Update on standard cross sections and thermal neutron constants

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+ IAEA Neutron Standard Data Development Project

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LANL, Los Alamos, USA

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Neutron Standards evaluation (2006)

www-nds.iaea.org/standards/

Reaction	Neutron Energy Range			
	1987	2002-2005/06		
			ENDF-6 Format	Free text Format
H(n,n)	1 keV to 20 MeV	1 keV to 20 MeV	std-001_H_001.endf	not available
^{3}He(n,p)	0.0253 eV to 50 keV	0.0253 eV to 50 keV (1987 adopted)	std-002_He_003.endf	not available
^{6}Li(n,t)	0.0253 eV to 1 MeV	0.0253 eV to 1 MeV	std-003_Li_006.endf	standards-6Li_xs-data.txt
^{10}B(n,α)	0.0253 eV to 250 keV	0.0253 eV to 1 MeV	std-005_B_010.endf	standards-10B_na-xs-data.txt
^{10}B(n,$α_1$γ)	0.0253 eV to 250 keV	0.0253 eV to 1 MeV	std-005_B_010.endf	standards-10B_na1-xs-data.txt
C(n,n)	up to 1.8 MeV	up to 1.8 MeV (1987 adopted)	std-006_C_000.endf	not available
Au(n,γ)	0.0253 eV, and 0.2 to 2.5 MeV	0.0253 eV, and 0.2 to 2.5 MeV	std-079_Au_197.endf	standards-197Au_xs-data.txt
^{235}U(n,f)	0.0253 eV, and 0.15 to 20 MeV	0.0253 eV, and 0.15 to 200 MeV	std-092_U_235.endf	standards-235U_xs-data.txt
^{238}U(n,f)	threshold to 20 MeV	2 to 200 MeV	std-092_U_238.endf	standards-238U_xs-data.txt

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On-going work on Neutron Standards
www-nds.iaea.org/standards/

IAEA TM, 1-5 Dec. 2014
Report INDC(NDS)-0677

Next TM, 25-29 July 2016

- **New experimental data added**
- **Recommended ^{235}U(n,f) fission RIs exp. verified (n_TOF)**
- **Preliminary fit undertaken (latest 03/2016)**
- **New Thermal Constants fit done**
- **^{235}U(n_{th},f) PFNS by GMA fit (Trkov, Capote, Pronyaev)**
- **Release of new Neutron Standards, 4Q 2016**

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IAEA TM on Neutron Standards, 12/2014

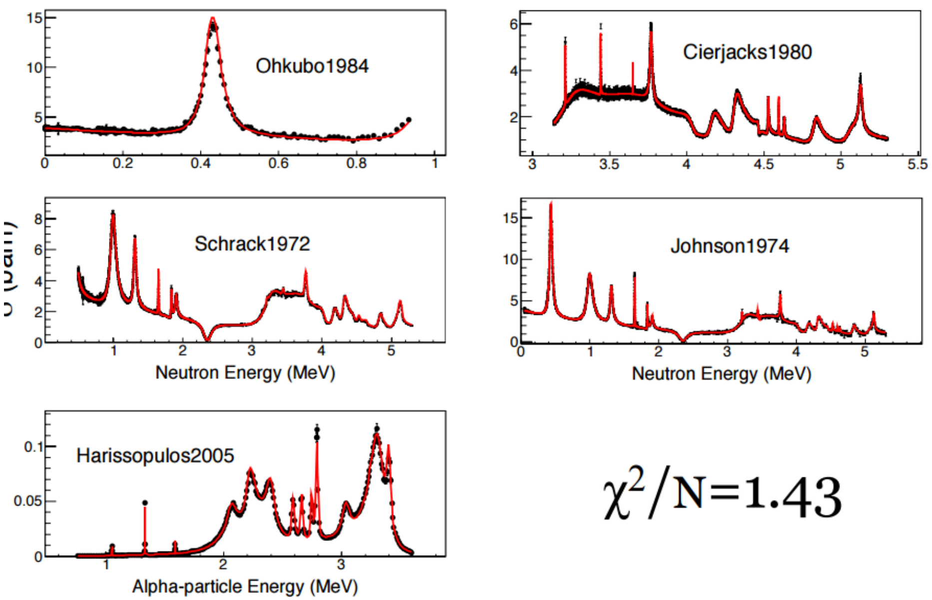
Two ^{16}O CIELO candidate evaluations: LANL (Hale), ORNL (Leal)
Kunieda et al, www-nds.iaea.org/index-meeting-crp/TM-neutron-std/docs/Kunieda-STD-2014.pdf (INDC(NDS)-0677 rep., IAEA 2015)

Results of Re-normalization

Reaction	Measurement	χ^2/N	Re-normalization to measurement
O(n,total)	Schrack+ (72)	1.28	0.999 ± 0.14%
	Johnson+ (73)	1.54	0.999 ± 0.09%
	Cierjacks+ (80)	1.25	1.046 ± 0.16%
	Ohkubo (84)	1.71	1.018 ± 0.35%
$^{13}C(\alpha,n)^{16}O$	Harissopulos+ (05)	10.52	1.462 ± 1.00%

- Present R-matrix analysis is nearly independent of systematic difference in measurements
- Present result supports "old" $^{13}C(\alpha,n)^{16}O$ measurements, Bair and Haas (73)

Fitted Results



$\chi^2/N=1.43$

=> Higher cross sections preferred ~ ENDF-B/VI values

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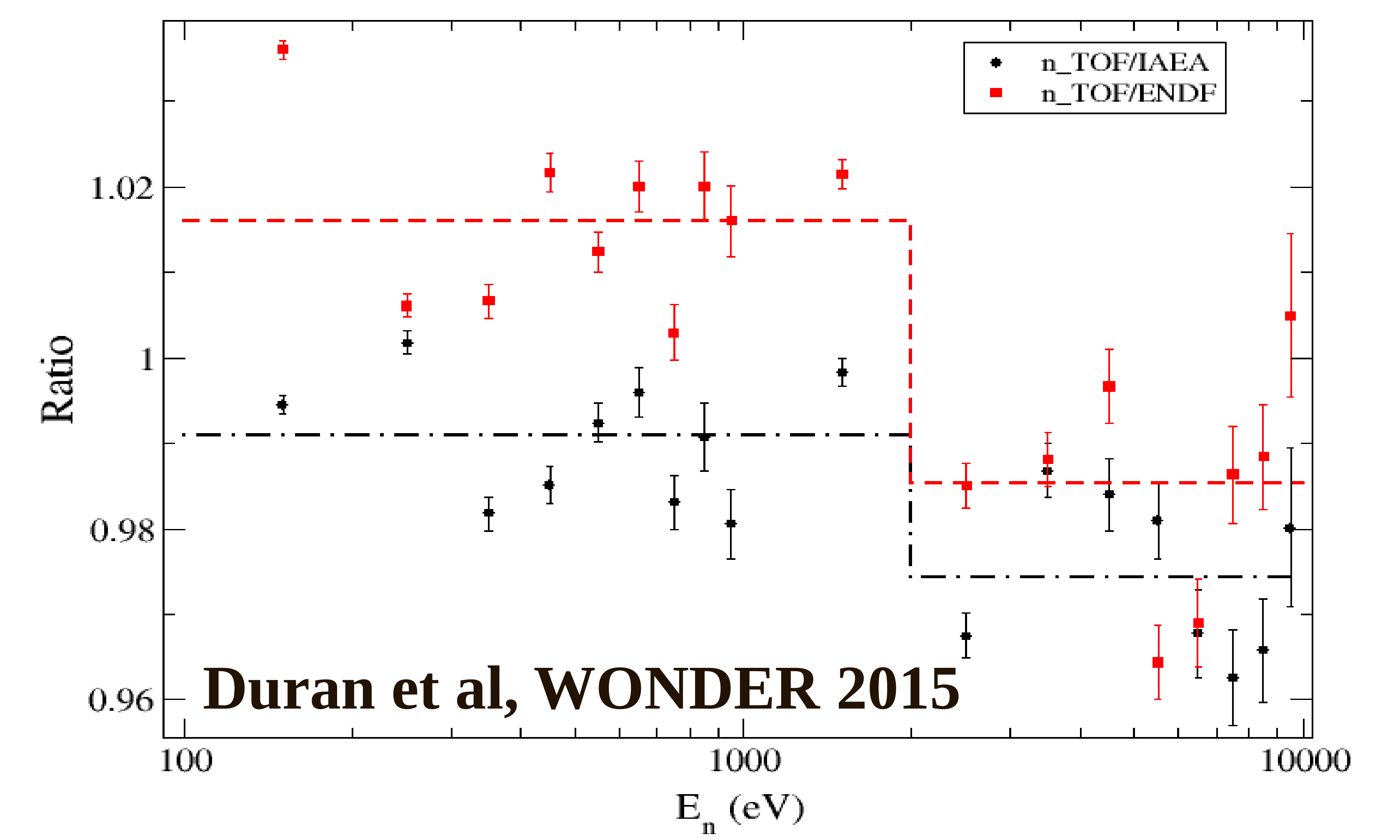
Recommended $^{235}U(n,f)$ resonance integrals confirmed by n_TOF



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NEW: (n,f) cross sections up to 1 GeV

www-nds.iaea.org/standards/

Neutron Cross-section References (2015)

The reference (n,f) cross sections were evaluated for the following 5 nuclei (detailed information is available in Report INDC(NDS)-0681 "^{209}Bi and ^{nat}Pb neutron fission cross sections as new references and extensions of the ^{235}U, ^{238}U and ^{239}Pu (n,f) standards up to 1 GeV", B. Marcinkevicius, S. Simakov and V. Pronyaev).

The ENDF-6 file with cross sections, energy-energy correlations and cross-reaction correlations for ^{209}Bi, ^{nat}Pb, ^{235}U, ^{238}U and ^{239}Pu (n,f is available here : High-En-Ref.endf

Reaction	Energy Range	ENDF-6 Format	NJOY plot	Free text format
235U(n,f)	0.0253 eV - 1 GeV	235U-Ref-HighErg.endf	file.pdf	235U_nf_Reference_xs_data.txt
238U(n,f)	0.0253 eV - 1 GeV	238U-Ref-HighErg.endf	file.pdf	238U_nf_Reference_xs_data.txt
239Pu(n,f)	0.0253 eV - 300 MeV	239Pu-Ref-HighErg.endf	file.pdf	239Pu_nf_Reference_xs_data.txt
209Bi(n,f)	34 MeV - 1 GeV	209Bi-Ref-HighErg.endf	file.pdf	209Bi_nf_Reference_xs_data.txt
natPb(n,f)	34 MeV - 1 GeV	natPB-Ref-HighErg.endf	file.pdf	natPb_nf_Reference_xs_data.txt

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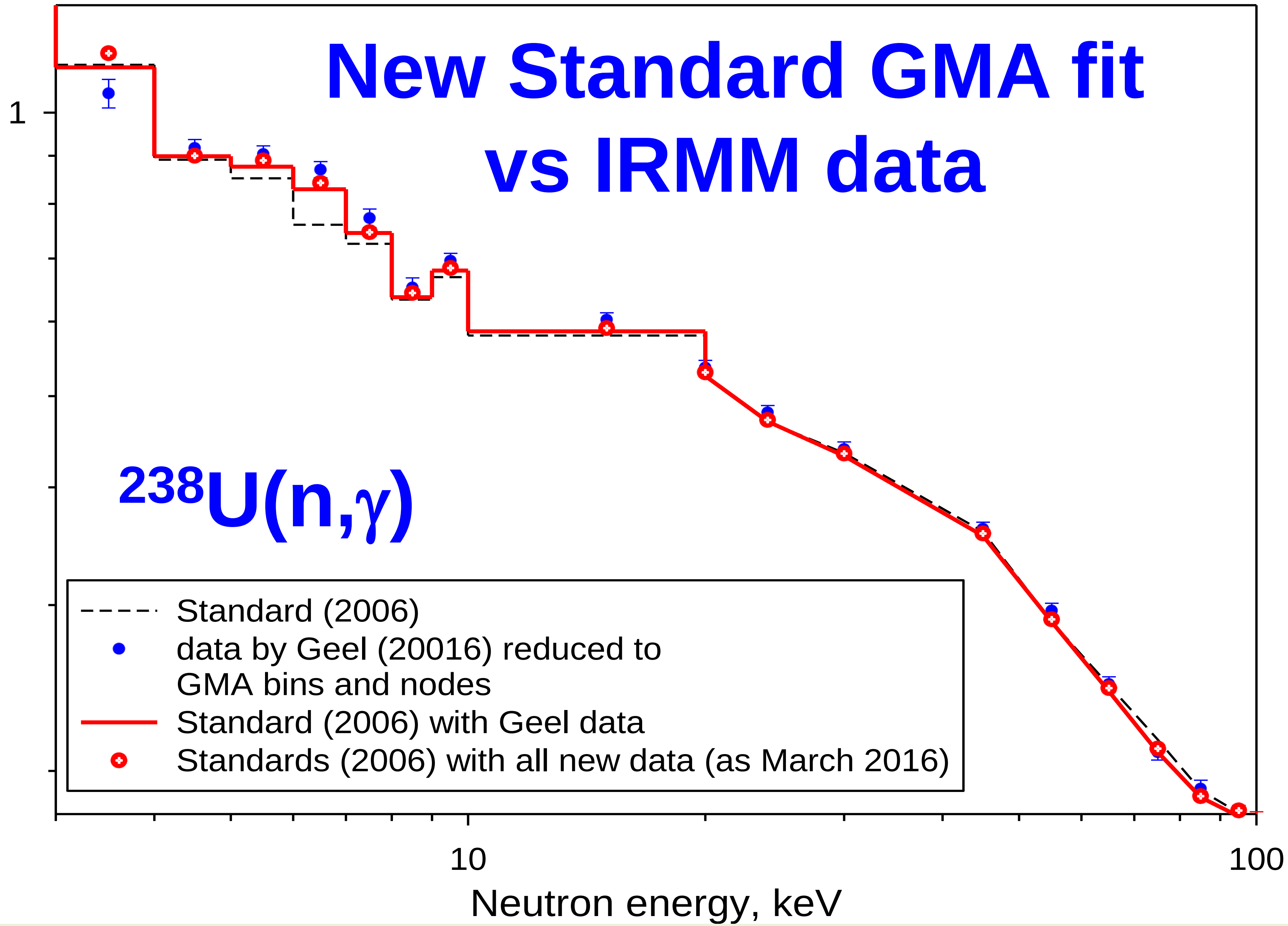

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New Standard GMA fit $^{238}U(n,g)$,$^{197}Au(n,g)$ vs Wallner AMS

$^{238}U(n,g)$

kT=25 keV
Wallner: 0.391± 0.017 b (4.3%)
GMA: 0.3939 b (+0.74%)

kT=426 keV
A. Wallner: 0.108±0.004 b (3.7%)
GMA: 0.1078 b (-0.2%)

$^{238}U(n,g)/^{197}Au(n,g)$

kT=25 keV
Wallner: 0.620±0.023 (3.7%)
GMA: 0.6276 (+1.2%)

kT=426 keV
Wallner: 0.687±0.022 (3.2%)
GMA: 0.6853 (-0.25%)

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2200 m/s and 20°C Maxwellian neutron data: Thermal Constants

- **WESTCOTT, C. H.** et al, Atomic Energy Review **3** (1965) 3
- HANNA, G. C., **WESTCOTT, C. H., LEMMEL, H. D.** et al,
  Atomic Energy Review **4** (1969) 3, also **INDC(NDU)-012**
- **LEMMEL, H. D.** et al, Proc. Conf. Nucl. Cross Sect. & Tech., Wash. DC,
  3-7 March 1975, *NBS Spec. Publ.* **425**, 286 (1975), also **INDC(NDS)-132**
- **LEMMEL, H. D.** et al, Proc. Int. Spec. Symp. Neutron Standards & Applications,
  NBS Spec. Publ. **493**, 170 (1977)
- **LEMMEL, H. D.**, IAEA Technical Reports Series **227** (1983), p.71
- STEHN, J. R., DIVADEENAM, M. and HOLDEN, N. E.,
  Conf. NDST, Antwerp, 1982, Proc. edited by K.H. Boeckhoff (1983) p. 685.
- DIVADEENAM, M. and STEHN, J. R., Ann. Nucl. Energy **11** (1984) 375-404
- AXTON, E. J., Geel Report GE/PH/01/86
- **PRONYAEV, V. G.**, CARLSON, A. et al., 2004-2016

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Evolution of Thermal Constants 1975-…

1) Lemmel 1975

	Micr+macr.	Micr. only
σ(*n*,f)	**583.5±1.3**	**587.7±1.9**
σ(*n*,γ)	**97.4±1.3**	**93±2**
ν(tot)	**2.400(5)**	**2.387(6)**

Mic-mac discrepancy noted

Axton 1986

	Micr+macr.	Micr. only
σ(*n*,f)	**582.8±1.17**	**585.1±1.62**
σ(*n*,γ)	**99.1±0.7**	**96.1±1.74**
ν(tot)	**2.4330(36)**	**2.4261(46)**
K1	**718.6**	721.24

Pronyaev et al, GMA 2004

	Micr+macr.	ENDF/B-VI
σ(*n*,f)	**584.2±1.1**	**584.88**
σ(*n*,γ)	**99.3±0.7**	**98.66**
ν(tot)	**2.4324(4)**	**2.4367(5)**
K1	**719.67**	**722.7**

Pronyaev et al, GMA 2015

	Micr+macr.	Micr. only
σ(*n*,f)	584.4±1.0	**587.2±1.4**
σ(*n*,γ)	99.30±0.72	**96.8±1.7**
ν(tot)	2.4321(36)	**2.4250(46)**
K1	719.9	**722.82**

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New Thermal constants (03/2016)

Constant	Microscopic & macroscopic data 2004 (GMA)		Microscopic & macroscopic data 03/2016 (GMA)	Microscopic data + Wallner AMS 03/2016 (GMA)
SF-U5	584.4	(585.0)	587.0±1.0	586.5±1.4
SG-U5	99.3	(98.7)	98.3±1.3	100.2±2.0
NU-U5	2.4358	(2.4367)	2.4256±0.0045	2.4264±0.0046 (2.429)
K1	721.35		722.2	721.0 (722.6)
Hardy	**722.7±3.9 (*)**			
SF-PU9	750	(747.9)	751.9±2.2	751.8±2.2
SG-PU9	271.5	(270.7)	270.8±3.1	271.1±3.2
NU-PU9	2.884	(2.8789)	2.878±0.006	2.878±0.006

Used by M. Pigni in ^{235}U(n,f) RP fit (o17)

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Pu-239 challenges

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Prompt Fission Neutron Spectra of Actinides

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IAEA Coordinated Research Project 2008-2014
Paper accepted by Nuclear Data Sheets (Jan. 2016)

PFNS average energy ^{235}U(n,f)

$\Delta\bar{\varepsilon} = -30$ keV

TABLE 28. Comparison of the PFNS average energies (in MeV) of ^{235}U(n,f) for the calculations and evaluations discussed within the IAEA CRP. The column header is the incident neutron incident energy, E_n, in MeV. The estimated uncertainty on the average energy due to the PFNS uncertainty is 10 keV. The * indicates an average over incident neutron energies, $0.3 \leq E_n \leq 2$ MeV.

PFNS source	Thermal	0.5 MeV	2 MeV	5 MeV
ENDF/B-VII.1 [148]	2.031	2.045	2.057	2.110
Maslov [156]	1.960	1.981	2.029	2.120
Kornilov (SCALE) [288]	1.970	–	–	–
Morillon (Sec. IV B 2)	1.970	1.978	2.002	2.050
Shu (Sec. IV D)	2.082	2.082	2.114	2.234
Vogt (Sec. VII H)	1.911	1.933	1.980	2.057
Talou (Sec. VII F)	2.001	2.014	2.054	2.129
GANDR fit (Sec. VII B)	2.001	2.017*	–	–
GMA fit (Sec. VII C)	2.000	–	–	–

non-model fit

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PFNS average energy ^{239}Pu(n,f)

$\Delta\bar{\varepsilon} = -30$ keV

TABLE 31. Comparison of the PFNS average energies (in MeV) of ^{239}Pu(n,f) for calculations and evaluations discussed within the IAEA CRP. The column header is the neutron incident energy E_n. The estimated uncertainty of the average energy due to the PFNS uncertainty is 10 keV.

PFNS source	Thermal	1 MeV	2 MeV	5 MeV
JEFF-3.1.1 [340]	2.112	2.140	2.168	2.226
ENDF/B-VII.1 [148]	2.112	2.138	2.163	2.236
JENDL-4.0 [149]	2.116	2.140	2.165	2.236
Maslov [341]	2.092	2.122	2.152	2.242
Morillon (Sec. IV B 2)	2.085	2.099	2.114	2.145
Talou (Sec. VII F)	2.083	2.111	2.138	2.215
Neudecker (Sec. VII E)	2.074	2.103	2.131	2.211
GMA fit (Sec. VII C)	2.074	–	–	–

non-model fit →

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R.C. et al, *Nucl. Data Sheets* 131(2015) 1

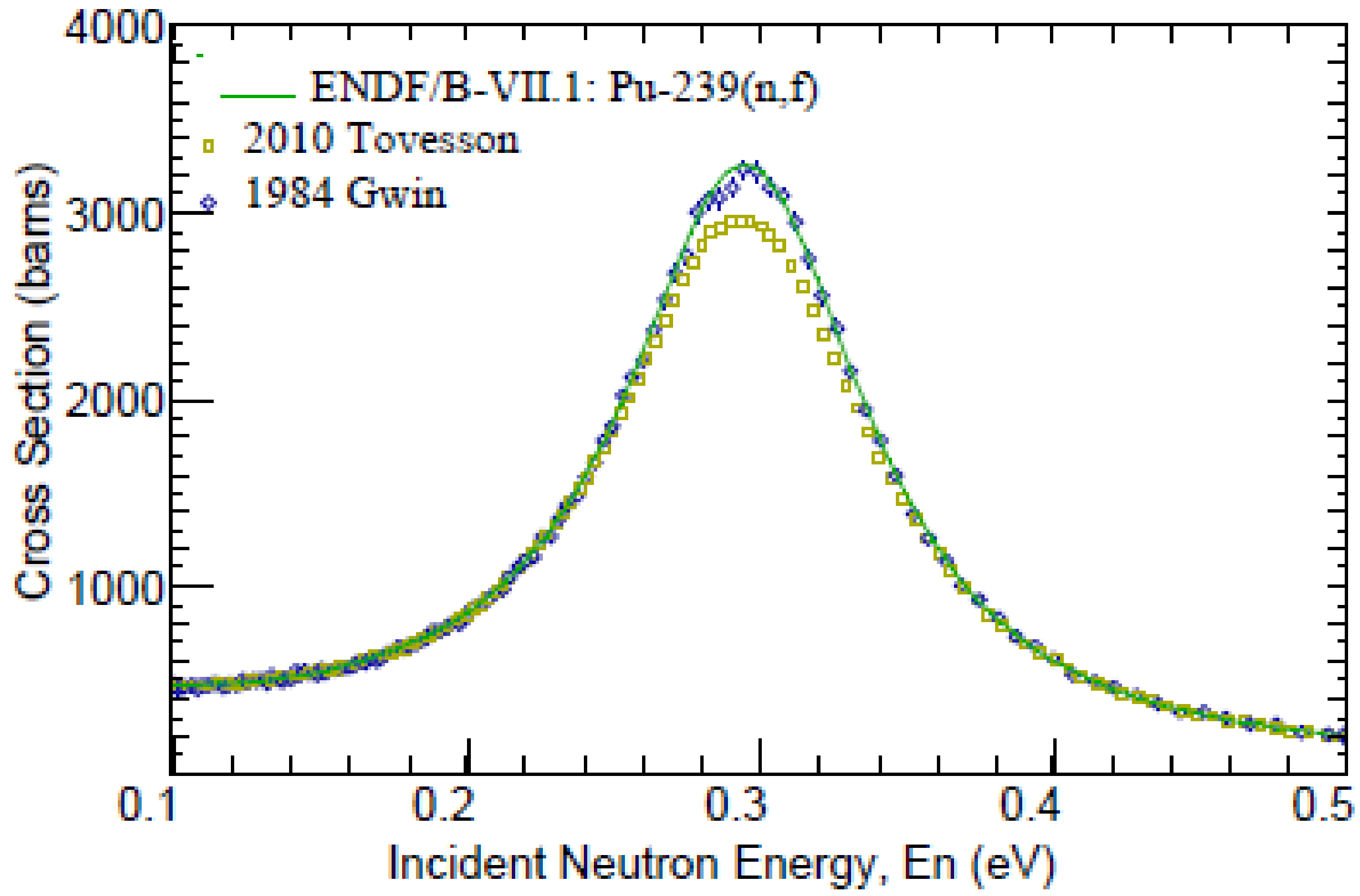

FIG. 63. (Color online) Comparison of the fission cross section of ^{239}Pu in the first resonance.

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Conclusions: New Standards will be ready

- Thermal constants mic-mac and micro fits **CONSISTENT**
  - Wallner et al. AMS ^{235}U capture data critical
- IAEA CRP ^{235}U(n$_{th}$,f) PFNS proposed as a reference neutron field (in addition to ^{252}Cf(sf))
- Recommended ^{235}U(n,f) resonance integrals below 10 keV confirmed by n_TOF experiment (problem in B/VII.1)
- New GMA fit for ^{197}Au(n,γ) and ^{238}U(n,γ) in excellent agreement with Wallner et al AMS data
- Light elements updated by Hale R-matrix fit
- IAEA CRP ^{239}Pu(n$_{th}$,f) PFNS with Eav= 2.073(10) discrepant from B/VII.1 value of 2.112

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