Status of the Database for The New International Evaluation of The Neutron Cross Section Standards

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If an experiment requires statistical analysis to establish a result, Then one should do a better experiment.

Ernest Rutherford (1871-1937)
English Physicist
Nobel prize for chemistry, 1908

Table 1. Neutron Cross Section Standards

Reaction	Proposed energy range
H(n,n)	1 keV to 200 MeV
^{3}He(n,p) †	0.0253 eV to 50 keV
^{6}Li(n,t)	0.0253 eV to 1 MeV
^{10}B(n,I)	0.0253 eV to 1 MeV
^{10}B(n,I 1K)	0.0253 eV to 1 MeV
C(n,n)*	0.0253 eV to 1.8 MeV
Au(n,K)	0.0253 eV, 0.2 to 2.5 MeV
^{235}U(n,f)	0.0253 eV, 0.15 to 200 MeV
^{238}U(n,f) ††	Threshold to 200 MeV

H(n,n)

[++]Nakamura, J. Phys. Soc. Japan 15 (1960) 1359, 14.1 MeV; error in transformation from laboratory to CMS angles; needs correction for proton scattering, an estimate of error associated with neglecting these corrections was made; tail problems; note Table II uncertainty is statistical only (mb/sr).

[++]Shirato, J. Phys. Soc. Japan 36 (1974) 331, 14.1 MeV, needs correction for proton scattering; tail problems.

[+]Ryves, 14.5 MeV, [(180°)/[(90°), Ann. Nucl. Energy 17, 657 (1990).

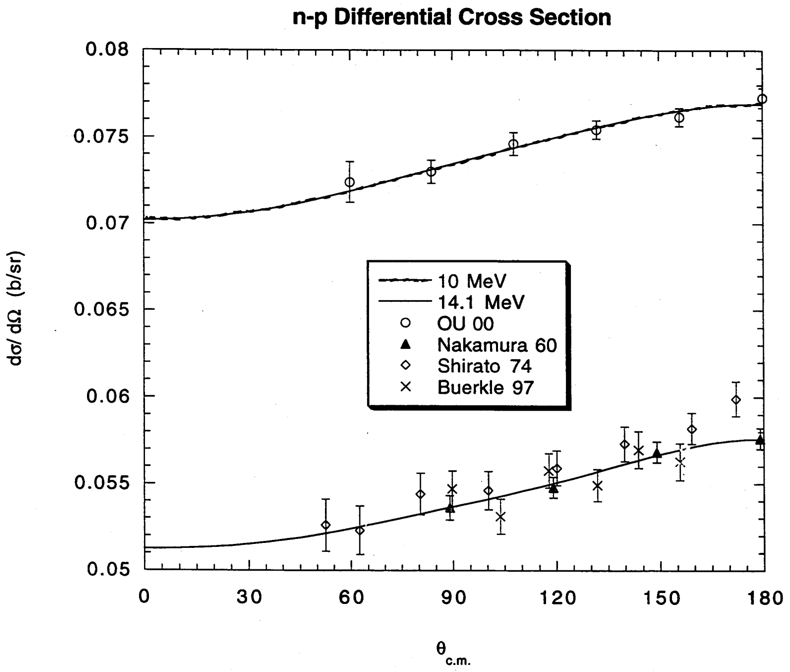
[++]Buerkle, 14.1 MeV, angular distribution from 89.7° to 155.7°, Few-Body Systems 22, 11 (1997). The angular range is too limited.

[++]Boukharouba, Phys Rev C 65, 014004, 10 MeV, angular distribution from 60° to 180°, additional work planned for 15 MeV.

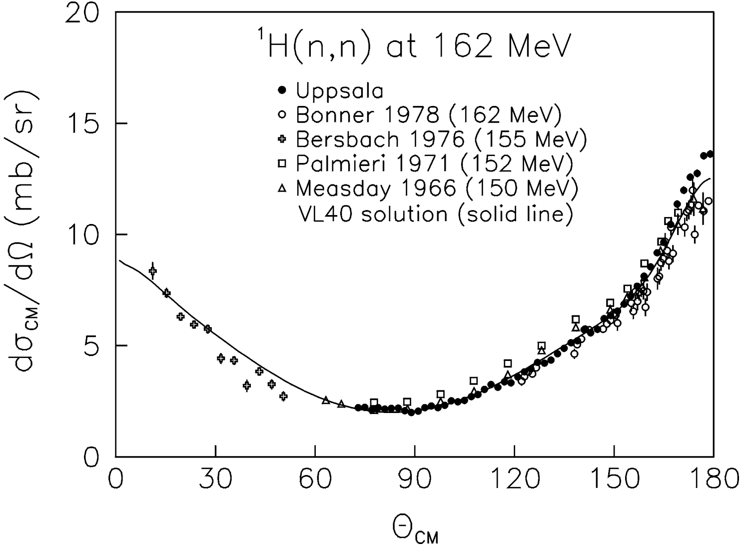
Uppsala data:
[+]Rönnqvist, Phys Rev C45, R496 (1992), 96 MeV angular distribution from 116° to 180°
[+]Rahm, Phys. Rev. C57, 1077 (1998) 162 MeV, angular distribution from 72° to 180°,

[+]Benck, (Louvain la Neuve), Nucl. Phys. A615, 222 (1997) and Proc. Conf. on NDST, Trieste (1997) p.1265, 28-75 MeV, angular distribution from 40° to 140°. Angular range is too limited.

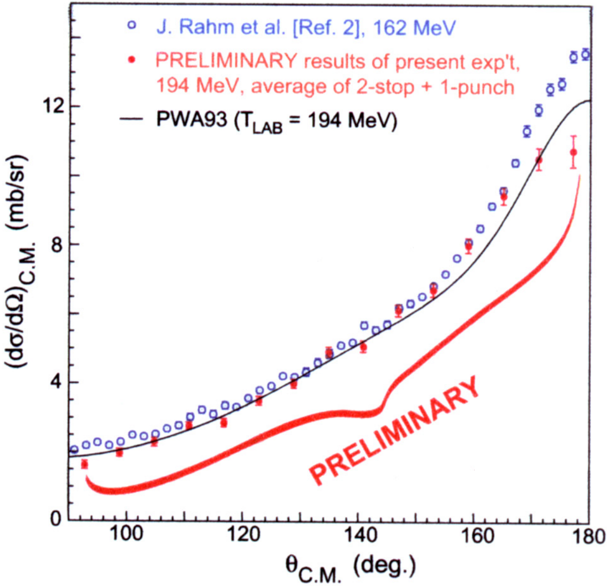
Vigdor (IUCF) 185-200 MeV, angular distribution from 90° to 180°. Data have been obtained. Sarsour is analyzing the data and has preliminary data at 200 MeV, Private Comm.



n-p Differential Cross Section
0.08
0.075
0.07
0.065
0.06
0.055
0.05
dσ/ dΩ (b/sr)
10 MeV
14.1 MeV
OU 00
Nakamura 60
Shirato 74
Buerkle 97
0
30
60
90
120
150
180
θ c.m.



$^1H(n,n)$ at 162 MeV
Uppsala
Bonner 1978 (162 MeV)
Bersbach 1976 (155 MeV)
Palmieri 1971 (152 MeV)
Measday 1966 (150 MeV)
VL40 solution (solid line)
$d\sigma_{CM}/d\Omega$ (mb/sr)
Θ_{CM}
0
5
10
15
20
0
30
60
90
120
150
180



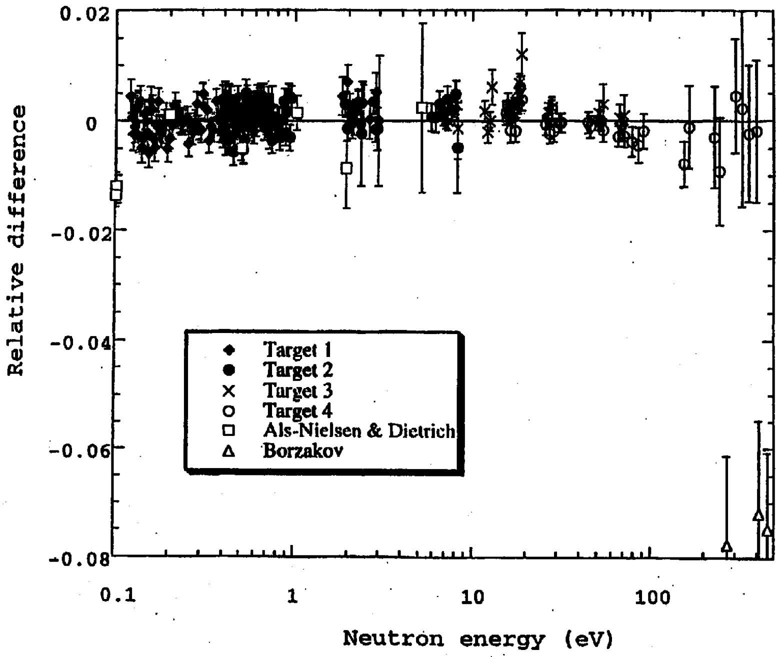
Indiana University Preliminary H(n,n) Results

^{3}He(n,p)

[++]Borzakov, 0.26 keV to 142 keV, relative to ^{6}Li(n,t), Sov. J. Nucl. Phys. 35, 307 (1982). OK

^{3}He total cross section

[++]Keith, 0.1 to 500 eV, BAPS DNP Oct 1997 paper IG.03 and thesis of D. Rich, U of Indiana. OK.



Relative difference between the data of Keith et al., using 4 different sample thicknesses, and a 1/v fit to the cross section. Also shown is a sampling of the data of Als-Nielsen & Dietrich, and Borzakov.

^{6}Li(n,t)

$^{+}$NIST collaboration, thermal measurement with high accuracy using cryogenic calorimeter, Private Comm. OK

$^{++}$Knitter, (1983) NS&E 83, 229; ^{6}Li(n,t)^{4}He angular distribution, 0.035-325 keV, new corrections required for particle leaking effect. Giorginis is investigating

$^{++}$Drosg, 0.50 MeV to 4.1 MeV, NIM B94, p.319 (1994), using concept based on the two groups from the source reaction. Set 1011. OK

Bartle, 2 to 14 MeV, angular distribution, Proc. Conf on Nuclear Data for Basic and Applied Science, Sante Fe (1985), p. 1337 (questionable value, due to energy range and information not available).

Schwarz, 1 to 600 keV, NP 63, p.593, some based on hydrogen scattering cross section. Assumptions need study!

Koehler, 1 keV to 2.5 MeV, angular distribution data (ratio of forward and backward hemispheres responses), private comm.

Yu Gledenov, .025 eV, 87KIEV 2 237 (1988) no data given

$^{+}$Guohui Zhang, 3.67 and 4.42 MeV, angular distribution, Comm. Of Nuclear Data Progress No.21 (1999) China Nuclear Data Center, also NSE 134, 312 (2000). Also 1.85 MeV and 2.67 MeV, NSE 143, 86 (2003). Has “particle leaking” effect.

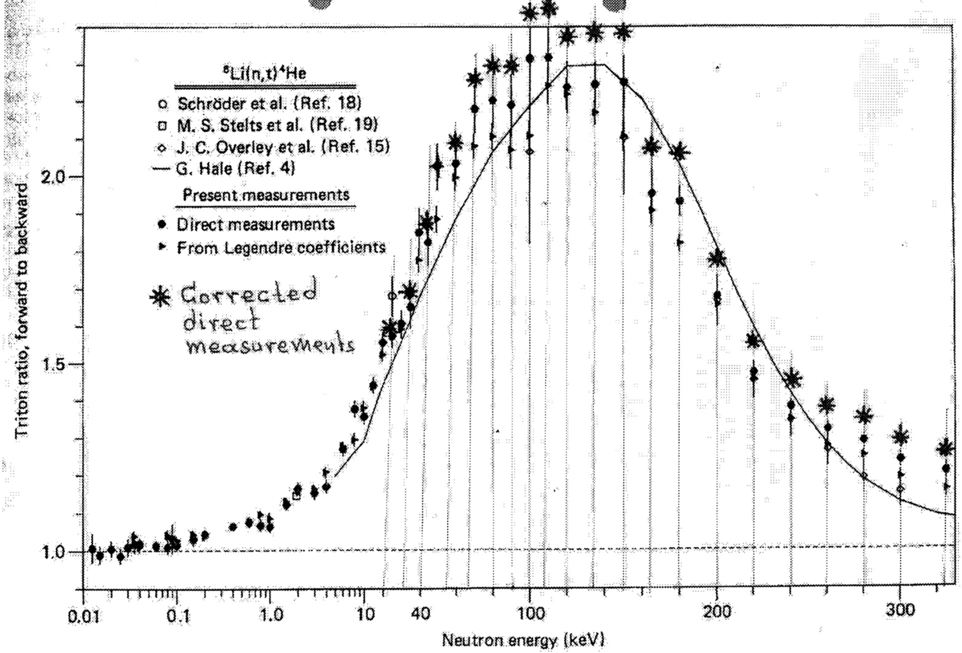


Fig. 8. The trition emission ratio of the reaction $^6Li(n,t)^4He$ into the forward and backward hemispheres of the laboratory reference system is plotted versus the incident laboratory neutron energy.

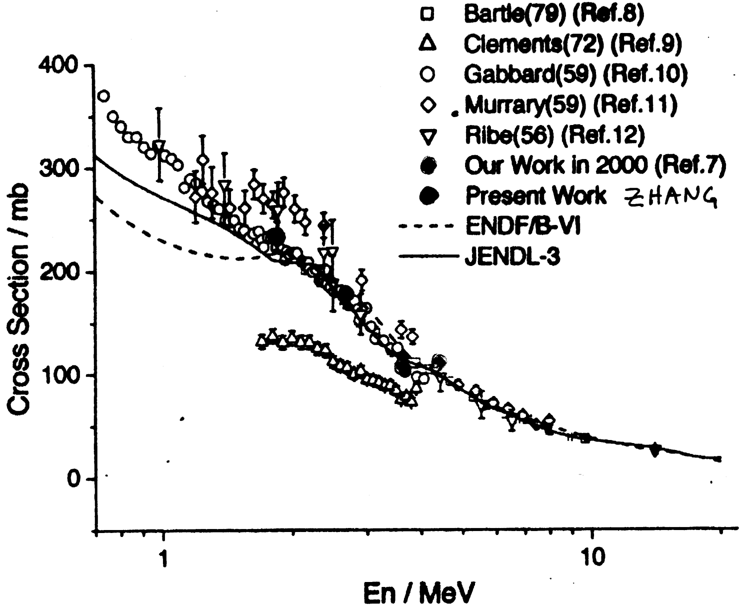


Fig. 5. The present results for the $^{6}Li(n,t)^{4}He$ reaction cross section compared with existing data.

$^{10}B(n,\alpha)$ Branching Ratio

++Weston, 0.02 MeV to 1 MeV, Solid State detectors, NSE 109, 113 (1991). Set 1024. May have systematic errors.

++Hambsch and Bax, ND2001, 0.04 MeV to 1.0 MeV, Frisch gridded ion chamber, in progress. Set 1015. Background problems

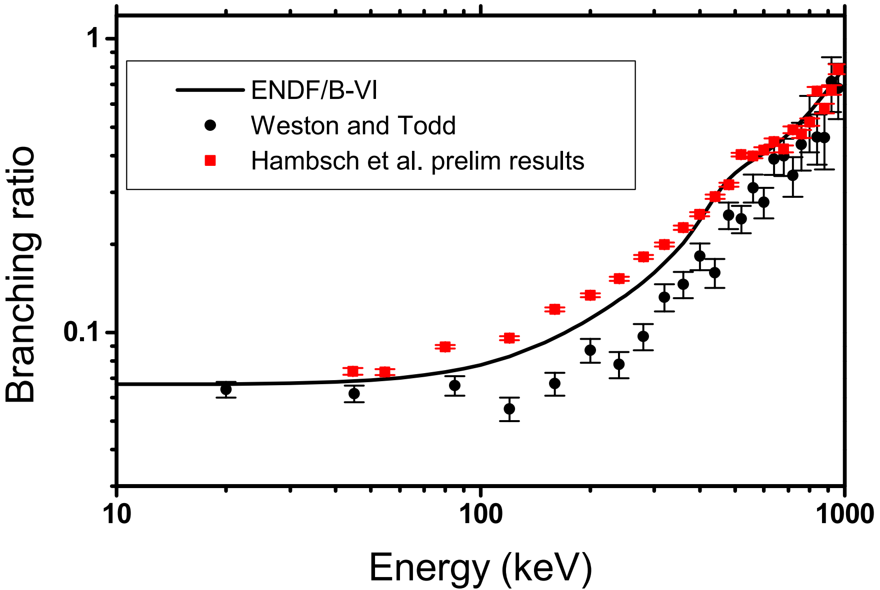
$^{10}B(n,\alpha)$

Haight, 1 MeV to 6 MeV, angular distribution at 30°, 60°, 90° and 135°, private comm.

Hambsch and Bax, ND2001, keV to MeV, angular distribution, Frisch gridded ion chamber, in progress.

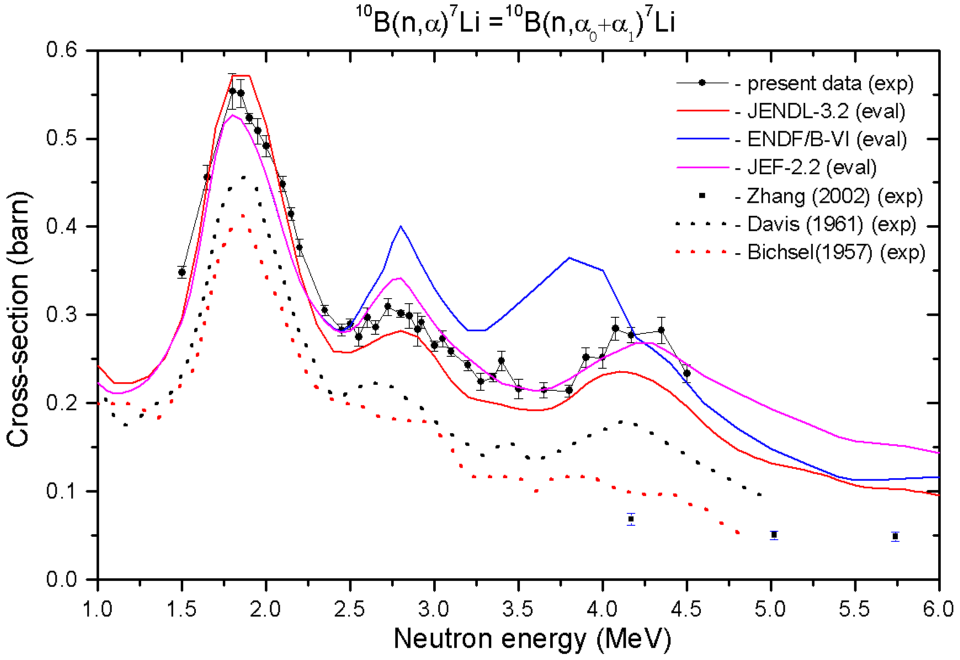
Giorginis and Khriachkov, MeV energies, angular distribution, VdG data.
The integrated cross sections are available. Private communication (2003). OK

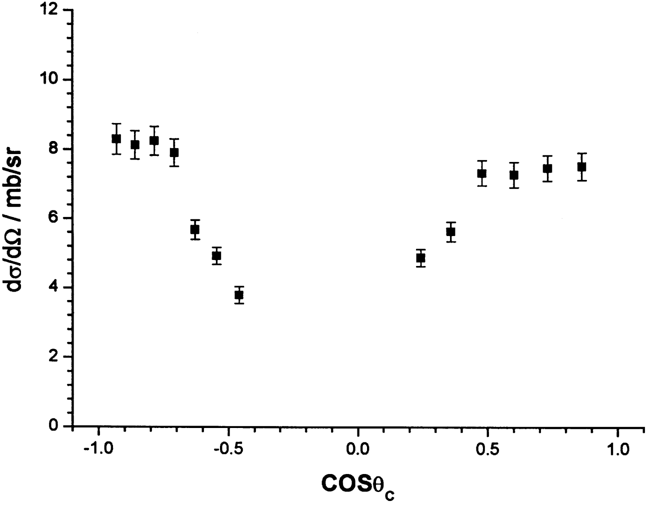
+Guohui Zhang, 4.17, 5.02, 5.74, 6.52 MeV angular distribution, submitted for publication to NSE. Problems with particle leaking.



ENDF/B-VI
Weston and Todd
Hambsch et al. prelim results
Branching ratio
1
0.1
10
100
1000
Energy (keV)

Present data: G. Giorginis and V. Khriatchkov, IRMM, June 2003





Differential cross section for the $^{10}B(n,\alpha)^{7}Li$ reaction at 4.17 MeV by Zhang et al.

$^{10}B(n,\alpha_1K)$
Maerten, 320 keV to 2.8 MeV, GELINA linac, relative to $^{235}U(n,f)$ and carbon standards, private comm. from H. Weigmann. Not enough information on uncertainties is available.

$^{++}$Schrack, 0.2 MeV to 4 MeV, shape data relative to Black Detector (at ORNL), NSE 114, 352 (1993). Set 113. OK

$^{+}$Schrack, 10 keV to 1 MeV, shape data relative to H(n,n) prop ctr (at ORNL), Proc. Conf. on NDST, Gatlinburg (1994)p. 43. Set 1034 OK

$^{+}$Schrack, .3 MeV to 10 MeV, relative to $^{235}U(n,f)$ ion chamber (at LANL), Private comm. Set 1033 OK

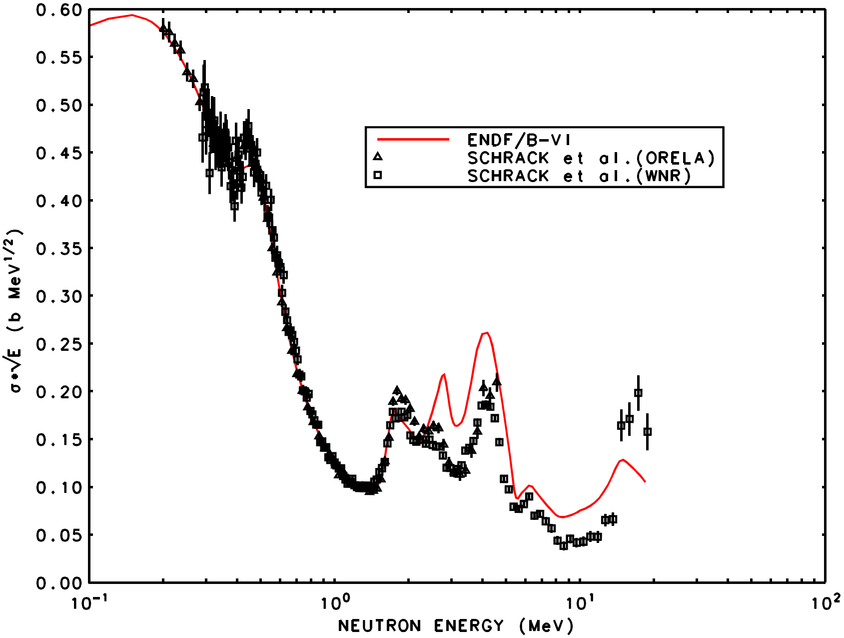


Fig. 15 Comparison of the $^{10}B(n,\alpha_1\gamma)$ cross section measurements of Schrack et al. at ORELA (BD mon) and WNR (FC mon) with ENDF/B-VI

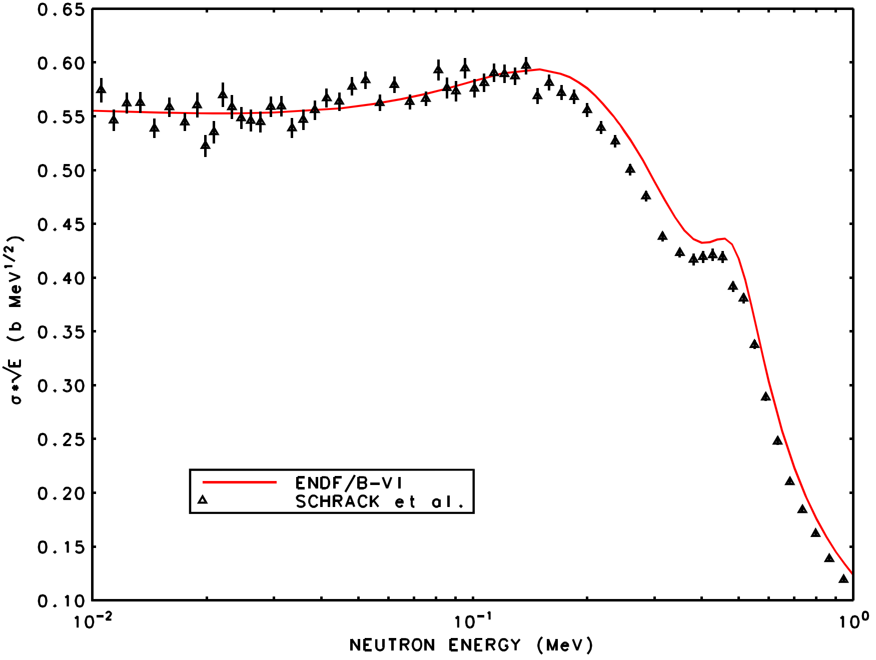


Fig. 14 $^{10}B(n,\alpha_1\gamma)$ **cross section measurements by Schrack et al at ORELA (PC mon)**

$^{10}B(n,\alpha_1)$

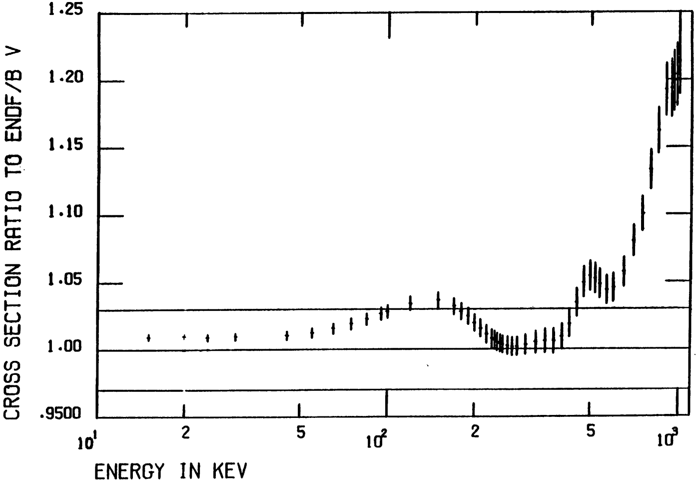


Fig. 28 Ratio of the result of this evaluation process to that of ENDF/B-V for the $^{10}B(n,\alpha_1)$ reaction from about 10 keV to 1 MeV. The lines at ratios of 0.97 and 1.03 are guides to the eye.

^{235}U(n,f)

$^{++}$Carlson, 2 MeV to 30 MeV, relative to H(n,n), Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U", p. 165. Set 524 OK

$^{++}$Merla, $^{+}$2.6, $^{+}$4.45, $^{+}$8.46, $^{+}$14.7, $^{+}$18.8 MeV ?, associated particle, Proc. Conf. on NDST Juelich (1991) p.510. Sets 591, 590, 592, 593, 587. OK

$^{++}$Lisowski, 3 MeV to 200 MeV, relative to H(n,n), Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U", p. 177, and private communication. Set 1028 OK

$^{+}$Nolte, 14 to 150 MeV, ND2001, and Private Comm. to increase energy range, Preliminary data. Concerns about 96 MeV point. Additional work underway

$^{++}$Buleeva, 0.624 MeV to 0.785 MeV, relative to H(n,n), Sov. J. Atomic Energy 65, 930 (1988). Set 522. OK

Grundl comment, ^{252}Cf spontaneous fission spectrum averaged cross section. NOTE; only the last NIST measurement (Schroder) should be used in the evaluation.

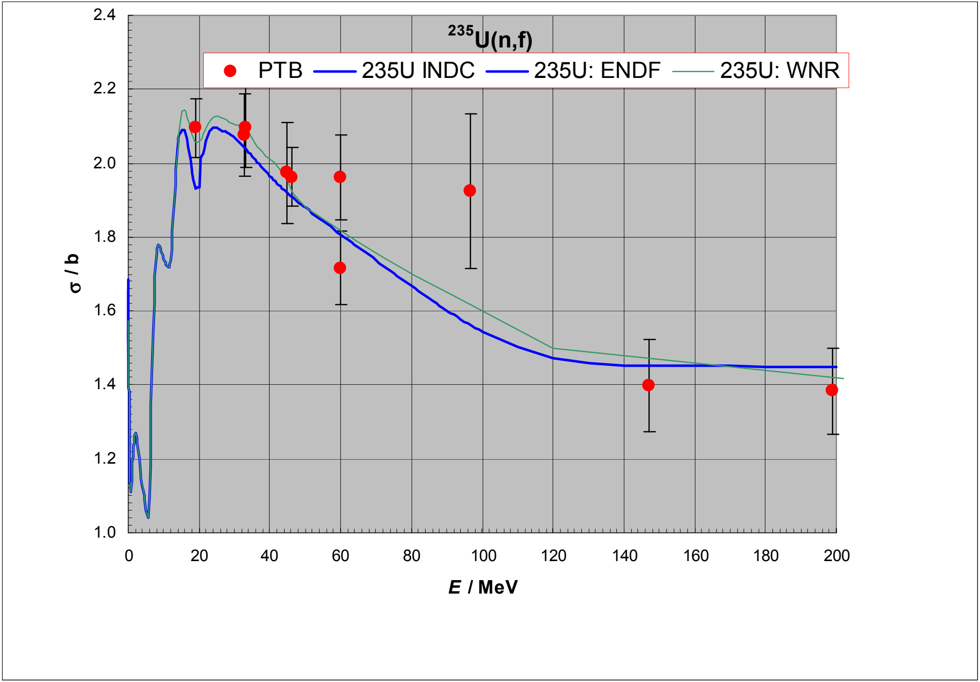
$^{++}$Kalinin, 1.88 MeV, 2.37 MeV CCW, assoc. particle, Sov. J. Atomic Energy 71,(2),181,1988 Set 1026 OK

$^{++}$Carlson, 0.3 MeV to 3 MeV, absolute fluence from black detector, Proc. IAEA Advisory Group Meeting on Nuclear Standard Reference Data, Geel Belgium, p.163, IAEA-TECDOC-335 (1985). Set 523. OK

$^{++}$Johnson, 1 MeV to 6 MeV, absolute fluence from a dual thin scintillator, Proc. Conf. on NDST Mito (1988) p.1037. Set 1025 OK

$^{++}$Iwasaki, 14 MeV (13.5 to 14.9 MeV), relative to H(n,n) and assoc. particle, Proc. Conf. on NDST Mito (1988) p. 87. Set 1027 OK

$^{++}$Weston and Todd, NSE 111, 415 (1992), relative to ^{10}B(n,α), 0.15 keV to 1.5 keV. Set 1023 OK



^{235}U(n,f)
PTB
235U INDC
235U: ENDF
235U: WNR
σ / b
E / MeV
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
20
40
60
80
100
120
140
160
180
200

^{238}U(n,f)

$^{++}$Merla, 5 MeV +, assoc. particle, Proc. Conf. on NDST Juelich (1991) p.510. Set 810. OK

$^{++}$Winkler, 14.5 MeV, rel.to Al(n,I) & ^{56}Fe(n,p), Proc. Conf. on NDST Juelich (1991), p.514. Set 809. OK

$^{++}$Lisowski, 0.8 MeV to 357 MeV, relative to H(n,n), Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, "U", p. 177, and private communication. Set 1030. OK, possible problems at highest energies compared with Shcherbakov

$^{+}$Nolte, 14 to 150 MeV, ND2001, and Private Comm. to increase energy range, Preliminary data.

$^{+}$Newhauser, 34, 46, and 61 MeV MeV, absolute, Proc. Conf. on NDST Juelich (1991),
removed from database.

$^{+}$Meadows, 14.74 MeV, CCW, ANE,15,421 (1988), relative to ^{235}U(n,f).

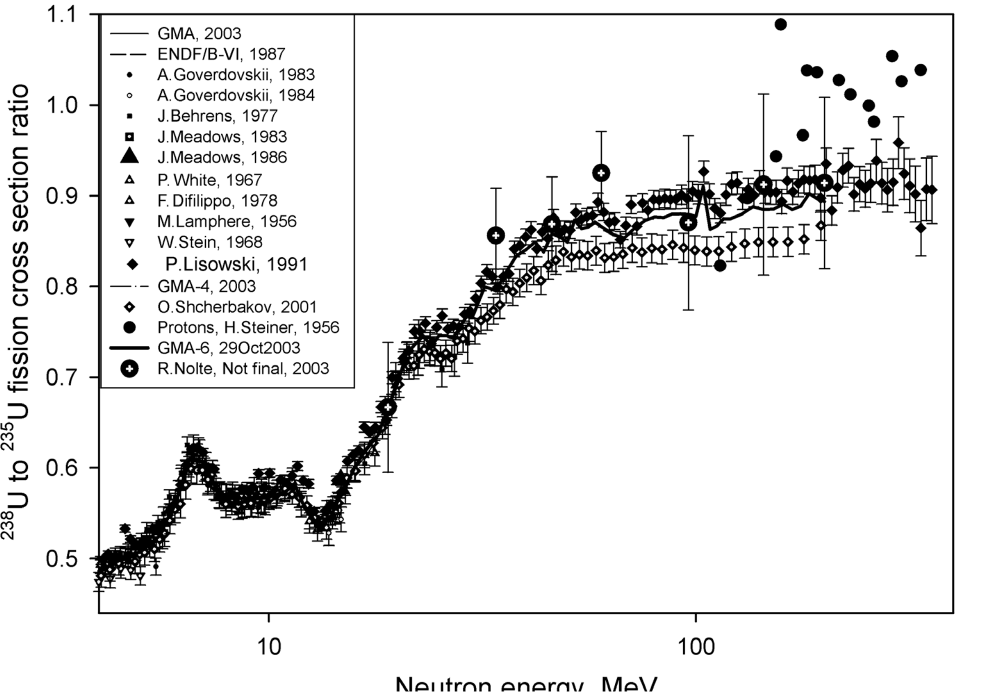
$^{++}$Baba, 4.6 MeV to 6 MeV, Van de Graaff relative to ^{235}U(n,f), J. Nucl. Sci. & Techn.,26,11 (1989). Set 1035

$^{++}$Shcherbakov, 1-196 MeV, relative to ^{235}U(n.f), ISTC 609-97, see also Fomichev, 0.7 MeV to 200 MeV, relative to ^{235}U(n.f), Proc. Conf. on NDST, Trieste (1997), p.1283, also ND2001 set 1013.
OK except possibly at the highest energies (incosistent with Lisowski there)

$^{+}$Li Jingwen, 14.7 MeV, CCW, ratio to ^{235}U(n,f) CNP,11,(3),17,89.

Eismont, Trieste conf, p.494, 33.7, 46 and 60.6 MeV, relative to hydrogen scattering cross section. See also Gatlinburg conference results at 135 and 160 MeV. Data not finalized. They have concerns about neutron fluence determination for getting smaller uncertainty.

$^{+}$Garlea, 14.7 MeV, relative to ^{235}U(n,f) cross section, RRP,37,(1),19,92.



GMA, 2003
ENDF/B-VI, 1987
A.Goverdovskii, 1983
A.Goverdovskii, 1984
J.Behrens, 1977
J.Meadows, 1983
J.Meadows, 1986
P. White, 1967
F. Difilippo, 1978
M.Lamphere, 1956
W.Stein, 1968
P.Lisowski, 1991
GMA-4, 2003
O.Shcherbakov, 2001
Protons, H.Steiner, 1956
GMA-6, 29Oct2003
R.Nolte, Not final, 2003
238U to 235U fission cross section ratio
Neutron energy, MeV
1.1
1.0
0.9
0.8
0.7
0.6
0.5
10
100

^{239}Pu(n,f)

$^{++}$Weston, linac, 0.15 keV to 15 keV, fission chamber, ^{10}B(n,I) standard, NSE 111,415 (1992). Set 1024 OK

$^{++}$Merla, 4.9, 8.65, 14.7 and 18.8 MeV, associated particle, Proc. Conf. on NDST Juelich (1991) p.510; see also Alkhazov, YK,1986,(4),19,198612.
Sets 611, 617, 615, and 616. OK

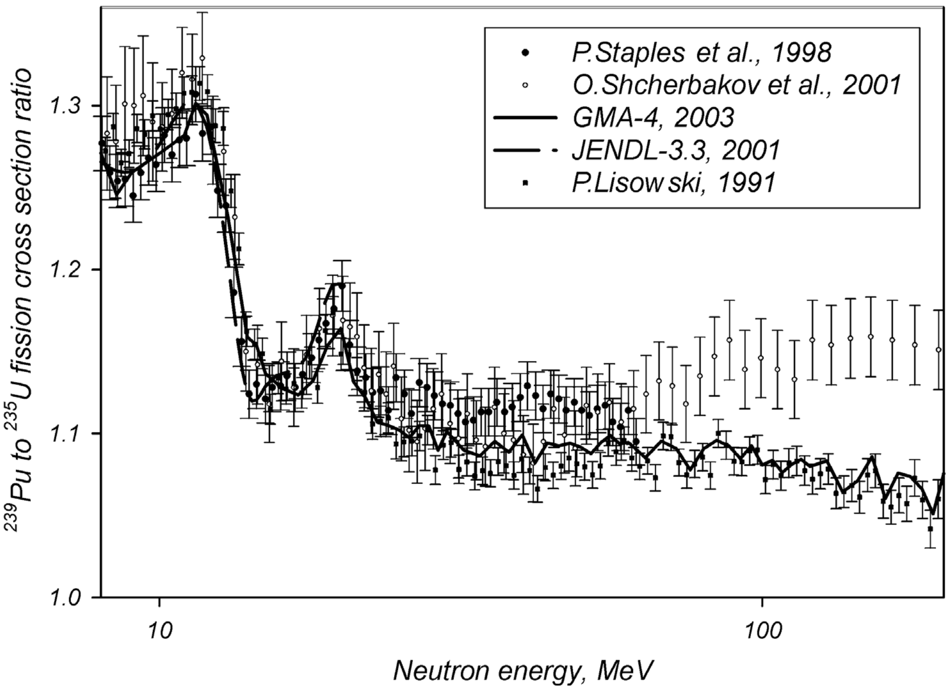
$^{+}$Meadows, 14.74 MeV, CCW, ANE,15,421,8808, relative to ^{235}U(n,f).

$^{+}$Shcherbakov, 0.6-196 MeV, relative to ^{235}U(n.f), ISTC 609-97 (2000). Set 1012.
OK but problems at high energy compared with Lisowski.

$^{+}$Staples, 0.8 MeV to 62 MeV, relative to ^{235}U(n,f), NSE 129, 149 (1998). Set 1014.
OK except differences compared with Lisowski and Shcherbakov at highest energies.

$^{+}$Lisowski, 0.5 MeV to 256 MeV, relative to H(n,n) and ^{235}U(n,f) ,
Proc. Spec. Meeting on Neutron Cross Section Standards for the Energy Region above 20 MeV, Uppsala, Sweden, 1991, Report NEANDC-305, “U”. Set 1029 OK
problems at highest energies compared with Shcherbakov

$^{++}$Garlea, 14.7 MeV, relative to ^{235}U(n,f) cross section, RRP,37,(1),19,92. Set 633 Value is high

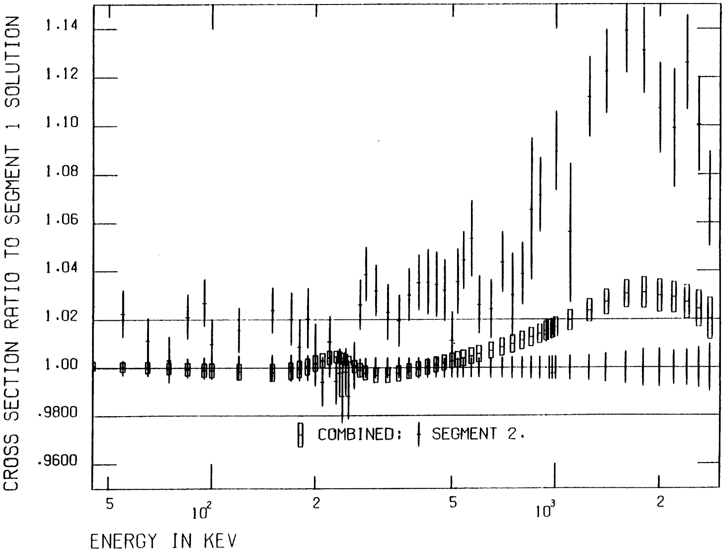


P.Staples et al., 1998
O.Shcherbakov et al., 2001
GMA-4, 2003
JENDL-3.3, 2001
P.Lisowski, 1991
1.3
1.2
1.1
1.0
10
100
^{239}Pu to ^{235}U fission cross section ratio
Neutron energy, MeV

Conclusion

Better measurements and improved methods to handle discrepant data are needed. But working with what is available, the database continues to be prepared for use in the new international evaluation of the neutron cross section standards.

^{6}Li(n,t)



7 Cross section ratios to the segment 1 solution for the ^{6}Li(n,t) reaction from about 50 keV to 2 MeV. The rectangles refer to the ratio of the combination output to the R-matrix fit of the segment 1 data. The ┼'s refer to the ratio of the simultaneous evaluation of the segment 2 data to the R-matrix fit of the segment 1 data. The error bars indicate the uncertainties for the fits. The error bars on the unit ratio line are the uncertainties in the R-matrix fit of the segment 1 data. The lines at ratios of 0.98 and 1.02 are guides to the eye.