Intercomparison

The present status can be summarized as follows:

1. The chamber itself has been constructed and a dummy foil assembly mounted satisfactorily. Enough components have been made to assemble three chambers (Standard ^{235}U chamber, Standard ^{238}U chamber and one chamber containing thinner ^{235}U deposits for cross-section measurements).

2. A complete set of ^{235}U foils of ~0.5 mg/cm^2 thickness has been made for the standard chamber and a complete set of ^{235}U foils of ~0.1 mg/cm^2 has been made for cross-section measurements. One double sided foil has also been made for each of the above sets for destructive mass-assay.

3. Work has not started on the ^{238}U foils.

4. The isotopic composition of the fissile material has been determined with mass spectrometers at Harwell and Aldermaston.

5. A medium geometry alpha-counter (co-operative effort of Nuclear Physics and Chemistry Divisions) has been built and is now being used to check the deposit masses determined by weighing. It is expected that the alpha-counter will be capable of determining the mass deposits with an uncertainty of ~0.2% (comparisons with accurately known standard sources confirm this).

6. All the prepared foils have been autoradiographed and qualitative comparisons of deposit uniformity will be made with a densitometer. Quantitative checks on uniformity will be made on selected foils by alpha-counting. The target specification is that the total deposit in any one area of 1 cm^2 shall not differ by more than 4% from the total deposit in any other area of 1 cm^2.

7. The two foils to be destructively assayed will have the total deposit determined by

   Weighing
   Controlled potential coulometry
   Isotope dilution and mass spectrometry

8. One Harwell Pulse Processing System NM8800 is available for use with the chambers. This uses a charge sensitive pre-amplifier with opto-electronic feedback for input signal restoration. The important feature of this device is its ability to restore very rapidly the charge released in the chamber by the intense gamma-flash from a linac.

9. It is expected that all the measurements on the ^{235}U foils will have been completed in a few weeks time and that a complete ^{235}U chamber will be available for initial tesitng in the early autumn.

Inquiries regarding the above device should be addressed to D. B. Gayther, Harwell (UK).

References

1. S. A. Biriukov, T. A. Mostovaya, V. I. Mostovoi, A. A. Ossochnikov, A. V. Svetsov, "The Measurement of the Neutron Fission Cross-Section of U-235 and U-233 in the energy range of 0.1-100 KeV". Report presented at the 5th All-Union Conference of Neutron Physics, Kiev, 15-19 September, 1980. See Conference Programme page 25.

2. R. Arlt, V. Grimm, M. Iosh, I. D. Almazov, L. V. Draptshinskij, K. A. Petrzhak, et al., "The U-235 Neutron Fission Cross-Section at 2.6 and 8.2 MeV". Reference same as for (1), page 25.

3. E. A. Zhagrov, Yu. A. Nemilov, A. V. Platanov, S. M. Soloviev, V. I. Fominykh. "U-235 and U-233 Fission Cross-Section at Intermediate Neutron Energies". Reference same as for (1), page 26.

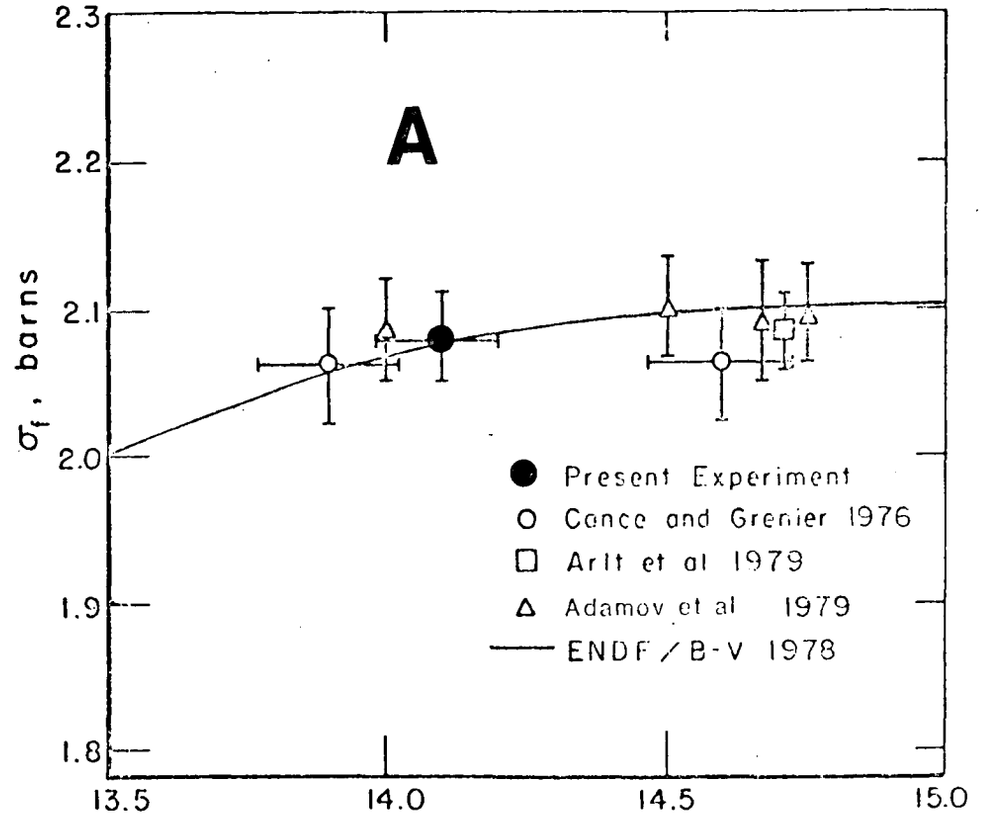
4. A. A. Bergman, A. G. Kolossovskij, S. P. Kuznetsov, A. N. Medvedev, A. E. Samsonov, V. A. Tolstikov, "The Measurement of the Pu-239 and U-235 Fission Cross-Sections and their Ratios on a Neutron Spectrometer using the Slowing Down Time in Lead Method in the Energy Range of 0.1-50. KeV". Reference same as for (1), page 25.

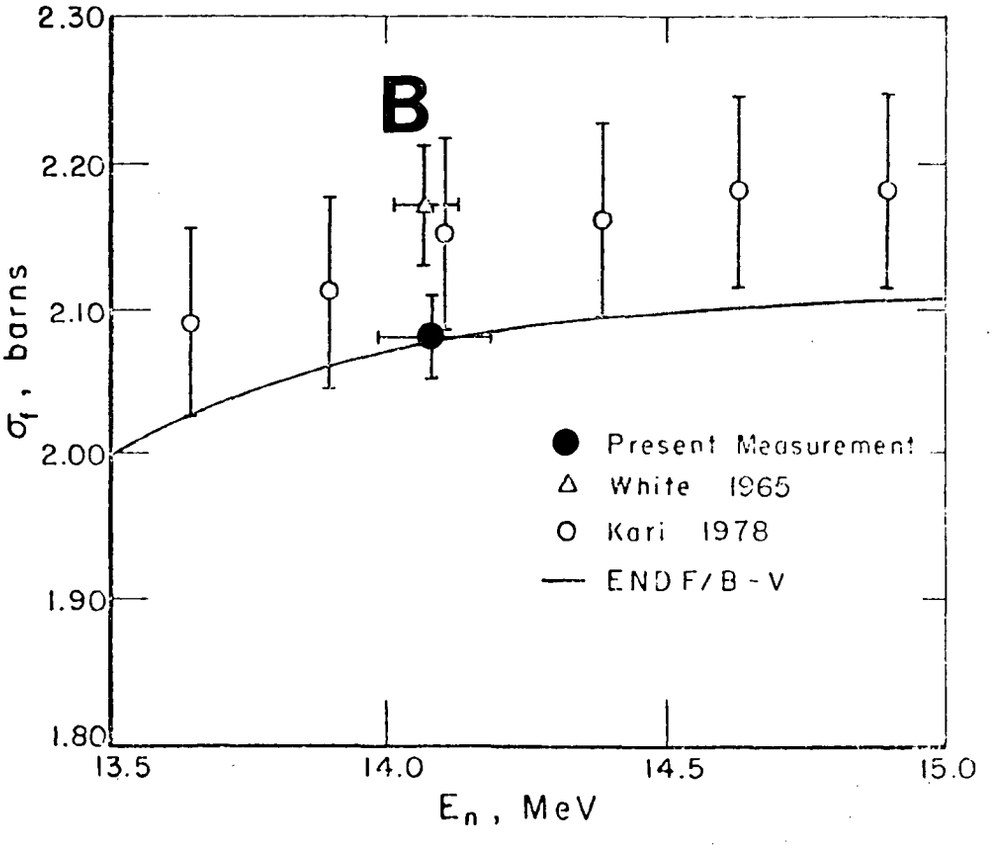
5. Petrzhak et al., At. En., 47 416(1979).

6. M. Cance and G. Grenier, INDC(FR)-47L (1981).

7. O. A. Wasson, A. D. Carlson and K. C. Duvall, to be published in Nucl. Sci. and Eng.

8. R. Arlt et al., To be published in Kernenergie.


A
2.3
2.2
2.1
2.0
1.9
1.8
σ_f, barns
13.5
14.0
14.5
15.0
Present Experiment
Conce and Grenier 1976
Arlt et al 1979
Adamov et al 1979
ENDF/B-V 1978


B
2.30
2.20
2.10
2.00
1.90
1.80
σ_f, barns
13.5
14.0
14.5
15.0
E_n, MeV
Present Measurement
White 1965
Kari 1978
ENDF/B-V

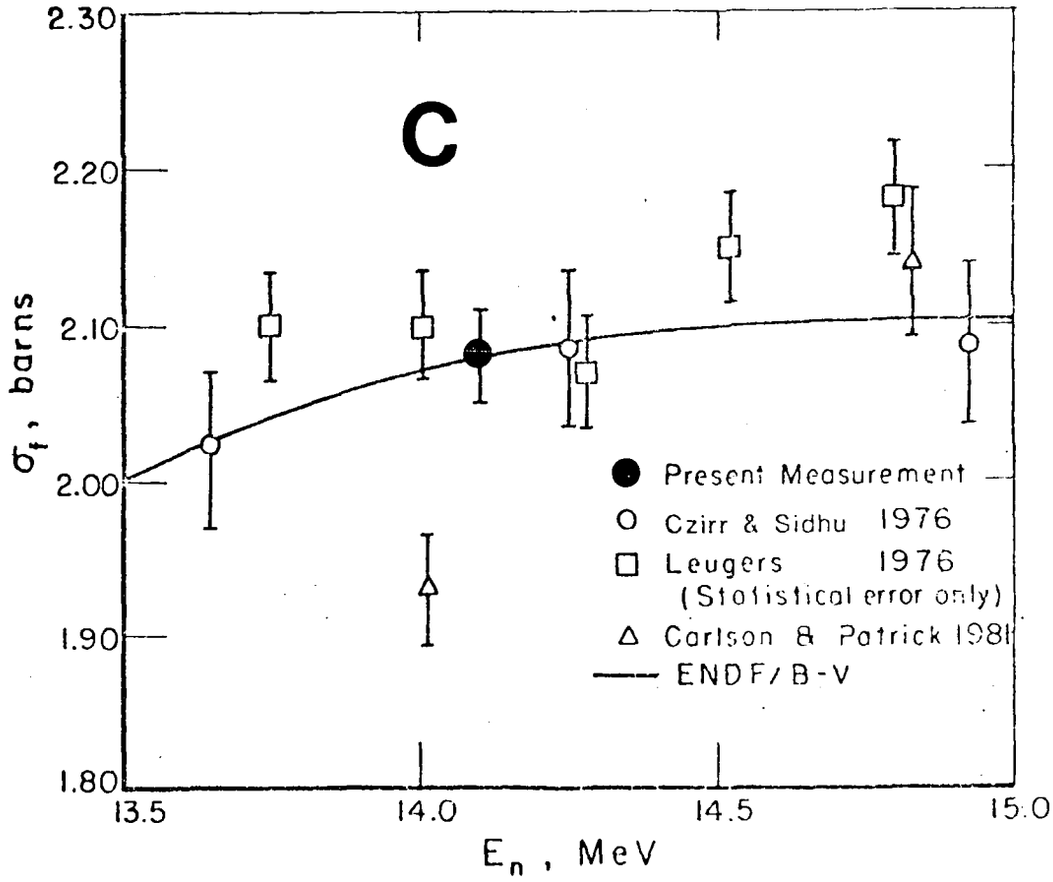


Fig. A, B, and C. Comparison of the recent 14 MeV, ^{235}U results of Ref. 7 with previously reported values in the relevant energy range.

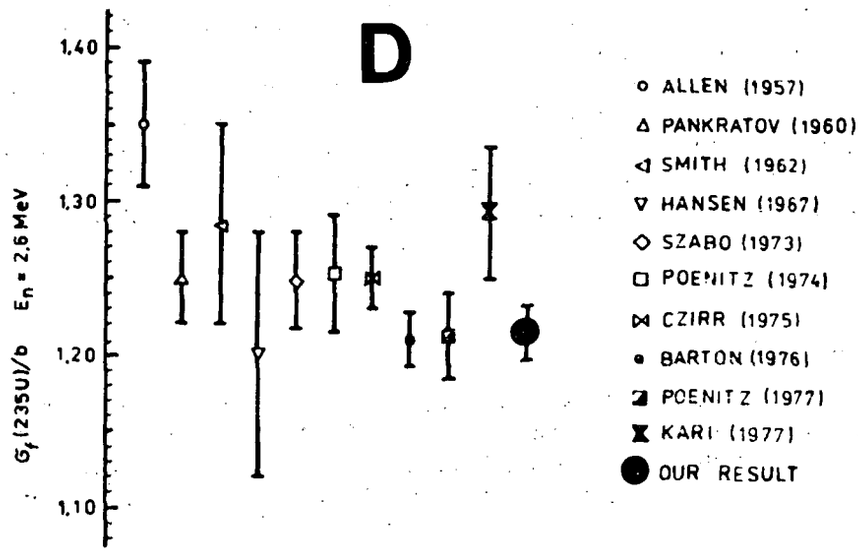


Fig. D. Comparison of 2.6 MeV ^{235}U results of Ref. 8 with previously reported values at similar energies.

B-VII. PROMPT-FISSION-NEUTRON SPECTRUM OF ^{252}Cf

A. Justification and Use

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 of Sec. B-VIII). The spectrum is also used as a relative flux standard in instrument calibrations.[2]

B. 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. This conclusion is complicated by the varying experimental conditions underlying the individual experimental measurements, even within a single measurement set, and by uncertainties as to important experimental corrections (e.g. dead-time corrections to typical time-of-flight measurements[4]). The maxwellian conclusion is supported by the recent experimental results of Boldeman,[5] illustrated in Fig. 1, and of Bensch.[6] The experimental definition is less suitable at low energies and in that region uncertainties persist. Recent measurements reported by Starostov et al.,[7] emphasizing the low energy region, show pronounced deviations from the maxwellian form as illustrated in Fig. 2. Similar deviations have been reported in some earlier work.[8] The evidence indicates that the maxwellian shape is consistent with the body of experimental evidence in the MeV region; below approximately 1 MeV such a conclusion is far less certain.

Assuming the maxwellian form, Blinov[3] concludes that the temperature is 1.42 MeV. This value is similar to that derived from the measurements of Boldeman[5] ($T = 1.426 \pm 0.003$ MeV), Bensch[6] ($T = 1.409 \pm 0.015$ MeV) and a number of others as summarized in Table I. The Blinov conclusion is also consistent with that derived in the evaluation of Grundl and Eisenhauer.[9] Interestingly, calculated spectra based upon systematics and theory tend to display higher average energies more similar to the higher values reported in a few of the very early measurements.[10]

C. Recommendations

Pending more accurate measurements, particularly at low energies, 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 results of measurements

now in progress become available and the situation can be re-evaluated. Future measurements should give particular emphasis to the energy region below 1 MeV as that is the area of outstanding uncertainty.

Argonne National Laboratory
5/81

References

1. A. Smith et al., Nucl. Sci. and Eng., 76, 357(1980).

2. A. Smith et al., Nucl. Instr. and Methods, 140, 397(1977).

3. M. V. Blinov, Proc. IAEA Consultants Mtd. on Neutron Source Properties, INDC(NDS)-114/GT (1980).

4. F. G. Perey, private communication (1980).

5. J. Boldeman, Trans. Am. Nucl. Soc., 32, 733(1979).

6. F. Bensch, INDC(AUS)-4 (1979).

7. B. I. Starostov et al., INDC(CCP)-164/L (1981).

8. J. W. Meadows, Phys. Rev., 157, 1076(1976).

9. J. Grundl and C. Eisenhauer, Natl. Bur. Stds. Pub., NBS-493 (1977).

10. L. Stewart, private communication (1980).

Table I. Summary of Data on Fission Neutron Spectrum of ^{252}Cf through 1979. Compiled by Blinov.[3]

Year	Authors	Neutron Energy Range (MeV)	Method of Neutron Detection	Results	
				T^{a}_{maxw} (MeV)	$\bar{E}$ (MeV)
1955	Hjalmar etc.[a]	> 2	Photoemulsion	1.40 ± 0.09	-
1957	Smith etc.	0.2 - 7.0	TOF, plast. scint.; photoemuls.	-	2.36
1961	Bonner	< 4	Integr. (Bramblett counter)	1.367 ± 0.030	-
1962	Bowman etc.	0.5 - 6.0	TOF, plast. scint.	-	2.34 ± 0.05
1965	Conde, During	0.07 - 7.5	TOF, ^{6}Li-glass, plast. scint.	1.39 ± 0.04	(2.09)
1967	Meadows	0.003 - 15	TOF, ^{6}Li-glass, liquid scint.	1.52	2.348
1969	Green	-	Integr. (Mn-bath)	1.39	(2.09)
1970	Zamjatnin etc.	0.005 - 6.0	TOF, ^{6}Li-glass, plast. scint.	1.48 ± 0.03	(2.22 ± 0.05)
1972	Jeki etc.	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, prop. counter	(1.42 ± 0.015)	2.155 ± 0.024 2.130 ± 0.022
1973	Green etc.	0.5 - 13	TOF, org. scint.	1.406 ± 0.015	2.105 ± 0.014
1973	Knitter etc.	0.15 - 15	TOF, org. scint.	1.42 ± 0.05	2.13 ± 0.08
1974	Spiegel	-	Integr. ("age")	-	2.21 ± 0.05
1974	Alexandrova etc.	2.04 - 13.2	Single-crystal spectrometer	1.42 ± 0.03	(2.13 ± 0.045)
1975	Kotelnikova etc.	0.5 - 7.0	TOF, liquid scint.	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 through 1979. Compiled by Blinov.[3] (Contd.)

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

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

[b]References to above are explicitly given in Ref. 3.

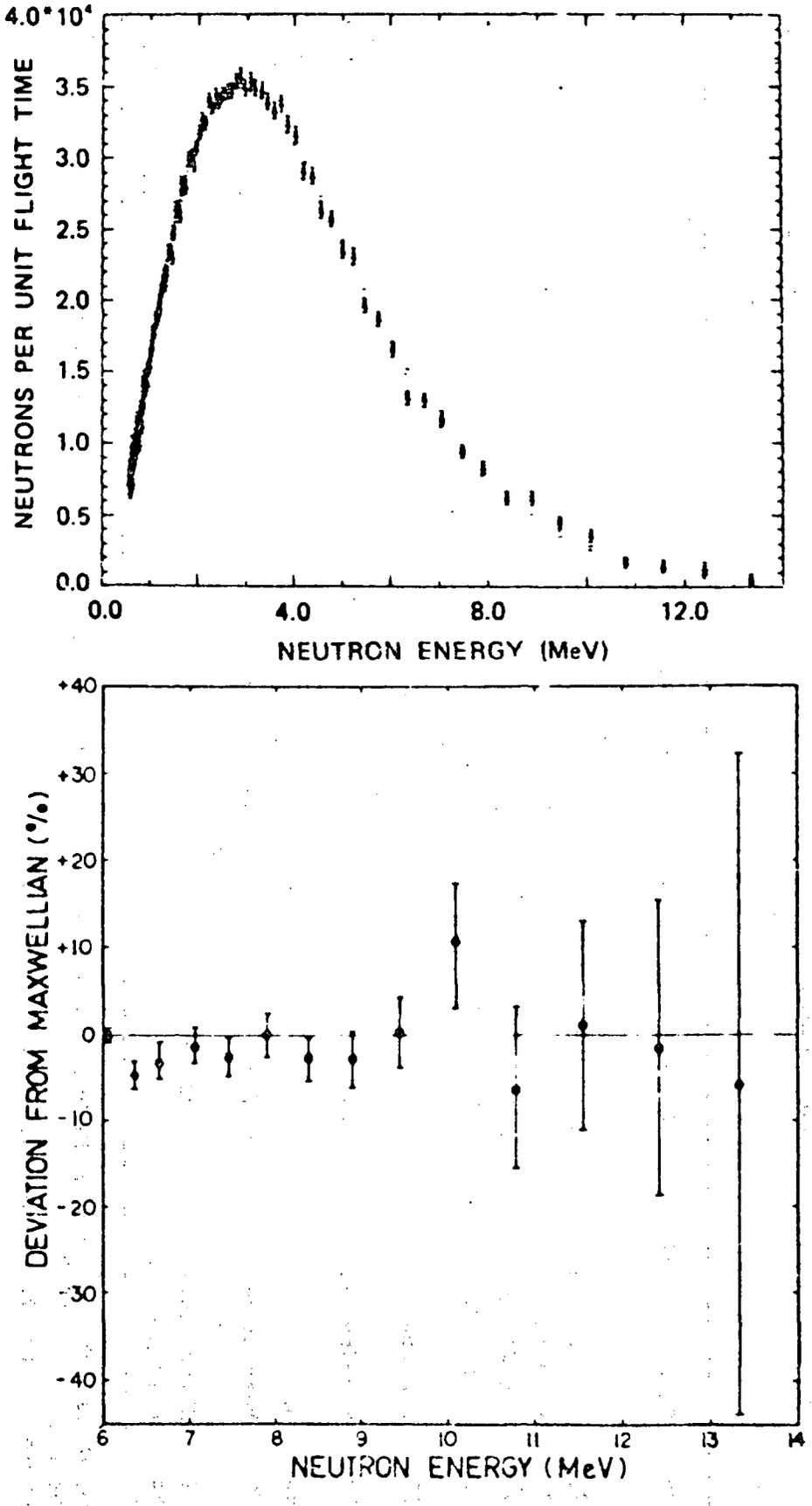


Fig. 1. A(top) Illustrative measured ^{252}Cf spectrum of Boldeman.[5]

B(bottom) Percentage deviation of measured-spectrum values from maxwellian having T = 1.424 MeV as given by Boldeman.[5]

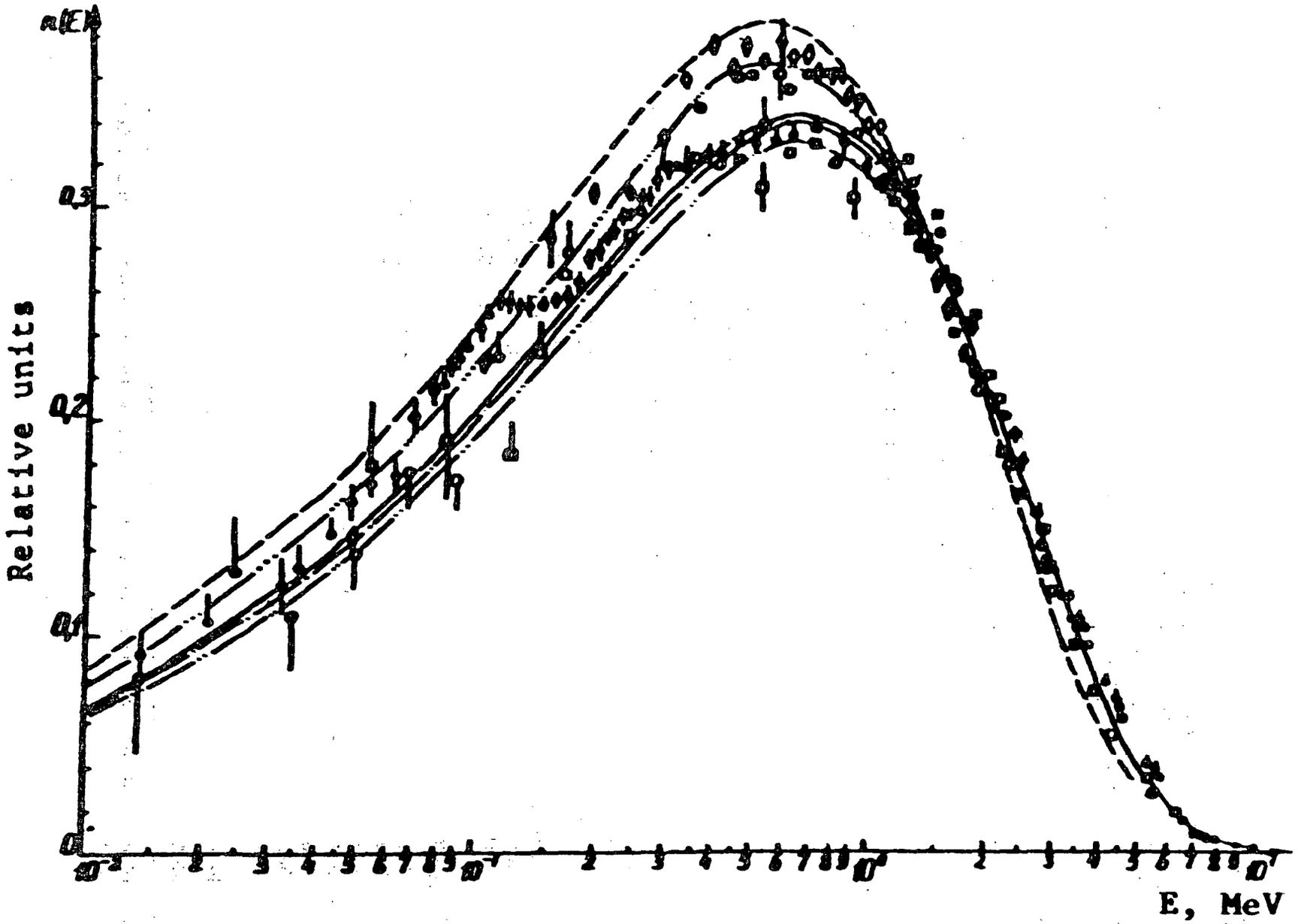


Fig. 2. Measured ^{252}Cf spectra. Solid data points are from Starostov et al.,[7] other data points are defined in Ref. 7. Curves denote maxwellian distributions with temperatures ranging from 1.4 to 1.6 MeV.

B-VIII. NU-BAR ^{252}Cf

A. Use and Importance

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

B. Summary Status

This topic was the subject of a comprehensive review at a workshop held in Washington (US), November 21, 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 nu-bar ^{252}Cf. The nu-bar values considered in these discussions are summarized in Table I below.

Table I. ^{252}Cf $\bar{\nu}_T$ Summary

Measurement	$\bar{\nu}$ (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*
DeVolpi	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 sulfur absorption cross section.

Some of the above values 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.

J. R. Smith has recently completed a new Mn-bath measurement (Trans. Am. Nucl. Soc., 35, 549(1980)). The result is nu-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 sulfur absorption (0.2%) and leakage corrections remain a concern (0.1 - 0.2% level). H. Bozorgmanish (University of Michigan) reported a 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 corrections factors will soon be available as an EPRI report. A major uncertainty in the bath technique is associated with the absorption cross section of sulfur. C. Robertson plans to directly measure the effect.

R. Spencer outlined the recent refinements in the ORNL scintillation tank measurements. The newest result is nu-bar-prompt = 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%. Zhang-Huan-Qiao and Liu Zu-Hua (Chin. J. Nucl. Phys., 1 9(1979)) 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 nu-bar = 3.738 ± 0.025% (based upon monoenergetic ^{235}U data) or 3.814 ± 0.8% (based upon thermal-maxwellian ^{235}U data). These implications are not entirely consistent with some of the values of Table I, above.

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

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B-IX. ACTINIDE HALF-LIVES

A Coordinated Research Program on the Measurement and Evaluation of Transactinium Isotope Decay Data (herein termed "Group") has been pursued under NDS auspices for several years. This program involves a number of international specialists in technical judgments and periodically results in a contemporary recommended list of actinide-decay properties. The most recent of these lists is given in INDC(NDS)-121/NE (12/'80). The standard-relevant numerical values given in Section A, above, were taken from this compilation. The complete listing of INDC(NDS)-121/NE includes a wide range of transactinium isotopes of interest in a broader context than that of the present nuclear standards. Relevant narrative sections of the document INDC(NDS)-121/NE are abstracted in the following.

The decay data listed in INDC(NDS)-121/NE are the result of a critical appraisal of the current status of the transactinium isotope half-lives and branching fractions by members of the IAEA Coordinated Research Programme on Measurement and Evaluation of Transactinium Isotope Decay Data.

The data compiled in this list have been drawn from the following existing decay-data files:

- ENSDF, the Evaluated Nuclear Structure and Decay Data File. Compiled by the Nuclear Data Project at Oak Ridge,

- 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,

- the UK Chemical Nuclear Data Committee Heavy Element Decay Data file, compiled at the AEE Winfrith Laboratory.

Whenever warranted, the data have been supplemented or superseded by the latest known measured and/or evaluated values.

The "Proposed Recommended List of Transactinium Isotope Decay Data. Part I. Half-lives (September 1979 Edition)", published in INDC(NDS)-108/N, was reviewed in the light of new measurements which have been completed since May 1979, and it was decided to enlarge the initial 1979 half-lives list to include the "Heavy Element Decay Data Table" presented in Table I of the summary report (INDC(NDS)-105) and an additional list of heavy element decay data taken from the UK Heavy Element Decay Data File compiled at the AEE Winfrith Laboratory.

In reviewing the measurements becoming available since 5/79, the Group noted significant changes in the status of ^{240}Pu quantities and thus:

> Adopted a new spontaneous fission half-life value of $(1.2 \pm 0.1) \times 10^{11}$y on the basis of new measurement by Budtz-Jørgensen and Knitter (Proceedings of a Meeting on Nuclear Data of Pu and Am Isotopes for Reactor applications, R. E. Chrien Ed., Brookhaven 1979). The adoption

of this value was also supported by a private communication transmitted from Dr. Sowerby (Harwell) at the 1980 Nuclear Transmutation of Actinides Meeting at Ispra, that the previously adopted value was too high.

The group has taken note of a number of newly reported values for the half-life of Pu-241. These are almost exclusively lower than the value recommended by this group. The uncertainties claimed for these measurements are sufficiently small to indicate that this newer work is not reconcilable with some of the previous measurements. No adequate reasons can be found for the rejection of any of the values published in the last ten years or for the discrepancies that exist. This Group recommends that no change be made at this time (i.e. June 1980) to the presently listed value of (14.7 ± 0.4)y for this quantity. When the measurements recently completed and those in progress are published, it is hoped that a value with the required accuracy can be recommended.

The remainder of the values given in Section A, above, are as given in the previous listing (INDC(NDS)-108/N).

Argonne National Laboratory
5/'81

B-X. THERMAL PARAMETERS FOR FISSILE NUCLEI

A. Data

^{235}U, ^{233}U, ^{239}Pu, ^{241}Pu 2200 m/s and 20°C Maxwellian average neutron cross sections and fission-neutron yields.

B. Significance

Thermal fission reactors.

Standard (^{235}U).

Normalization values for cross-section curves at thermal and higher energies.

C. Status

The existing discrepancies were pointed out in last year's report (ANL/ND-77-1, p. 58). The present situation of discrepancies was described by H. D. Lemmel at the 1977 Gaithersburg Symposium on Neutron Standards and Applications.

Until some years ago, the uncertainty of half-lives contributed much to the uncertainty of fission cross-sections. This problem appears now to be solved. The half-lives of ^{233}U and ^{234}U were established earlier with sufficient accuracy, and for the ^{239}Pu half-life a revised value of about 24130 ± 50 years seems now to be the preliminary consensus of several independently performed experiments. (See comments of preceding section.) This leads to an increased ^{239}Pu fission cross-section at 0.0253 eV of about 748 ± 3 barns. Although one does not yet fully understand why the older half-life determinations produced significantly larger half-life values than presently established, the half life values needed for accurate determination of fission cross-sections will be sufficiently accurate after the release of the final results for the present ^{239}Pu half-life measurements.

The neutron-yield data ($\bar{\nu}$ and η) of the U and Pu isotopes seem to be sufficiently well established since the value of $\bar{\nu}(^{252}Cf)$ seems to be settled with sufficient accuracy (Editor, see $\bar{\nu}$-^{252}Cf section).

The only important discrepancy left over is a systematic discrepancy between cross-section measurements with monoenergetic neutrons of 0.0253 eV and those made in thermal neutron spectra. It seems as if uranium samples in a thermal neutron spectrum have a 1 to 1.5% smaller fission cross-section and a 10 to 15% larger capture cross-section than can be expected from the 0.0253 eV cross-sections and Westcott g-factors. No such discrepancies seem to exist for plutonium samples.

It is therefore recommended to continue to investigate the possible sources for this discrepancy. Detailed recommendations to the effect were given already in last year's report (ANL/ND-77-1, p. 60). At least at NBS and at Geel investigations are being performed to check the influence of the sample structure on effective cross-sections at low energies.

Of considerable importance is still the absolute determination of the 0.0253 eV fission cross-section of ^{233}U, since no accurate measurement exists. Present values of $\sigma_f^o(^{233}U)$ are deduced only indirectly from σ_a, $\bar{\nu}$ and η, or from the thermal Maxwellian value with the Westcott g-factors.

The recently established Pu-239 half-life of 24 119 ± 26 years [W. W. Strohm, Int. J. of Appl. Rad. and Isotopes 29 481 (August 1978)] is in agreement with the value assumed by Lemmel [1977 Gaithersburg Symposium on Neutron Standards and Applications] of 24 130 ± 50 years, so that related cross-sections reported there are not affected.

Reviewer: H. D. Lemmel
IAEA/NDS
2/79

Editor's Comment:

An extensive re-analysis of the above area is now in progress under the auspices of the National Nuclear Data Center, Brookhaven National Laboratory. The results are not expected for six months to a year. Thus the above summary should be accepted as an interim statement of status.

B-XI. GAMMA-RAY STANDARDS

The values tabulated below are taken from the NDS-IAEA file compilation. They have been reviewed by the Laboratoire de Metrologie des Rayonnements Ionisants, CEA Saclay. Detailed referencing and specific comments are available from A. Lorenz, IAEA Nuclear Data Section.

GAMMA-RAY STANDARDS, HALF-LIVES

NUCLIDE	DECAY-MØDE	HALF-LIFE	
4-BE- 7	EC	53,29+-0,07	(D)
9-F - 18	B+	109,77+-0,05	(M)
11-NA- 22	B+	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-CØ- 56	EC	77,12+-0,10	(D)
27-CØ- 57	EC	271,73+-0,14	(D)
27-CØ- 58	EC	70,78+-0,10	(D)
27-CØ- 60	EC	5,271+-0,001	(Y)
28-NI-065	B-	2,520+-0,001	(H)
29-CU- 64	EC	12,701+-0,002	(H)
30-ZN- 65	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	(Y)
41-NB- 95	B-	35,05+-0,10	(D)
43-TC- 99	B-	2,14+-0,05	(Y)
43-TC- 99M1	IT	6,007+-0,002	(H)
46-PD-109	B-	13,46+-0,02	(H)
47-AG-108M1	B+	127,0+-21,0	(Y)
47-AG-110M1	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-113M1	IT	99,49+-0,06	(H)
49-IN-115M1	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	9,69+-0,01	(D)
55-CS-134	B-	2,066+-0,001	(H)
55-CS-134M1	IT	2,913+-0,002	(H)
55-CS-137	B-	30,18+-0,05	(Y)
56-BA-133	EC	10,6+-0,2	(Y)
56-BA-137M1	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	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	31.97+-0.05	(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)
91-PA-233	B-	27.0+-0.1	(D)
95-AM-241	A	432.6+-0.6	(Y)

GAMMA-RAY STANDARDS, ENERGIES AND INTENSITIES

NUCLIDE	ENERGY(KEV)	INTENSITY
4-BE- 7	477.0	0.1032+-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	0.99876+-0.00008
19-K - 42	1524.665+-0.020	0.179+-0.005
21-SC- 46	889.2	0.999836+-0.000016
	1120.5	0.999871+-0.000012
24-CR- 51	320.0842+-0.0009	0.0983+-0.0014
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	0.100+-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	142.65+-0.01	0.0098+-0.0004
	192.34+-0.01	0.0295+-0.0008
	334.99+-0.05	0.0027+-0.0001
	382.5+-0.2	0.00021+-0.00003
	1099.22+-0.03	0.561+-0.010
	1291.56+-0.03	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
	1175.098+-0.010	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
	2015.179+-0.011	0.0303+-0.0004
	2034.759+-0.011	0.0778+-0.0012
	2598.460+-0.010	0.1695+-0.0006
	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

	3546,180+-0,120	0,0019+-0,0001
27-C0- 57	122,06135+-0,00030	0,8566+-0,0013
	136,4743+-0,0005	0,1067+-0,0013
27-C0- 58	810,775+-0,009	0,99445+-0,00010
	863,959+-0,009	0,0069+-0,0002
	1674,730+-0,009	0,00519+-0,00004
27-C0- 60	1173,236+-0,004	0,9989+-0,0002
	1332,502+-0,005	0,999830+-0,000006
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	0,0159+-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
	469,1+-0,2	0,000032+-0,000006
	572,5+-0,2	0,00038+-0,00002
	617,6+-0,2	0,000045+-0,000002
	821,7+-0,2	0,000013+-0,000002
35-BR- 82	92,184+-0,007	0,0072+-0,0005
	137,23+-0,04	0,0012+-0,0003
	221,48+-0,03	0,0227+-0,0009
	273,47+-0,03	0,0081+-0,0005
	554,348+-0,003	0,706+-0,003
	606,33+-0,02	0,0125+-0,0009
	619,106+-0,004	0,433+-0,007
	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
	1044,02+-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	0,00437+-0,00011
38-SR- 85	514,009+-0,012	0,9929+-0,0004
39-Y - 88	898,042+-0,004	0,934+-0,007
	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
	724,18+-0,02	0,4425+-0,0040
	756,72+-0,02	0,5444+-0,0040

	765.76+-0.02	0.9980+-0.0002
41-NB- 94	702.645+-0.0006	0.98+-0.02
	871.119+-0.004	1.00
41-NB- 95	765.78+-0.02	0.9980+-0.0002
43-TC- 99	140.466+-0.015	0.8897+-0.0024
43-TC- 99M1	141.	0.8875+-0.0014
46-PD-109	88.04+-0.05	0.0361+-0.0034
47-AG-108M1	79.141+-0.03	72.+-8.0
	433.939+-0.004	991.+-3.0
	614.281+-0.006	997.+-3.0
	722.938+-0.008	1000.+-3.0
47-AG-110M1	446.811+-0.003	0.034+-0.002
	620.360+-0.003	0.026+-0.002
	657.762+-0.002	0.938+-0.008
	677.622+-0.003	0.109+-0.003
	687.015+-0.003	0.067+-0.003
	706.682+-0.003	0.162+-0.002
	744.277+-0.003	0.044+-0.002
	763.944+-0.003	0.225+-0.004
	818.031+-0.004	0.069+-0.002
	884.685+-0.003	0.731+-0.013
	937.493+-0.004	0.340+-0.005
	1384.300+-0.004	0.258+-0.005
	1475.788+-0.006	0.042+-0.002
	1505.040+-0.005	0.137+-0.003
	1562.302+-0.005	0.012+-0.001
48-CD-109	88.034+-0.002	0.0365+-0.0006
49-IN-111	171.28+-0.03	0.909+-0.006
	245.35+-0.04	0.940+-0.002
	537.0+-1.0	0.87
49-IN-113M1	391.688+-0.014	0.6489+-0.0017
49-IN-115M1	336.0	0.459+-0.003
50-SN-113	255.115+-0.015	0.0182+-0.0004
51-SB-124	602.728+-0.012	1000.0+-3.0
	645.858+-0.012	75.5+-0.5
	709.320+-0.013	13.8+-0.2
	713.793+-0.013	23.2+-0.3
	722.789+-0.016	110.+-1.0
	790.727+-0.016	7.6+-0.1
	968.208+-0.017	19.3+-0.2
	1045.138+-0.020	18.8+-0.4
	1325.516+-0.021	16.6+-0.4
	1368.179+-0.030	26.8+-0.5
	1488.886+-0.024	7.1+-0.3
	1690.992+-0.026	484.+-6.
	2090.962+-0.035	57.+-1.
53-I -125	35.4919+-0.0005	0.0667+-0.0013
54-XE-133	79.623+-0.010	0.0022+-0.0007
	80.998+-0.006	0.380+-0.007
	160.613+-0.008	0.00066+-0.00007
	223.234+-0.012	0.0000025+-0.0000004
	302.845+-0.006	0.000051+-0.000005
	383.845+-0.009	0.0000023+-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+-0,00006
	1365,16+-0,02	0,03015+-0,00013
55-CS-134M1	11.28+-0,02	0.0094+-0,0018
	127.42+-0,06	0,142+-0.012
	138.70+-0,03	0,00004+-0,00001
55-CS-137	32.1	0,063+-0.002
	36.4	0,012+-0.001
	37.3	0,0029+-0,0003
	661,661+-0,003	0,850+-0.005
56-BA-133	53.156+-0,008	0,0220+-0,0006
	79,623+-0,010	0,0264+-0,0012
	80,998+-0,005	0,343+-0,006
	160.613+-0,008	0,0062+-0,0002
	223,234+-0,012	0,00447+-0,00020
	276,397+-0,007	0,0712+-0,0007
	302,845+-0,006	0,183+-0,002
	356,006+-0,010	0,621+-0.0007
	383,845+-0,009	0,0892+-0,0009
56-BA-137M1	661,649+-0,012	0,9007+-0,0010
58-CE-139	165,857+-0,006	0,799+-0,001
58-CE-141	145,440+-0,010	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	0,00001
	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	1362,+-16,
	244,6989+-0,0010	358,+-6,
	295,939+-0,008	21,1+-0,5
	344,2811+-0,0019	1275+-19,
	367,789+-0,005	40,5+-0,8
	411,115+-0,005	107,+-1,
	443,976+-0,005	148,+-2,
	586,294+-0,006	22,+-0,5
	688,678+-0,006	40,+-2,0
	778,903+-0,006	619,+-8,
	810,459+-0,007	15,2+-0,2
	841,586+-0,008	7,8+-0,1
	867,388+-0,008	199,+-4,
	919,401+-0,008	20,9+-0,5
	964,131+-0,009	692,+-9,
	1005,279+-0,017	31,0+-0,7
	1085,914+-0,013	465,+-7,0
	1089,700+-0,015	82,+-1,0
	1112,116+-0,017	649,+-9,
	1212,950+-0,012	67,+-0,8
	1299,124+-0,012	78,+-1,0
	1408,011+-0,014	1000,+-3,0
	1457,628+-0,015	23,3+-0,3

64-GD-153	69.6720+-0.0020	0.0242+-0.0012
	83.367+-0.003	0.00206+-0.00022
	97.430+-0.003	0.295+-0.009
	103.1790+-0.0020	0.211+-0.008
69-TM-170	84.2568+-0.0015	0.0326+-0.0016
70-YB-169	63.12081+-0.00004	123.+-5.
	93.61497+-0.00007	7.2+-0.3
	109.77988+-0.00006	49.+-2.0
	118.18996+-0.00020	5.4+-0.2
	130.52365+-0.00008	32.+-2.
	177.21417+-0.00009	61.+-3.0
	197.95792+-0.00009	100.
	261.07865+-0.00012	4.8+-0.2
	307.73766+-0.00013	28.+-1.
73-TA-182	31.7378+-0.004	27.5+-0.6
	42.7154+-0.006	8.6+-0.7
	65.72247+-0.00014	87.5+-0.7
	67.75001+-0.00020	1310.+-100.
	84.6818+-0.0003	71.9+-0.4
	100.10653+-0.00030	404.+-5.0
	113.6723+-0.0004	53.4+-0.5
	116.4136+-0.0007	12.6+-0.2
	152.4308+-0.0005	199.5+-1.0
	156.3874+-0.0005	75.9+-0.8
	179.3948+-0.0005	88.2+-0.9
	198.3530+-0.0006	41.9+-0.4
	222.1099+-0.0006	216.+-2.0
	229.3220+-0.0009	103.9+-0.8
	264.0755+-0.0008	102.6+-0.8
	1121.301+-0.005	1000.+-3.0
	1157.505+-0.015	29.2+-0.3
	1189.050+-0.005	471.+-4.0
	1221.408+-0.005	778.+-3.0
	1231.016+-0.005	331.+-2.0
	1257.418+-0.005	43.6+-0.4
	1273.730+-0.005	19.5+-0.2
	1289.156+-0.005	42.9+-0.4
	1342.731+-0.025	7.4+-0.1
	1373.836+-0.005	6.8+-0.1
	1387.402+-0.005	2.7+-0.1
	1411.177+-0.045	1.17+-0.04
77-IR-192	136.343+-0.001	0.0018+-0.0001
	205.7955+-0.0003	0.0331+-0.0006
	295.9582+-0.0003	0.287+-0.002
	308.4569+-0.0003	0.297+-0.003
	316.5079+-0.0004	0.830+-0.003
	468.0715+-0.0006	0.478+-0.003
	484.578+-0.001	0.0316+-0.05
	588.564+-0.002	0.0448+-0.0004
	604.414+-0.001	0.0807+-0.0006
	612.465+-0.001	0.0527+-0.0005
	884.541+-0.001	0.0029+-0.0001
79-AU-198	411.8044+-0.0011	0.9555+-0.0008
	675.8875+-0.0019	0.0082+-0.0003
	1087.6905+-0.0030	0.00167+-0.00009
79-AU-199	158.37945+-0.00010	100.

	208.20595+-0.00012	22.7+-0.7
80-HG-203	70.8319+-0.0008	0.038+-0.001
	72.8715+-0.0009	0.064+-0.002
	82.4	0.0214+-0.001
	85.2	0.00631+-0.0003
	279.197+-0.001	0.814+-0.002
83-BI-207	569.702+-0.002	0.9774+-0.0005
	1063.662+-0.004	0.7408+-0.0040
	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
91-PA-233	28.54+-0.05	0.00065+-0.00008
	40.35+-0.01	0.00036+-0.00008
	75.28+-0.01	0.0117+-0.0010
	86.59+-0.01	0.0176+-0.0024
	103.86+-0.02	0.0069+-0.0024
	271.48+-0.08	0.00284+-0.00033
	300.12+-0.03	0.0619+-0.0045
	311.98+-0.03	0.36+-0.02
	340.50+-0.04	0.0421+-0.0049
	348.5+-0.5	0.00054+-0.00022
	375.45+-0.04	0.0056+-0.0011
	398.62+-0.08	0.0119+-0.0016
	415.76+-0.04	0.0151+-0.0017
95-AM-241	11.890+-0.007	0.0085+-0.0003
	13.9	0.133+-0.004
	17.8	0.193+-0.007
	20.8	0.0493+-0.0021
	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	0.357+-0.005

B-XII. NEUTRON-FLUX COMPARISONS

The Committee recommended that this section be limited to a contemporary outline of the status of international neutron-flux comparisons. As presented to the Committee, these fell into four categories.

1. Activities correlated by the Bureau International des Poids et Measures (BPIM).

BPIM is the correlating center for neutron-flux intercomparisons between national metrologie laboratories. The Bureau organizes periodic intercomparisons with the objectives of establishing contemporary accuracies and of promoting long-term improvement. A comparison of monoenergetic fast-neutron flux at 0.25, 0.565, 2.2, 2.5 and 14.8 MeV was carried out between December 1973 and February 1978. Nine laboratories participated in this effort, the results of which were published in Metrologia 16 31(1980). A second intercomparison program is being organized to start in 1980. The selected intercomparison energies are 0.144, 0.565, 2.5, 5.0 and 14.8 MeV. Another portion of the intercomparison effort involves the determination of the neutron emission of a reference ^{252}Cf spontaneous fission source (intensity approximately 4×10^7/s). A dozen laboratories are participating in this latter effort.

2. Reference measurement of absolute neutron fluxes at BPIM.

Correlated with the above, BPIM has undertaken the absolute measurement of neutron fluxes at 2.5 MeV (the $D(d,n)^3He$ reaction) and at 14.68 MeV (the $T(d,n)^4He$ reaction). The necessary deuteron beams are obtained with an electrostatic generator of the SAMES type having a maximum energy of 150 MeV. The flux determination employs the associated-particle technique at a 2% accuracy level.

3. Flux intercomparisons using Induced-activity Techniques

An intercomparison program of this nature, under the joint initiative of BPIM and CBNM, has been proposed. Sixteen laboratories have expressed an interest in participating commencing in 1981. Inquiries should be addressed to H. Liskien (CBNM) or A. Allisy (BPIM).

4. Fission-chamber Transfer Instruments

This program is outlined in some detail in Section VI dealing with ^{235}U, above.

6/80, Updated 3/81

B-XIII. NEUTRON ENERGY STANDARDS

Editor's Comment

Neutron energy standards were extensively reviewed by G. D. James at the recent Symposium on Neutron Standards and Applications (NBS Special Publication 493). A copy of that paper follows. Selected values are given in Section A. Subsequent to the above review the KFK Group has provided additional neutron-resonance calibration points as per the following table (INDC-20L):

O(n,n) resonances Energy(keV)	Width(keV)	ΔE/E
10729.0 ± 1.2	20.0	1×10^{-4}
9414.7 ± 1.0	4.3	1×10^{-4}
7371.6 ± 0.7	3.0	9×10^{-5}
6674.6 ± 0.6	3.8	9×10^{-5}
6075.7 ± 0.6	5.0	8.2×10^{-5}
5369.5 ± 0.5	4.5	8.2×10^{-5}
4594.4 ± 0.4	2.5	8.1×10^{-5}
3443.6 ± 0.2	1.5	5.8×10^{-5}
3441.2 ± 0.2	0.5	5.7×10^{-5}
3211.7 ± 0.2	1.6	5.7×10^{-5}

C(n,n) resonances Energy(keV)	Width(keV)	ΔE/E
6647.8 ± 0.6	4.2	8.2×10^{-5}
4936.8 ± 0.4	3.2	8.1×10^{-5}

NEUTRON ENERGY STANDARDS

G. D. James
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In recent years there have been several examples of discrepancy between the neutron energy scales from different spectrometers. Some of the work undertaken to review and improve neutron energy determination is noted and some suggestions on how errors can be reduced are listed. The view advocated by Youden that the only worthwhile estimates of systematic error are those made experimentally is presented. Comparison of energy determinations for a few resonances show that at best resonance energies can be quoted to an accuracy of about one in 10 000. A list of 41 narrow resonances, over the energy range 0.6eV to 12.1MeV, which should prove suitable as energy standards is given. At present, not all the energies listed are known to the highest accuracy attainable.

(Accurate neutron energy determination, energy standards)

1. Introduction

Neutron energy standards are required to help ensure that all neutron spectrometers produce data on energy scales that agree to within the estimated errors of measurements. Discrepancies in neutron energy scales, of which there have been several examples in recent years, present additional problems for evaluators and compilers, for the users of data, for example those who wish to use transmission data for the calculation of neutron shielding, and for analysts who wish to undertake a combined study of partial and total cross section data. The work required to revise and correct energy scales could be saved if a set of accurately measured resonance energies became available. These could then be checked on each spectrometer, preferably during each experiment. At least one such list has been published[1] but improvements in neutron spectrometer resolution demand that this should be revised or supplemented by much narrower resonances.

As energy measurements become progressively more accurate, several examples of energy discrepancies have arisen some of which have been successfully removed but some of which are still outstanding. A discrepancy of 20keV at 6MeV between measurements made using the $^{2}H(d,n)$ reaction compared with those made using the $^{3}H(p,n)$ reaction was explained by Davis and Noda[2] in terms of a field dependent calibration factor. More recently, a discrepancy of 25keV at 1.5MeV in the energy scale of $^{238}U/^{235}U$ fission cross section measurements as measured on white source spectrometers[3-6] was removed when inadequacies in the method of calibrating one of the spectrometers by the resonance technique were revealed and the results were revised using a direct calibration in terms of measured flight path length[7]. Measurements of the same ratio[8] using a mono-energetic Van de Graaff neutron source give results which are about 20keV above the mean of the broad spectrum measurements. A discrepancy of 7keV, again indicating that data from mono-energetic sources tend to lie higher than white sources, is presented by data on the energy of the peak of the resonance in the total cross section of ^{6}Li near 250keV. The data available on this cross section are presented in sect. 5.1. This resonance is very broad and neither it nor the ^{238}U threshold are suitable for accurate energy comparison. Nevertheless they easily reveal discrepancies which amount to about 1%. Within the group of white source spectrometers the discrepancies are not so large. Böckhoff et al.[9] have shown, however, that the energies of ^{238}U resonances below 2.7keV as measured at Geel and Columbia[10] differ by 0.1%. This difference is almost independent of energy and is equivalent to a 10cm discrepancy in the lengths of the 200m flight paths used in each experiment. This is far greater than the errors of measurement which are about 1cm or less.

As a framework for considering how to improve the measurements and comparison of neutron energies, the methods in use on three spectrometers and the random and systematic errors in each of the methods are briefly reviewed in sect. 2. Some considerations which can help to reduce inaccuracies are described in sect. 5 and the important concept of making experimental measurements of systematic errors, so ably advocated by Youden[11], is presented in sect. 4. Examples of the accuracies which are achieved in energy measurements at present are discussed in sect. 5 where the results available from transmission measurements for ^{6}Li, ^{23}Na, ^{238}U and ^{12}C are discussed. In sect. 6 a list of forty-one resonances over the energy range 0.6eV to 12.1MeV is presented. This list was drawn from examples of narrow resonances kindly suggested to me by members of an INDC sub-group on neutron energies*. It does not yet carry the imprimatur of the sub-group but it is likely that the list finally adopted will contain most if not all the resonances given in sect. 6. The establishment of a recognised list of resonances is important in that it will encourage the measurement and intercomparison of the energies of these resonances by scientists who recognise the need to establish accurate energy scales for their spectrometers. The conclusions that can be drawn from the studies presented in this paper are discussed in sect. 7.

2. Neutron resonance energy determination

Two methods of neutron energy determination are in use; those based on neutron time-of-flight and those based on the uses of mono-energetic charged particles to produce mono-energetic neutrons. The

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former require pulsed sources and spectrometers based on electron linear accelerators, cyclotrons, synchrocyclotrons and pulsed Van de Graaff machines are in operation. The latter method is based exclusively on Van de Graaff machines which alone can produce charged particle beams with energies known to sufficient accuracy. In this section the methods used to determine energy on three spectrometers which are typical of the range of instruments in use are presented so that the relative magnitudes of random and systematic errors can be more readily appreciated.

2.1 Neutron energy determination at ORELA

In the ORELA neutron time-of-flight spectrometer, short bursts of 140MeV electrons of minimum width 5ns strike a water cooled tantalum target to produce bursts of fast neutrons which are moderated in water to produce a pulsed source of neutrons covering the energy range from several MeV down to the Maxwellian spectrum at thermal neutron energy. Neutrons are detected by a detector set at a known distance from the source. Part of the interval between the time when the neutrons are produced and the time when neutrons are detected is measured and recorded by a time digitizer in units of timing channel width which have a minimum value of 2ns. Another part of the interval is determined by the delay between the electron pulse and the opening of the first timing channel - the so called initial delay. As an example[12] to illustrate the contribution of systematic and random errors, in an experiment to measure the transmissions at a path length of 135441 ± 10mm, the following equations are used to derive neutron energy E_c and the relativistically corrected energy E_R

$$E_c = \frac{72.2977(135441-10\text{mm})^2}{t-(2695\pm 2\text{ns})} \qquad \ldots 1(a)$$

$$E_R = E_c(1 + 1.5965\ 10^{-9}E_c) \qquad \ldots 1(b)$$

Here 2695 ± 2ns is the initial delay and t is the part of the flight time recorded on the time digitizer. Examples of the results obtained for a few selected resonances in Pb, Al, S, Na and ^{238}U are given in table 1 which gives the contribution to the quoted uncertainty made by dE_{ch}, the error in locating the peak of the resonance, dE_t the error in energy due to the 2ns uncertainty in the initial delay and dE_L the error in energy due to the 10mm uncertainty in the neutron flight path. Below the Al resonance at 5903.5eV the error is dominated by the uncertainty in flight path length. Above this energy the error is dominated by the error in locating the peak of the resonance by the fitting programme SIOB.

2.2 Neutron energy determination on the Harwell Synchrocyclotron

In the Harwell synchrocyclotron neutron time-of-flight spectrometer, pulses of protons are accelerated to an energy of 140MeV and deflected downwards to strike a 2cm thick tungsten target to produce fast neutrons by spallation. The salient features of the target and detector system are illustrated in fig. 1. Fast neutrons from the proton target reach a 2cm thick beryllium faced water moderator tank from which a pulse of moderated neutrons travels towards the detector.

Table 1

ORELA 150m Neutron Energies

Isotope	Resonance Energy (eV)	dE_{ch} (eV)	dE_t (eV)	dE_L (eV)	BNL-325[13] (eV)
^{206}Pb	3357.4 ±0.5	0.1	0.07	0.43	3360 ±10
^{27}Al	5903.5 ±0.8	0.3	0.16	0.76	5903 ± 8
^{32}S	30378 ±6	4	2	4	30350 ±90
^{23}Na	53191 ±27	26	4	7	53150 ±30
^{206}Pb	71191 ±18	14	6	9	71000 ±100
^{32}S	97512 ±28	22	10	13	96600 ±500
^{32}S	112186 ±33	27	12	14	111400 ±500
^{27}Al	257.3 ±0.3*	276	41	33	257.5 ±1.8*
^{238}U	1419.76±0.18	0.04	0.02	0.18	1419.5 ±0.3
^{238}U	2489.18±0.32	0.03	0.04	0.32	2488.4 ±0.7

*keV

Since late 1973 transmission measurements have generally been carried out using either a 2.5cm thick Li-glass detector at 50m or using a 1.2cm thick NE110 detector at 100m. The 50m measurements give results over the energy range 100eV to 100keV and the 100m measurements give results over the energy range 10keV to 10MeV. During 1974 the distances between reference marks at 1m, 4m, 13m, 49m and 98m from the neutron source were measured to better than 0.5mm accuracy by a tellurometer*. The equations used to determine neutron energy are set out in Appendix 1 where the symbols used have the following meaning. L is the distance from the face of the moderator to the point in the detector where a neutron interacts to give a detectable pulse. It is made up of the moderator face to detector face distance P and the distance D traversed inside the detector. The neutron time-of-flight is the difference between the time t_{no} when a neutron leaves the face of the moderator and the time t_n when it is detected. Using $t_{\gamma o}$, the time when γ-rays and fast neutrons leave the proton target, and t_γ when the γ-flash is detected, t can be re-stated in terms of t_1, the recorded time between the detected γ-flash in channel Xo and a neutron in channel X, t_2 the γ-ray time-of-flight over a distance L_γ, t_3 the transit time of fast neutrons from the proton target to the water moderator and t_4 the neutron slowing down time delay. The channel width is denoted by w, D_γ is distance travelled by γ-rays in the detector and S_γ is the distance travelled by γ-rays to reach the face of the moderator from which they emerge. In calculating the transit time of fast neutrons it is assumed that detected neutrons of energy E are produced by neutrons of energy 2E. The slowing down time delay is calculated from the formulae of Groenewold and Groendijk[14]. In an experiment to determine the energy of the peak of the resonance near 250keV in the total cross section of ^6Li carried out in 1974, the Li-glass detector was used, exceptionally, at 100m. In the same experiment the energies of three peak cross sections in ^{23}Na and ^{27}Al were also determined. A careful assessment of the errors arising in the measurement have been made[15] and are presented in table 2.

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Table 2

Harwell Synchrocyclotron 100m Neutron Energies

Isotope	Resonance Energy (keV)	dE_{ch} (eV)	dE_t (eV)	dE_L (eV)
Al-27	119.753±0.042	3	18	28
Li-6	242.71 ±0.34	330	68	58
Al-27	257.16 ±0.13	90	74	62
Na-23	299.19 ±0.12	15	97	72

2.3 Energy measurements at the Argonne Fast Neutron Generator.

Recently, Meadows[16] has undertaken a close scrutiny of the techniques involved in energy determination at the Argonne FNG when used as a source of mono-energetic neutrons. Yield curves and neutron energy spectra were calculated for some (p,n) reactions commonly used as neutron sources for energy calibration purposes. These calculations take into account the energy spread of the incident proton beam and the statistical nature of the proton energy loss. Meadows shows that when thresholds are observed by detecting neutrons at 0 deg. to the proton beam direction, the best results are obtained by plotting the square of the yield against proton energy and extrapolating to zero yield. A linear plot of neutron yield against proton energy can be in error by 1 - 2keV if the energy spread of the proton beam is large. A calibration was established by locating the $^{7}Li(p,n)^{7}Be$ threshold (1880.60 ± 0.07keV) and the $^{11}B(p,n)^{11}C$ threshold (3016.4 ± 1.6keV). Using this calibration a measurement of a carbon resonance gave the value for a mean over five target thicknesses of 2078.2 ± 2.8keV. This error allows for systematic uncertainties. The error in the mean derived from the spread of the five readings is 0.67keV. The calibration was also confirmed by a neutron time-of-flight measurement which at E_n= 2.7739 ± 0.0046MeV gives E_p = 4.4624 ± 0.0046MeV to be compared with the value E_p = 4.466 ± 0.004MeV derived from the analysing magnet calibration.

3. Reduction of uncertainties

Several techniques are available which can be used to reduce uncertainties in some of the quantities involved in the determination of neutron energy. Five of these are discussed in this section.

3.1 Effect of resolution on s-wave resonance energies

In total cross section and transmission measurements, s-wave resonances show a marked asymmetry caused by resonance-potential interference which causes a minimum on the low energy side of the resonances. With worsening energy resolution, the energy at the observed peak of the cross section, E_M, shifts to higher energy and the energy difference between the peak and the interference minimum, observed at E_m, increases. This effect is illustrated for the 299keV resonance in Na, in fig. 2 which is taken from a paper by Derrien[17]. Derrien shows that provided both E_M and E_m are known, the effects of spectrometer resolution can be allowed for to derive E_r, the energy at the resonance peak observed with perfect resolution. Values of E_r derived from six measurements of different resolution are illustrated in fig. 3. The mean of the six values of E_r is 298.65 ± 0.32keV. Even after carrying out the correction, however, only the three measurements with the best energy resolution agree within the error in the mean. Taking these three values only, the mean value of E_r is 298.550 ± 0.082keV which corresponds to an error of one in 3650. This effect of energy resolution on asymmetric s-wave resonances makes them less suitable for accurate energy comparison than symmetric resonances.

3.2 Cumulative probability plot

Fitting programmes such as SIOB in use at Oak Ridge[18] are not always available for the determination of the position of the peak of a resonance in energy or time. When the observed shape of a resonance is Gaussian, or at least close to symmetric, the error in deducing the position of the resonance peak can be considerably reduced by the use of a cumulative probability plot (ogive curve) in which, after the subtraction of a suitable background representing the neighbouring value of the data, the data (cross section, transmission or observed counts per timing channel) are treated as probability values and plotted on probability graph paper against timing channel number. The linear portion of the graph is fitted by the least squares method to derive the timing channel corresponding to the centre of the resonance at 50% probability. Half a channel must be added to the result obtained because of the binning of data into channels. This technique readily allows peak positions to be estimated to within an error of 0.1 channels or less and an example is shown in fig. 4. The extent to which the resonance shape is not normal is immediately apparent. Only the linear portion of the curve is fitted and the error derived reflects any departure from normality.

3.3 The $\Delta L/\Delta t$ method

In deriving neutron energies by the direct method set out in sect. 2.2 and in Appendix 1, it will be seen that several of the quantities involved can only be estimated with relatively large uncertainties. These quantities are the distance D traversed by a neutron within the detector before detection, the energy, transit distance and transit time, t_3, of the fast neutrons which generate the neutrons under consideration, the slowing down time delay t_4 and any difference δ, caused by differences in pulse shape, between the detection of neutrons and coincident gamma rays. It is shown in Appendix 1 that all these quantities can be removed from the equations used to determine energy if the neutron flight times t_1 and t_2 are measured with the same detector at two path lengths L_1 and L_2. However, a disadvantage of the method is that the effective path length is reduced to $\Delta L = L_1 - L_2$. In principle the method allows $(t_3 + t_4)$ to be measured but only at the expense of re-introducing the poorly known quantities D, $L_{\gamma 1}$, $L_{\gamma 2}$ and δ. However, by careful design, such as the use of thin detectors to reduce D, improved measurements of $(t_3 + t_4)$ could be made.

3.4 Y^2 - H Method

This method, described by Meadows[16], for reducing the error in determining the energy at the threshold of a (p,n) reaction has been described in sect. 2.3.

3.5 Effect of counting statistics on the energy uncertainty

In their measurement of the ^{6}Li total cross section peak energy, the statistical quality of the data was not good but James et al.[15] were able to

derive accurately the error in determining the peak energy caused by the errors in the counts per timing channel. This was done using random number (Monte Carlo) techniques to vary each measured transmission datum by an amount controlled by the normal law of errors and by the standard deviation of each datum. The data set obtained in this way was fitted and another estimate of peak cross section energy obtained. This process was repeated ten times to get a measure of the spread of the values derived. In this numerical experiment, uniform pseudo-random variates were converted to normal variates using the simple but exact Box-Müller transformation[19]. It was found that even for the broad resonance near 250keV in ^{6}Li the peak could be located to an error of 0.33keV.

4. Experimental determination of systematic errors

When a constant has been measured in several independent studies, it becomes necessary to undertake some data evaluation with the aim of determining a best value and of setting some limit to the error in this best value. In a series of papers which are models of clarity, W.J. Youden[111] has shown that the aim should be to establish 'enduring values' which are best values with an error range within which future best values will lie. By examining fifteen values of the astronomical unit measured between 1895 and 1961 and 21 measured values of the velocity of light, Youden shows that, as so often happens, the data differ from one another by more than would be expected from the ascribed estimates of uncertainty. He attributes this to a poor assessment of systematic errors and argues that the only worthwhile estimates of systematic errors are those which are made experimentally. To achieve this it should be noted that when an experiment is done at another laboratory everything gets changed whereas an investigator at one laboratory makes only minor changes to his equipment. Youden argues elegantly for making a direct experimental assessment of systematic errors by planning experiments in which everything which could make a difference to the experiment, and even a few things which are regarded as not affecting the measurement, is changed. Often the things or quantities changed will have only two descriptions or values but the benefit in bringing systematic errors to light will be immense. The time devoted to the experiments need not increase inordinately. Clearly, more will be learnt by making six changes and accumulating data for a sixth of the time after each change than if no changes are made. Youden also clearly shows that if the changes are properly planned a large reduction in the error in the mean can be achieved by changing more than one thing at a time. Many papers on the way such experiments should be planned are now available, some in the collection of Ku[20].

5. Comparison of data for certain resonances

In this section the data available on single resonances in Li, Na and C and five resonances in ^{238}U are presented. Average values derived by taking the best value from each laboratory are given and used to produce a comparison factor G which equals the mean value divided by the error in the mean. The resonances selected differ markedly from one another. The resonance near 250keV in ^{6}Li is broad and will not be used as an energy standard but it is interesting to note the accuracy achieved for the quoted peak cross section energy. This resonance also shows the importance of measuring a well defined quantity such as the energy at the maximum of the cross section rather than the value of the 'resonance energy' which appears in the theoretical expression for the cross section. The resonances in Na and ^{238}U are s-wave resonances, which in the case of Na have been corrected by Derrien for the effects of instrumental resolution, whereas the resonance in carbon has $l = 2$ and is symmetric.

5.1 The resonance in ^{6}Li total cross section near 250keV

Values of the energy at the maximum of the ^{6}Li total cross section near 250keV are available from four white source time-of-flight measurements and from four mono-energetic measurements on Van de Graaff accelerators. The data are presented in table 3 and illustrated in fig. 5 in chronological order. The data of Harvey and Böckhoff have been reanalysed using the formulae used initially by Uttley and then by James so that there is no difference in the method of analysis for the four time-of-flight values quoted. The average of these values is 244.0 ± 0.5keV corresponding to G = 488. This contrasts with the four mono-kinetic beam Van de Graaff measurements all of which lie at or above 246keV. In fairness to the early measurers it must be stated that the energy at the peak was not a prime consideration in these papers and no errors are quoted on the values given. The errors of ±1keV given in the table are judgements made by experienced workers. The value of 0.33keV given by James et al.[15] is derived from a careful assessment of all the errors involved in their measurement including, as described in sect. 3.5 above, the effect of limited counts per timing channel on the energy derived. It is likely that an experimental determination of systematic errors as advocated in sect. 4 above would lead to an upward revision of this error.

Recently a value, given preliminarily as 242 ± 2keV, has been measured by time-of-flight on a Van de Graaff in an experiment which allows the succeeding gamma flash to fall at the peak of the ^{6}Li resonance. If confirmed, this would reduce the average of all measurements made by the time-of-flight method of 243.60 ± 0.58keV.

Table 3

Neutron energy at the maximum of the ^{6}Li total cross section

Author	Year	E(max) (keV)
Hibdon & Mooring[21]	1968	246
Farell & Pineo[22]	1968	250.6
Meadows & Whalen[23]	1972	252.5
Uttley[24]	1975	*243.5 ± 1
James et al.[15]	1975	*242.71 ± 0.33
Harvey et al.[25]	1975	246 ± 1
Harvey (James)	1975	*244.8 ± 1
Böckhoff et al.[9]	1975	245.0 ± 1
Böckhoff (James)	1975	*245.0 ± 1
Knitter[26]	1976	247.0 ± 3
Average of values marked *		244.0 ± 0.5

5.2 The resonance in ^{23}Na at 298.550 ± 0.082keV

As discussed in sect. 3.1, the data available on the observed peak energy E_M for the s-wave resonance near 299keV in ^{23}Na have been corrected by Derrien[17] for the effects of instrumental resolution. The values of E_M and the values of E_r which would be observed with perfect resolution are illustrated in

fig. 3 and listed in table 4. The mean of the three values with the best energy resolution corresponds to $Q \approx 3640$

Table 4

Observed and corrected peak energy values for the 298.55keV resonance in Na

Origin	E_H(keV)	E_r(keV)
Saclay II	298.94 ± 0.37	*298.39 ± 0.37
Karlsruhe	299.26 ± 0.20	*298.66 ± 0.20
Columbia	298.5 ± 1.0	297.35 ± 1.0
Harwell S.C.	299.2 ± 0.2	*298.6 ± 0.34
Cadarache	302 ± 4	299.4 ± 4.0
Saclay I	303 ± 3	299.5 ± 3.0
Average		298.65 ± 0.32
Average of values marked *		298.550 ± 0.082

5.3 Five resonances in ^{238}U

It is suggested in sect. 6 that resonances in ^{238}U could be selected for use as standard over the energy range 6eV to 3keV. The data available on five of these resonances are presented in table 6. All the measurements made at the Harwell synchrocyclotron used a Li-glass detector. A 50m measurement was made in August 1976. For other reasons, the flight path was then raised by 3cm and the source geometry was altered so that the water moderator stood in front of the proton target instead of underneath it. Energy measurements of ^{238}U resonances were then made, in November 1976, both at 50m and at 100m. Results were also derived using the $\Delta L/\Delta t$ method discussed in sect. 3.3. The $\Delta L/\Delta t$ method is based on the same data as the two other results obtained in November and the correct method of deriving the best value and an error in this best value remains to be formulated. For the present, the four results obtained for each resonance are regarded as independent and the average value is given. However, the error quoted in the average value is that for an individual reading derived from the spread of the measurements. Results from Oak Ridge for three of the resonances were not available to me when the table was prepared. An unweighted average from all laboratories together with an error in the mean derived from the spread is also given. The agreement between Harwell and Oak Ridge is well within the quoted errors and all the Harwell values are within the quoted range of the average from all laboratories. The discrepancy between Geel and Columbia has already been noted[27]. The results for the resonance at 2489.47 ± 0.5eV are illustrated in fig. 6.

5.4 The resonance in carbon at 2078.05 ± 0.32keV

The data available on the energy of the resonance in the total cross section of carbon near 2078keV are presented in table 5. Two measurements were made on the Harwell synchrocyclotron in August 1976 one using a Li-glass detector at 50m and one using an NE110 detector at 100m. The value obtained from the measurements by the $\Delta L/\Delta t$ method are also given although, with two dissimilar detectors, the distances D travelled by neutrons within the detectors are not eliminated from the equations. Source distance uncertainties are, of course, still eliminated. The measurements of Heaton et al. and of Meadows were made on Van de Graaff accelerators by the mono-energetic beam technique. All the other measurements are made by neutron time-of-flight. The excellent agreement between the two methods is clear. The three central values are quoted more precisely than the others. Taken alone these values have an average of 2078.11 ± 0.16keV corresponding to 3 greater than 10 000.

Table 5

Measured peak energy for the resonance in carbon at 2078.05 ± 0.32keV

Reference	Date	Energy - keV
Harwell 50m	Aug 1976	2079.2 ± 1.1
" 100m	Aug 1976	2078.31 ± 0.44
" $\Delta L/\Delta t$	Aug 1976	2077.45 ± 0.84
" Average*		2078.33 ± 0.89
Davis & Noda[2]	1969	2079 ± 3
Heaton et al.[28]	1975	2079 ± 3
James	1977	2078.33 ± 0.89
Meadows[16]	1977	2078.2 ± 2.8
Perey et al.[29]	1972	2077.8 ± 1.5
Bockhoff et al.[9]	1976	2077 ± 1
Cierjacks et al.[30]	1968	2077 ± 1
Average**		2078.05 ± 0.32

*Error in individual reading derived from spread of the data

**Error in the mean derived from spread of the data

6. Resonances for use as energy standards - a selected list

To compare the energy scales of different spectrometers and thereby help to establish accurate energy standards it is necessary that those concerned with this task should all make measurements on the same set of resonances. To promote this development the INDC set up a sub-group with the task of producing a list of suitable resonances. Seventy-six narrow resonances were suggested in the energy range 0.6eV to 12.1MeV. This list is probably too long and I have reduced it by selecting about six resonances in each decade which have the smallest value of $(\Gamma + \Delta)/E$. Here Γ is the resonance width, Δ is the Doppler width and E is the resonance energy. The reduced list of forty-three resonances is presented in table 7. The resonances are all in the total cross section of the eleven elements listed. Apart from sodium and iridium, all the elements are commonly occurring, readily available and easily fabricated into suitable transmission samples. The energies given are listed as nominal energies to emphasise the fact that they do not represent evaluated data. Nevertheless the best values of energy available are given wherever possible. No errors are given for the U-238 resonances of ref.(12) but it is known that the errors are likely to be of the order of 1 in 5000. The distribution of the resonances listed is shown in fig. 7. It will be seen that the largest gaps on a logarithmic energy scale are between 0.6eV and 6eV and between 6keV and 30keV. It may be necessary to augment the list within these ranges.

As more data become available more stringent evaluation of the energies of the resonances listed in table 7 will be possible. Evaluators may then reasonably demand that the only data to be considered are those for which full details of all steps in the

Table 6

Measured peak energies for five resonances in ^{238}U

Origin	Energy - eV				
Harwell 50m Aug 1976	145.634 ± 0.037	463.23 ± 0.12	708.44 ± 0.19	1420.12 ± 0.045	2490.16 ± 0.40
" 50m Nov 1976	145.578 ± 0.051	462.93 ± 0.15	708.62 ± 0.27	1419.56 ± 0.35	2489.96 ± 1.1
" 100m Nov 1976	145.593 ± 0.033	463.09 ± 0.12	708.09 ± 0.13	1419.80 ± 0.34	2489.26 ± 0.79
" ΔI/Δt Nov 1976	145.606 ± 0.071	463.24 ± 0.25	707.59 ± 0.29	1420.02 ± 0.46	2488.61 ± 1.54
Harwell average*	145.603 ± 0.024	463.12 ± 0.14	708.18 ± 0.45	1419.88 ± 0.25	2489.50 ± 0.71
Oak Ridge[12]				1419.76 ± 0.19	2489.18 ± 0.42
Geel[27]	145.68 ± 0.10	463.62 ± 0.20	708.59 ± 0.25	1420.7 ± 0.3	2490.8 ± 0.4
Columbia[10]	145.57 ± 0.15	462.8 ± 0.4	707.9 ± 0.4	1419.2 ± 0.3	2488.4 ± 0.7
Average**	145.617 ± 0.033	463.18 ± 0.24	708.22 ± 0.20	1419.88 ± 0.32	2489.47 ± 0.5
G	4412	1929	3541	4437	4978

*Error quoted here is that in an individual reading derived from the spread of four values
**Error in the mean derived from the spread is quoted

energy determination are published. At present, such a demand would mean that almost no resonance energy data could be evaluated.

7. Conclusion

This report has reviewed the methods of neutron energy determination in such a way as to indicate the sources of error, and methods whereby some of the errors can be reduced have been described. The errors quoted on published energy values are often derived from reasoned judgements by experienced scientists. Better estimates of the systematic errors would clearly be derived by adopting the suggestion made by Youden that as many experimental components as possible should be deliberately varied preferably more than one at a time in a planned way. From a comparison of the data available on certain resonances it appears that at best energy measurements from different laboratories agree to a fraction approaching one in 10 000. Furthermore, the work of Meadows has shown that with the development of careful methods there is no discrepancy between monoenergetic and white source measurements. A list of forty-three narrow resonances suitable for energy comparison and calibration has been drawn up which may encourage experimentalists to measure the energies of the resonances listed both as a means of improving energy standards and also as a means of keeping a continual check on the energy scales of their spectrometers. The confirmation of at least one energy from a list such as that in sect. 7 should be encouraged whenever changes are made which could result in a changed energy scale. Very few papers have been published giving the full details of energy determination which could reasonably be demanded by an evaluator. It is hoped that this situation will change and that soon energy values from fully documented published sources will be available for all the resonances used in energy intercomparisons.

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It is a pleasure to acknowledge the interest taken in this work by Basil Rose who in the course of lively discussions suggested the use of the ogive curve method and stimulated the development of the ΔI/Δt method. Experiments on the synchrocyclotron enjoy the unstinting support of Colin Whitehead and the active participation of P. H. Bowen, A. D. Gadd, D. B. Syme and I. L. Watkins. Many of the energy calculations were carried out by A. D. Gadd.

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Table 7

Narrow resonances suitable for use as energy standards

Energy Range (eV)	Isotope	Nominal Energy		Order*	Reference
0.1 - 1	Ir-191	0.6551	± 0.0014	1	13
1 - 10	U-238	6.672		1	12
10 - 100	U-238	10.236		5	12
	U-238	20.864		4	12
	U-238	36.671		3	12
	U-238	66.015		2	12
	U-238	80.729		1	12
100 - 1000	U-238	145.617	± 0.033	7	Table 5
	U-238	189.64		8	12
	U-238	311.18	± 0.25	5	13
	U-238	397.58		4	12
	U-238	463.18	± 0.24	3	Table 5
	U-238	619.95		2	12
	U-238	708.22	± 0.20	1	Table 5
	U-238	905.03		6	12
1000 - 10 000	U-238	1419.88	± 0.32	7	Table 5
	U-238	1473.8		5	12
	U-238	2489.47	± 0.5	3	Table 5
	U-238	2672.2		4	12
	Pb-206	3360	±10	8	13
	U-238	3458.1		6	12
	U-238	4512.0		2	12
	U-238	5650.6		1	12
	Al-27	5903	± 8	9	13
(keV)		(keV)			
10 - 100	S-32	30.378	± 0.006	3	12
	Na-23	53.191	± 0.027	6	12
	Si-28	67.73	± 0.02	5	31
	Pb-206	71.191	± 0.018	4	12
	Fe-56	90.134	± 0.016	2	32
	S-32	97.512	± 0.028	1	12
100 - 1000	S-32	112.186	± 0.033	3	12
	Fe-56	266.347	± 0.053	2	32
	S-32	412.3		1	31
	S-32	818.7		6	31
1000 - 10 000	O-16	1651	± 2	6	13
	C-12	2078		5	33
	C-12	2818	± 4	3	13
	O-16	3211.1	± 1.5	1	13
	C-12	6293	± 5	2	13
10 000 - 100 000	C-12	12100	± 100	1	

*Order of $(\Gamma+\Delta)/E$ within an Energy Range

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Appendix 1

DETERMINATION OF NEUTRON ENERGY

DIRECT METHOD

$L = P + D$

$t = t_n - t_{n_o}$

$= (tn - t_\gamma) + (t_\gamma - t_{\gamma_o}) - (t_{n_o} - t_{\gamma_o})$

$= t_1 + t_2 - (t_3 + t_4)$

$= (x - x_o)\, w + L_\gamma/0.29979$ - (fast transit time + slowing down time delay)

$L_\gamma = P + D_\gamma + S_\gamma$

$\beta = L/(t \times 0.29979)$

$E = 469776.3\ (\beta^2 + 0.75\beta^4)$

$\Delta L/\Delta t$ METHOD

Perform experiment at L_1 and L_2

$L_1 = P_1 + D$

$t_1 = (X_1 - X_{O1} + \delta)w + L_{\gamma 1}/0.29979 - (t_3 + t_4)$

$L_2 = P_2 + D$

$t_2 = (X_2 - X_{O2} + \delta)w + L_{\gamma 2}/0.29979 - (t_3 + t_4)$

$L_{\gamma 1} = P_1 + D_\gamma + S_\gamma$; $L_{\gamma 2} = P_2 + D_\gamma + S_\gamma$

$\Delta L = P_1 - P_2$

$\Delta t = (X_1 - X_{O1})\, w - (X_2 - X_{O2})\, w + (P_1 - P_2)/0.29979$

$\beta = \Delta L/(\Delta t \times 0.29979)$

$E = 469776.3\ (\beta^2 + 0.75\beta^4)$

Note: δ D D_γ S_γ and $t_3 + t_4$ are removed

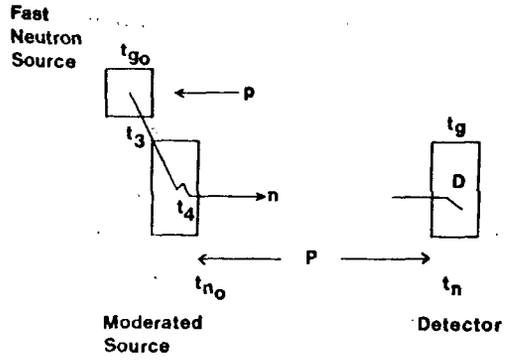

Fig. 1 Arrangement of target and detector in the Harwell synchrocyclotron neutron time-of-flight spectrometer illustrating some of the symbols used in Appendix 1.

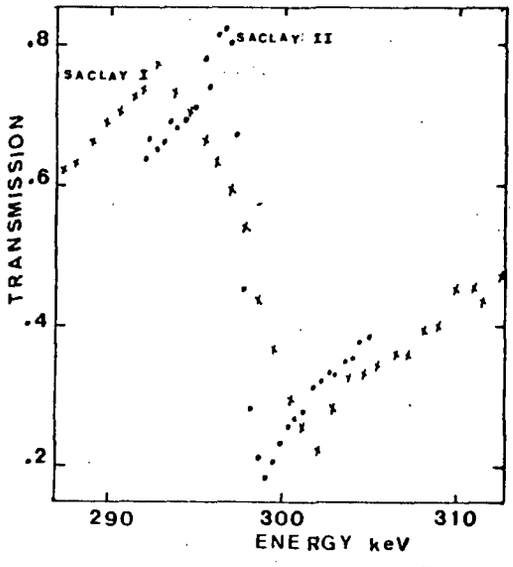

Fig. 2 The transmission of sodium near the resonance at 299keV measured with good resolution, Saclay II, and poor resolution, Saclay I, as presented by Derrien[17]. It illustrates the effect of resolution on the observed energy of the transmission maximum and minimum.

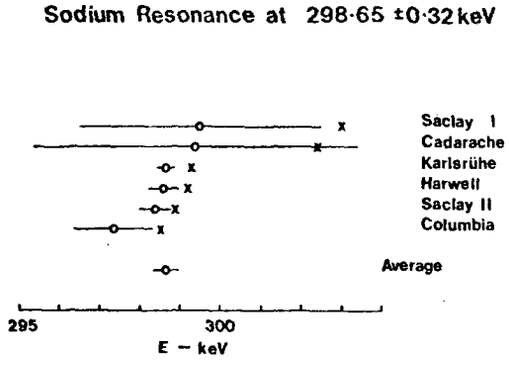

Fig. 3 The energy of the sodium resonance at 298.65 ± 0.32keV as measured in six laboratories (X) and the values obtained by Derrien[17] after correcting for the effect of spectrometer resolution (O).

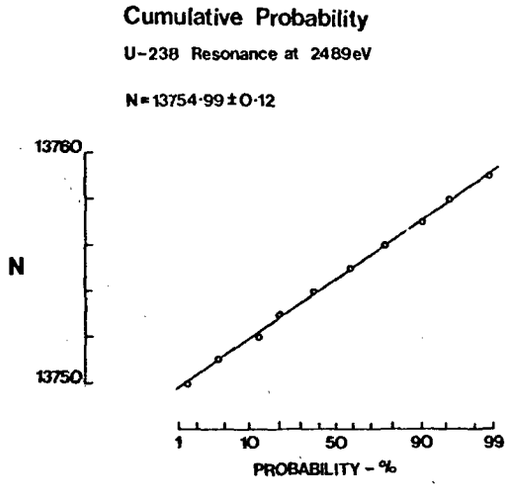

Fig. 4 Cumulative probability distribution for the transmission of a resonance in U-238 at 2489eV. A least squares fit to the data plotted on probability graph paper enables the resonance timing channel N to be located to 0.12 units.

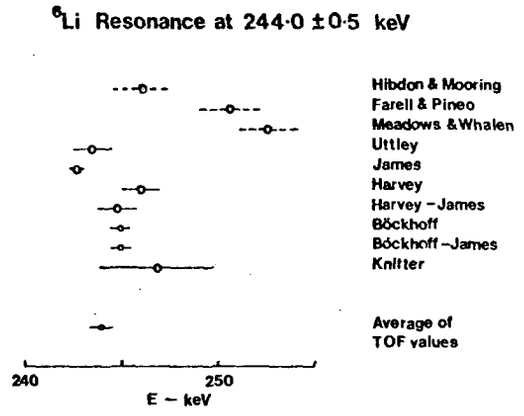

Fig. 5 Energies at the peak of the ^{6}Li total cross section near 250keV.
(James) denotes results obtained after fitting the data by the formulae used by Uttley and by James. The average of results obtained by time-of-flight experiments is 244.0 ± 0.5keV

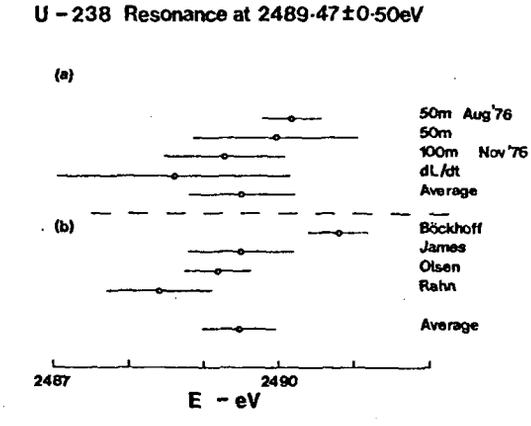

Fig. 6 An illustration of the data for the resonance in the total cross section of ^{238}U at 2489.47 ± 0.5eV presented in table 6.

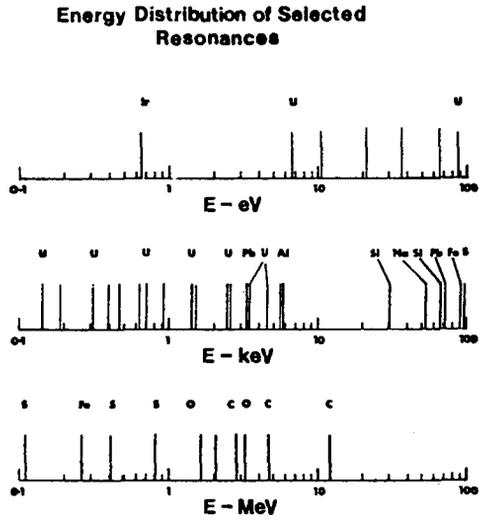

Fig. 7 Energy distribution of narrow resonances selected as suitable for use as standards. The largest relative gaps are between 0.6eV and 6eV and also between 6keV and 30keV.

B-XIV. THE $^{27}Al(n,\alpha)^{24}Na$ CROSS SECTION

A. Summary

This activation reaction is recommended as a Category-I dosimetry reference and is widely employed as a standard in dosimetry and activation meaurements. The previous report (INDC-30/L+SP) pointed out that the desired accuracies of 5%, implied by a Category-I dosimetry status, had not been generally achieved and that the reference evaluation (ENDF/B-V) was not contemporary. 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 S. Tagesen and H. Vonach (Evaluation of the cross sections for the reaction $^{27}Al(n,\alpha)^{24}Na$; to be published). The results of this recent work, given in the numerical tables above, generally define the cross section to better than few-percent accuracies from 7-20 MeV. These new results are compared with the previous evaluation (ENDF/B-V) in Fig. 1. The two evaluated cross-section sets are very similar in magnitude throughout the energy range of appreciable magnitude but the later work implies a greatly improved accuracy that is now consistent with the 5% uncertainties usually associated with a Category-I dosimetry reference standard. Indeed, the quoted evaluated accuracies in the region about 14 MeV make this a very well known standard suitable for a wide spectrum of measurement applications.

B. 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 matrixes 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, due 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%. 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% 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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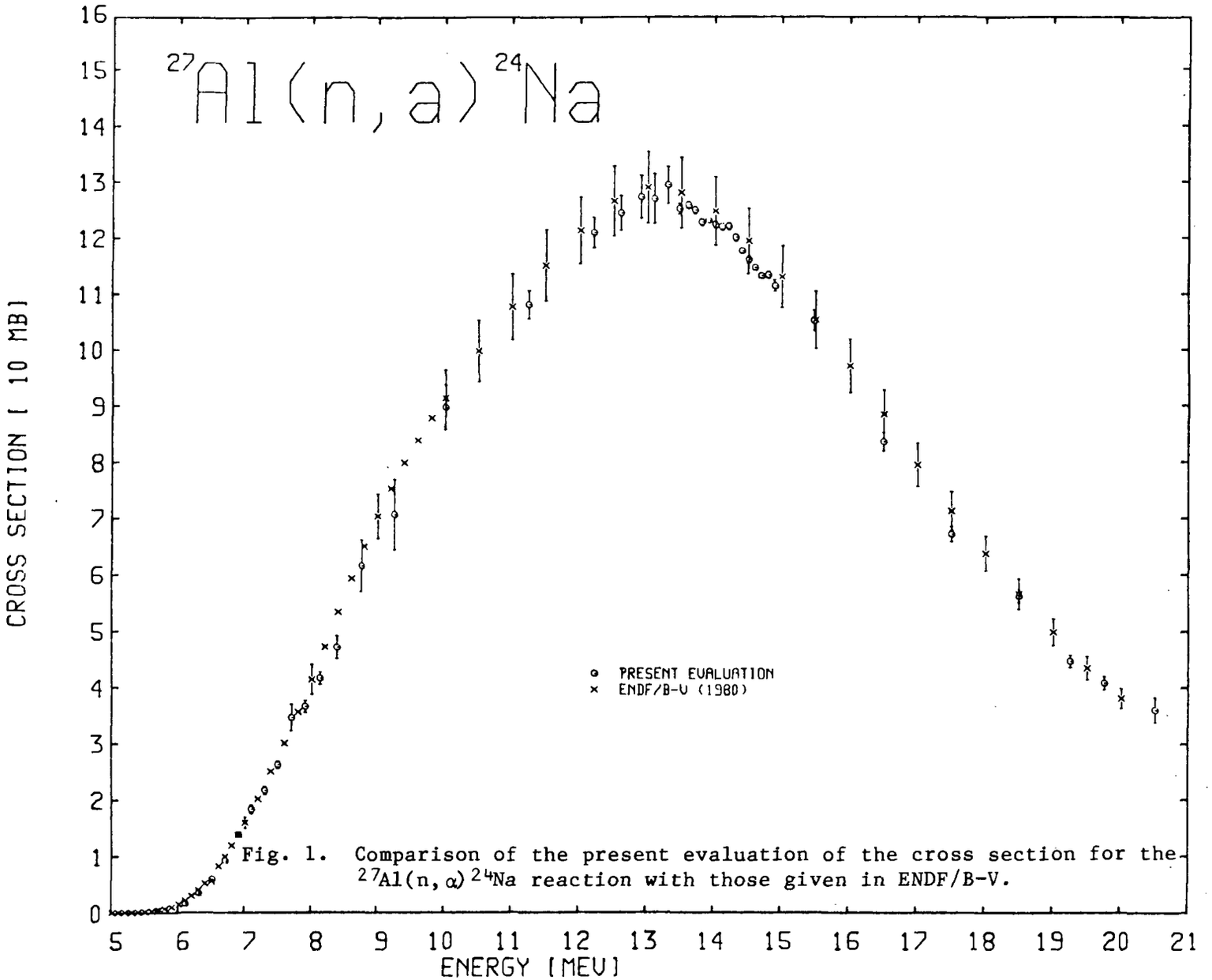

Fig. 1. Comparison of the present evaluation of the cross section for the $^{27}Al(n,\alpha)^{24}Na$ reaction with those given in ENDF/B-V.

B-XV. ^{238}U FISSION CROSS SECTION

A. Justification and Use

This cross section is a useful reference standard in fast-neutron flux determinations, relative fission-cross-section measurements and in 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.

B. Status

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

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 employing 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 above tabulation.

Illustrative comparisons of the above 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.

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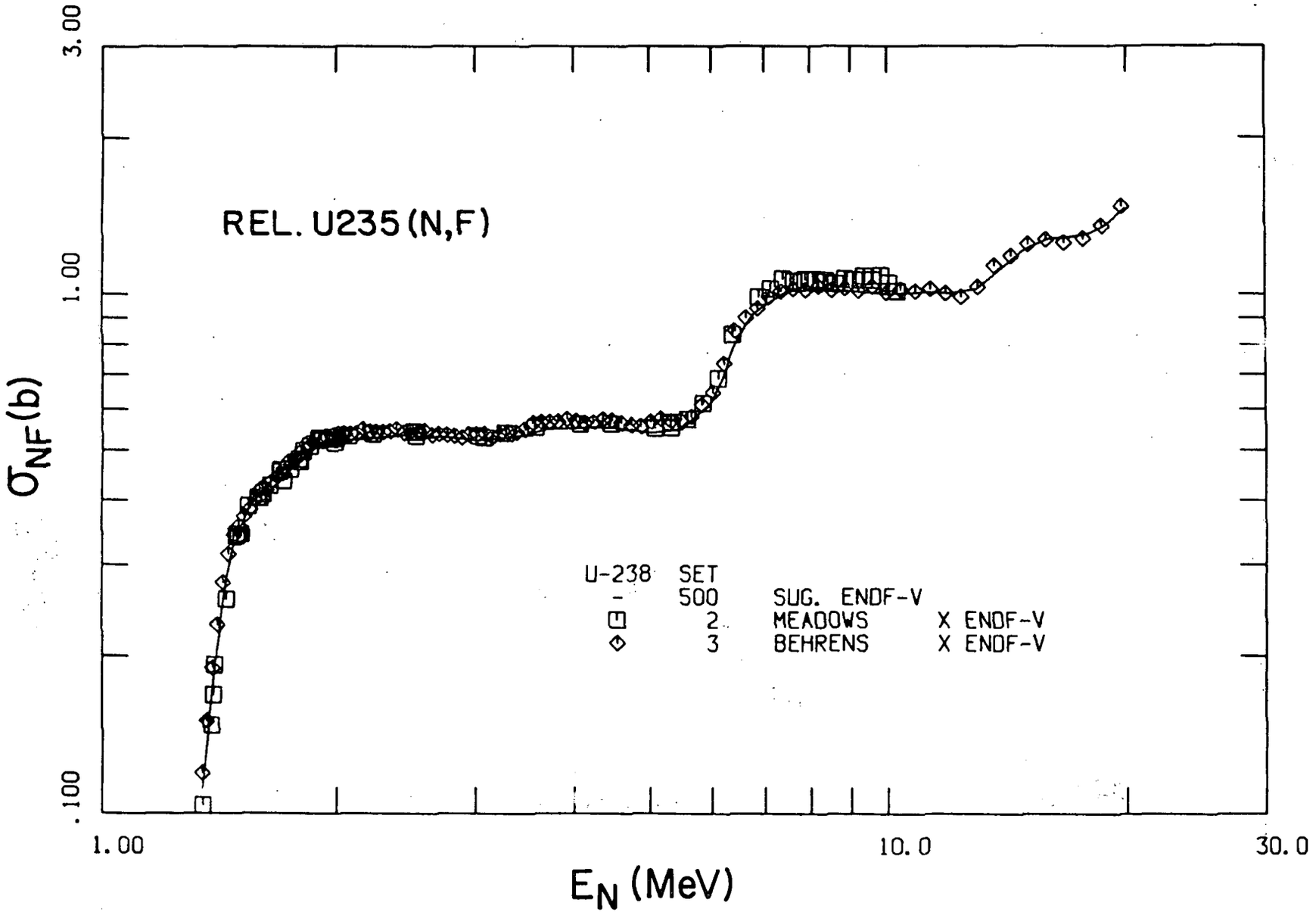

Fig. 1. Comparison of the ENDF/B-V evaluated data with values implied by the measurements of Refs. 4 and 5.

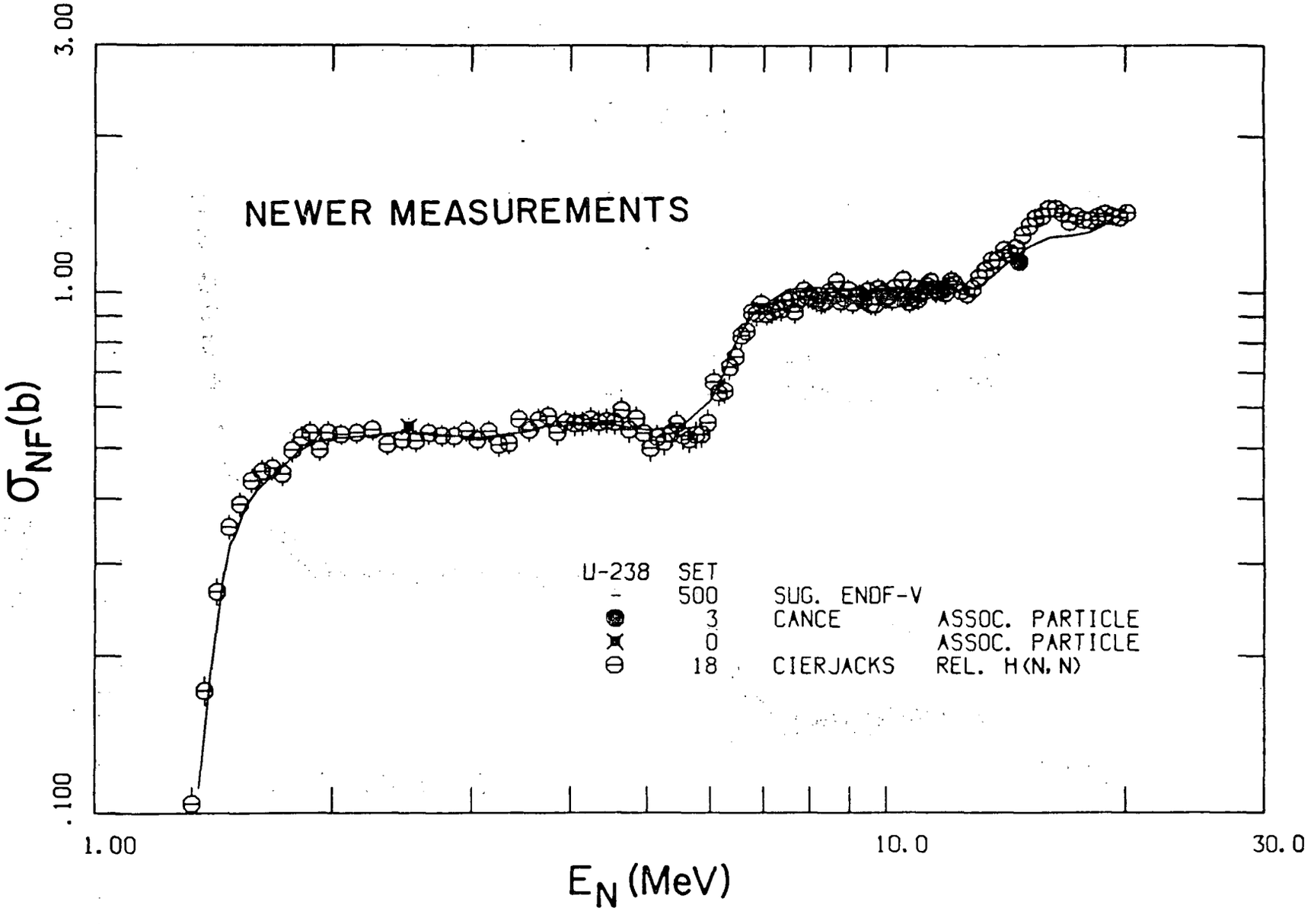

Fig. 2. Comparison of the ENDF/B-V evaluated data with the experimental results of Refs. 1 and 8.

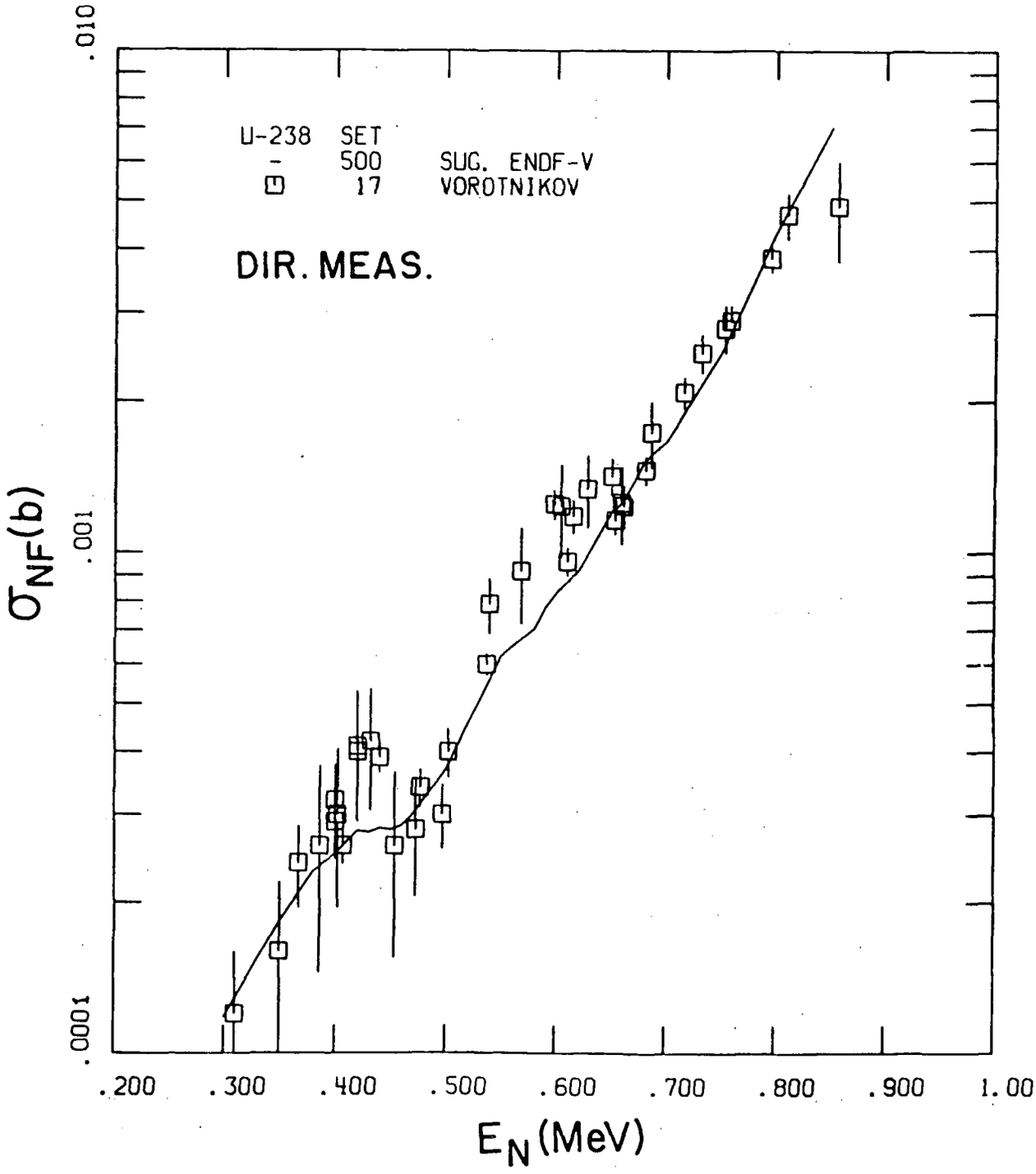

Fig. 3. Comparison of the ENDF/B-V evaluated data with the measured values of Ref. 7.

B-XVI. REMARKS ON MONOENERGETIC NEUTRON SOURCES

The Committee recommended that this document briefly outline the status of a few primary monoenergetic-neutron-source reactions. The primary reference for these remarks is the Proc. of the IAEA Consultant's Meeting on Neutron Source Properties[1] and the serious reader is referred there to for detailed information. Here we limit our remarks to the four principle reactions $^{3}H(p,n)$, $^{2}H(d,n)^{3}He$, $^{3}H(d,n)^{4}He$ and $^{7}Li(p,n)$ as those most commonly employed in precise monoenergetic neutron measurements. The range of applicability is qualitatively defined in Fig. 1.[2]

A. The $^{3}H(p,n)^{3}He$ Reaction

This reaction is attractive due to the low threshold (1.020 MeV), good yield, relatively large monoenergetic range, and freedom from associated gamma-ray emission. These are practical drawbacks associated with the active target material (tritium in gas or gas-absorbed form), energy resolution is relatively coarse (compared to D, below), and the yield has a sharp angular dependence. The multiparticle breakup threshold it at 8.342 MeV ($^{3}H(p;n,p)^{2}H$). A comprehensive evaluation of the respective cross sections has been published by Liskien and Paulsen[3] and the contemporary status of this reaction has been summarized by Drosg.[4a] The zero-degree reaction cross section, as given in Ref. 4, is shown in Fig. 2 and the breakup cross section in Fig. 3.

B. The $^{2}H(d,n)^{3}He$ Reaction

This reaction has a positive Q-value (+3.268 MeV), prolific yield, and is monoenergetic over more than 4.0 MeV. The threshold for the breakup reaction D(d;n,p)D is at 4.45 MeV. The drawbacks are; relatively high minimum neutron energy, problems in the practical target usage in either gas or gas-absorbed form, relatively broad energy resolutions, and a sharp angular dependence of the emitted neutrons. The source is widely used at low-energy accelerators (e.g. few 100 keV) and at higher incident energies privides reasonably monoenergetic neutrons up to 8-10 MeV.[2] Liskien and Paulsen[3] have published a comprehensive evaluation of this reaction and later relevant information is defined in the recent review of Drosg.[4] The character of the zero-degree reaction cross section for both the primary emission and the breakup process is illustrated in Figs. 4 and 5 respectively.

C. The $^{3}H(d,n)^{4}He$ Reaction

The characteristics of this reaction are similar to those of the $^{2}H(d,n)$ reaction, above, but the positive Q-value is much larger (+17.639 MeV). The cross section has a large resonance at ~120 keV (E_d) making the reaction

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[a]Evaluated cross sections for the $^{3}H(p,n)$, $^{2}H(d,n)$ and $^{3}H(d,n)$ as given by Drosg[4] are available in numerical form from the Nuclear Data Section, IAEA.

particularly attractive for the production of ~14 MeV neutrons at low-energy accelerator facilities. The practical problems of application are similar to those encountered with the D(d,n) reaction, above, and the breakup threshold is relatively low, 4.98 MeV (^{3}H(d,2n)^{3}He). A comprehensive evaluation of the respective cross sections, illustrated by Fig. 6, has been published by Liskien and Paulsen[3] and a summary of more recent values is given in the review of Drosg.[4]

D. The ^{7}Li(p,n)^{7}Be Reaction

This reaction is widely used due to prolific yields, ease of application and control, and a relatively low-energy threshold (1.881 MeV). The drawbacks are a relatively small monoenergetic energy range and appreciable gamma-ray emission. The secondary neutron group threshold due to the ^{7}Li(p,n)^{7}Be* reaction is at 2.380 MeV and the multiparticle breakup commences at a threshold of 3.68 MeV due to the ^{7}Li(p;n,^{3}He)^{4}He reaction.[2,6] The zero-degree cross sections for the primary neutron group are illustrated in Fig. 7. Figures 8 and 9 show the relative yields for the secondary group and breakup reaction, respectively. A detailed evaluation of the relevant cross sections by Liskien and Paulsen is given in Ref. 7 and more recent results are summarized in the review of Drosg.[5] Characteristics of the breakup process are given in Ref. 2.

There are a number of other monoenergetic-source reactions as setforth in Ref. 1. They tend to be of a special-purpose nature. A notable example is the ^{1}H(^{3}H,n) reaction which has advantages of high yield, as illustrated by the comparisons of Fig. 10, and a wide monoenergetic range.[4] The difficulty of application is in the requirement for a relatively high-energy tritium beam. Many of the other special-purpose source reactions have modest yields, limited monoenergetic range and, frequently, highly resonant cross sections (e.g. the ^{5}V(p,n) reaction). Other attributes, such as more isotropic emission, may make them useful in special applications.

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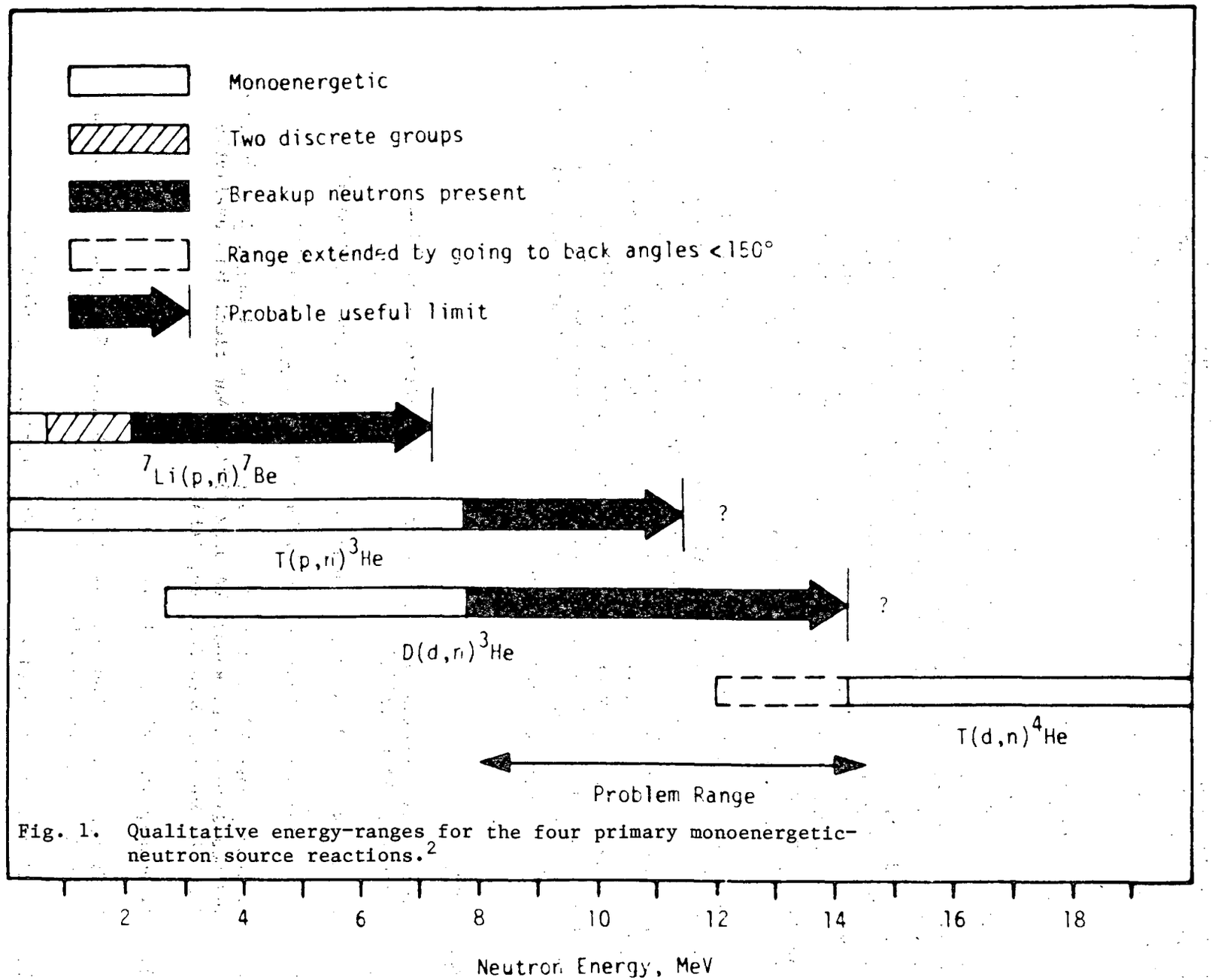

Fig. 1. Qualitative energy-ranges for the four primary monoenergetic-neutron source reactions.[2]

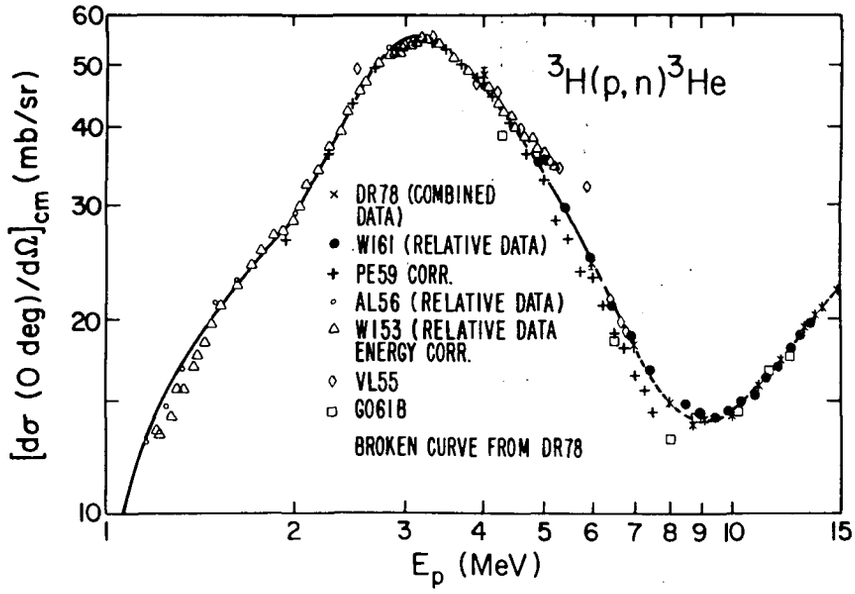

Fig. 2. Zero-degree cross section for the $^3H(p,n)^3He$ reaction taken from Drosg.[4] Symbolism is defined in Ref. 4.

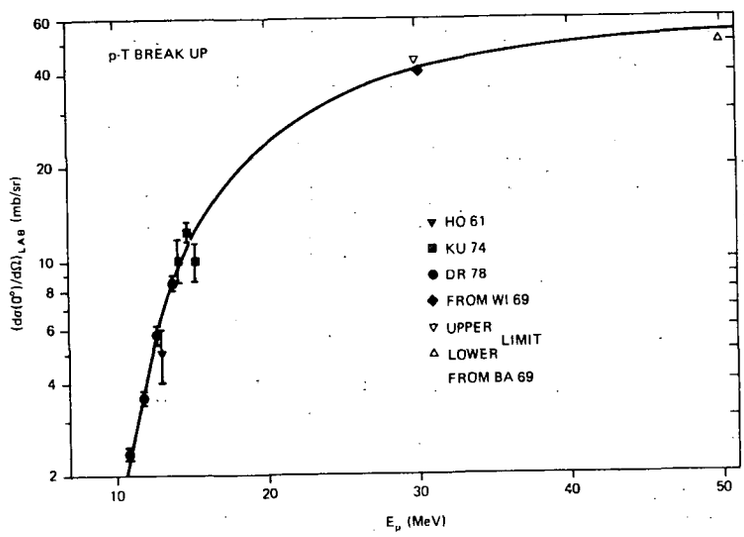

Fig. 3. Zero-degree breakup cross section for the $^3H(p,n)$ reaction taken from Drosg.[4] Symbolism is defined in Ref. 4.

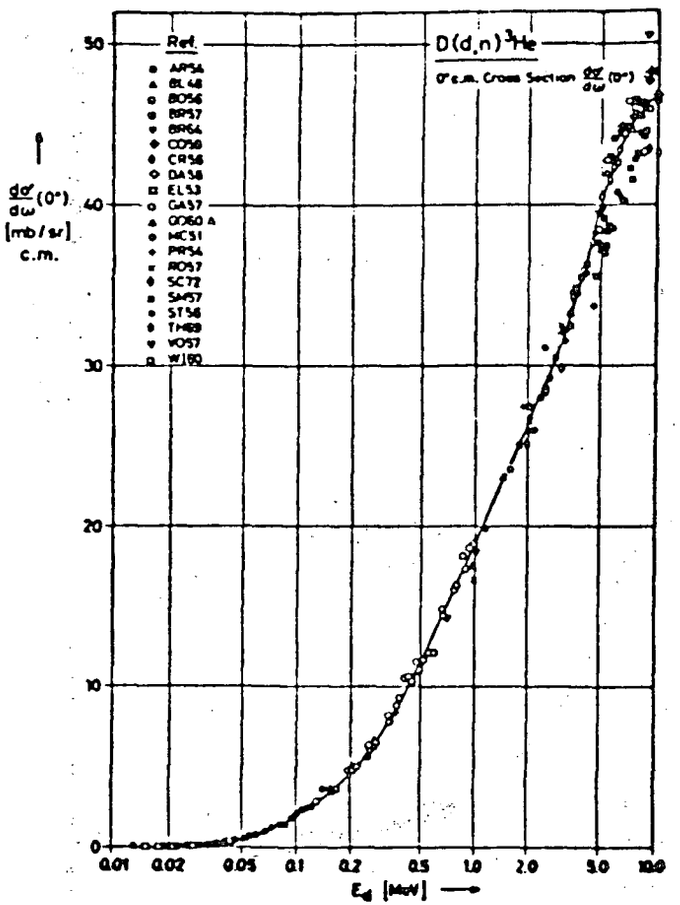

Fig. 4. Zero-degree (C.M.) cross sections (data points) and recommended value (curve) for the $^{2}H(d,n)^{3}He$ reaction taken from Ref. 3.

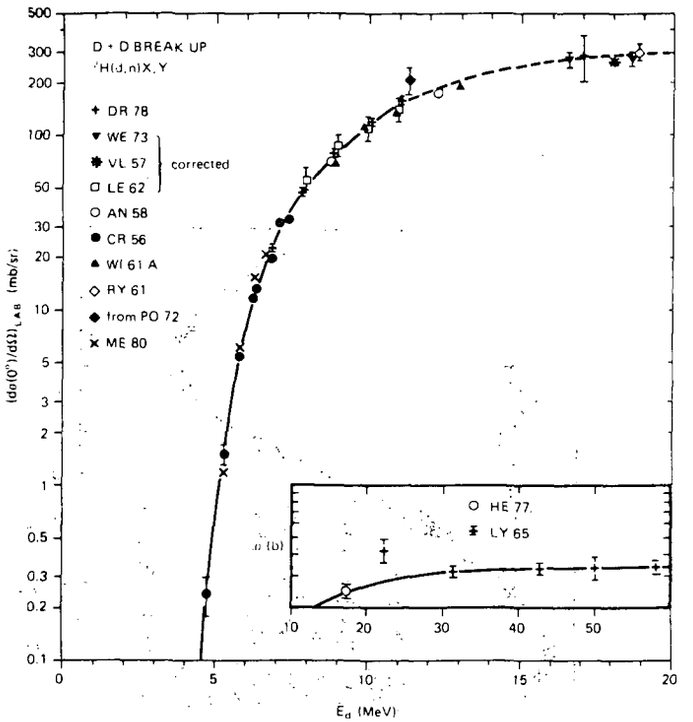

Fig. 5. Zero-degree cross section for the $^{2}H(d,n)$ breakup reaction taken from Ref. 4.

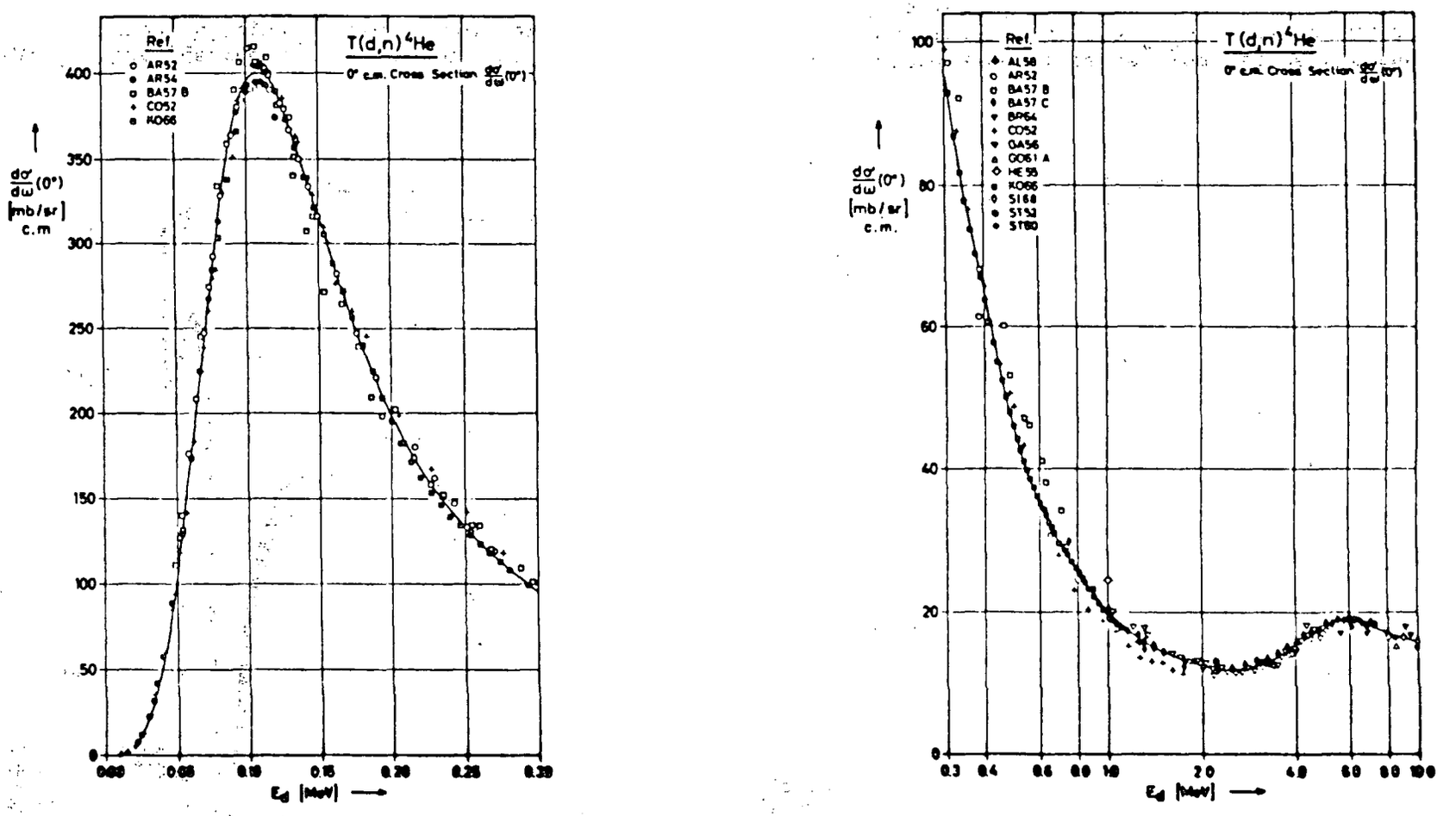

Fig. 6. Zero-degree cross sections for the reaction $^{3}H(d,n)$ taken from Ref. 3.

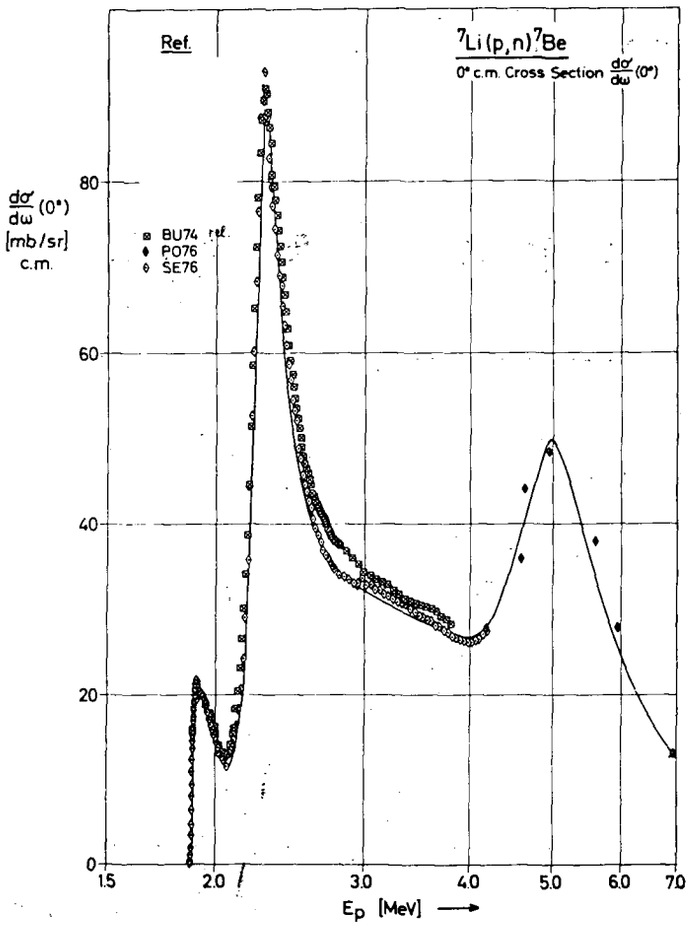

Fig. 7. Zero-degree cross sections for the reaction ^{7}Li(p,n)^{7}Be taken from Ref. 5.

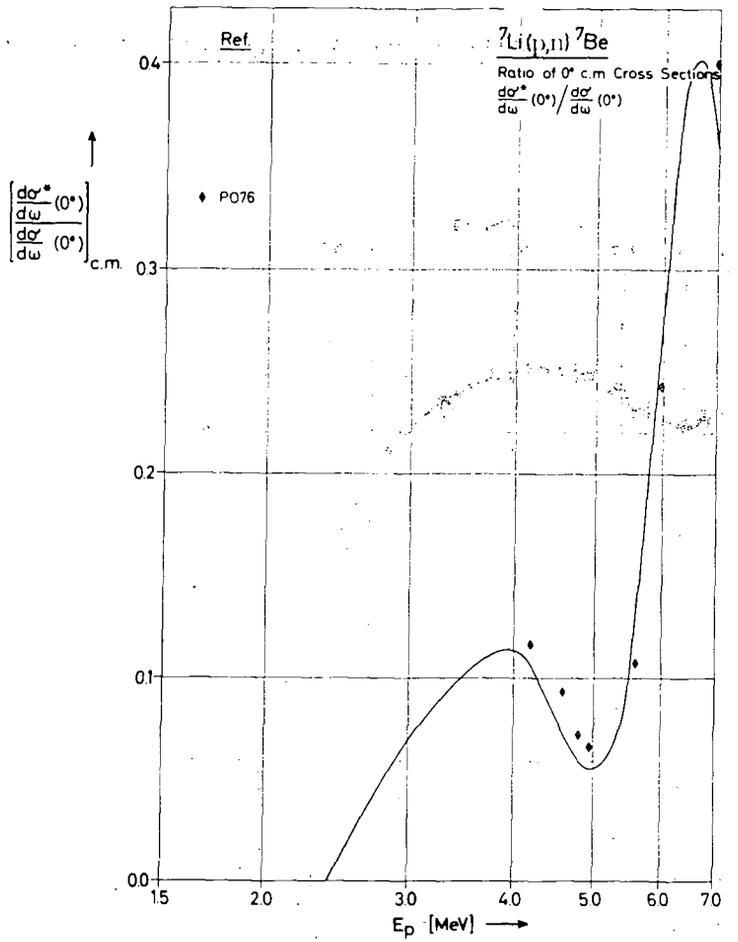

Fig. 8. Zero-degree cross section ratios for the reaction ^{7}Li(p,n)^{7}Be*/^{7}Li(p,n)^{7}Be taken from Ref. 5.

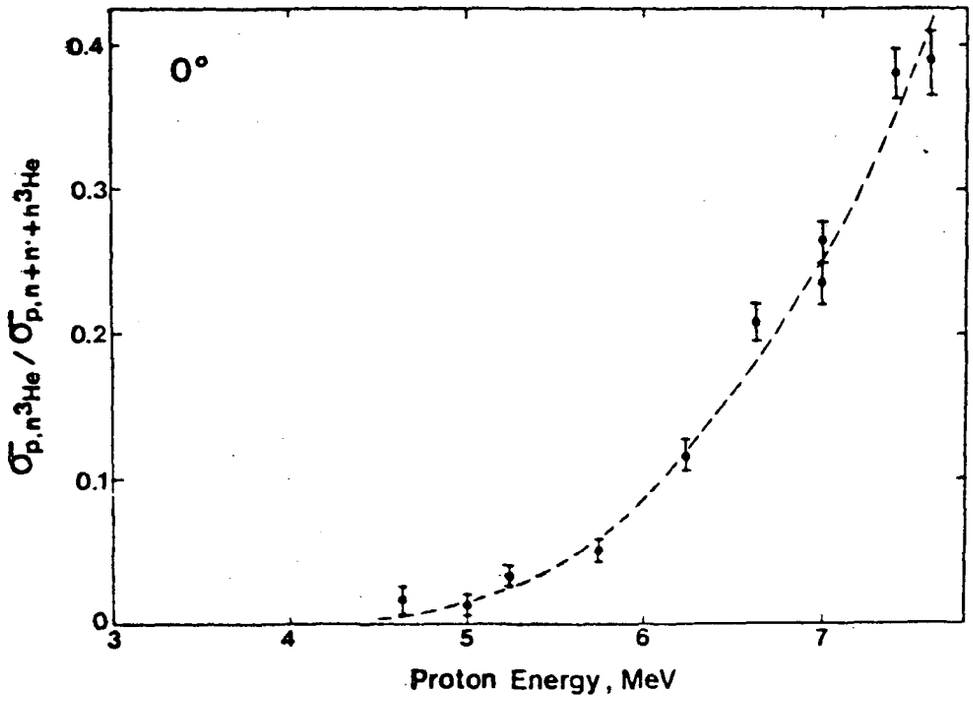

Fig. 9. Ratio of the zero-degree ^{7}Li(p,n) breakup cross section to the total neutron-production cross section, taken from Ref. 2.

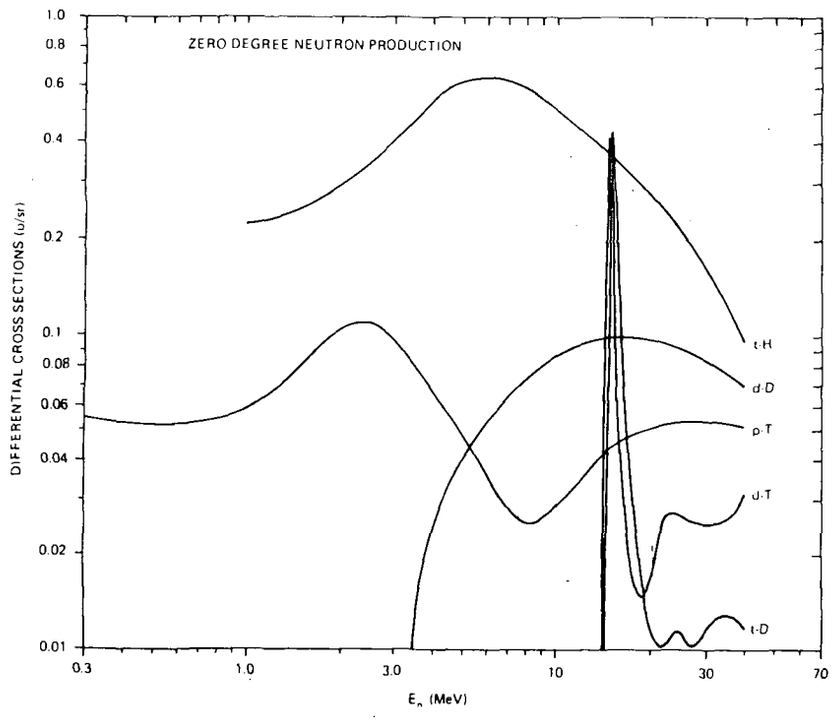

Fig. 10. Laboratory cross sections for neutron production from hydrogen isotopes at zero degrees (taken from Ref. 4).