IAEA evaluations within CIELO: ^{238}U, ^{235}U, Thermal Constants

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Thanks to all IAEA project participants
Special thanks to Luiz Leal for resonance work on U-235

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NEA/WPEC CIELO collaboration

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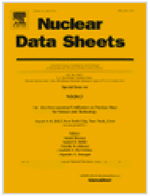

The CIELO Collaboration: Neutron Reactions on ^{1}H, ^{16}O, ^{56}Fe, ^{235,238}U, and ^{239}Pu

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IAEA contributions (www-nds.iaea.org/CIELO) :

- Actinide PFNS project
- Neutron Standards project (^{1}H, ^{235,238}U, ^{239}Pu)
- *n* + ^{238}U evaluation; *n* + ^{235}U evaluation

- Collab. with NNDC/BNL on Fe (Herman et al talk)

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)

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	–	–	–

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

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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On-going work on Neutron Standards

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

Next TM, 25-29 July 2016

- **New experimental data added**
- **Release of new Neutron Standards, Dec. 2016**

- **New Thermal Constants fit done (see Report)**

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IAEA TM on Neutron Standards, 12/2014

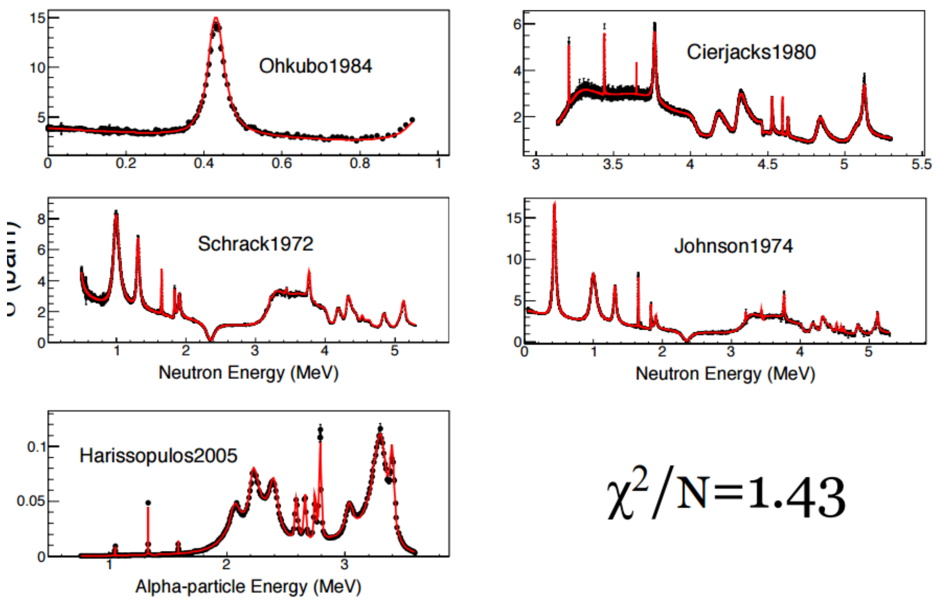
Two ^{16}O CIELO candidate evaluations: LANL (Hale), ORNL (Leal)
Kunieda et al, www-nds.iaea.org/index-meeting-crp/TM-neutron-std/docs/Kunieda-STD-2014.pdf (INDC(NDS)-0677 rep., IAEA 2015)

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

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- 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., 2004-2015

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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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Thermal constants (Neutron Standards)

Constant	Microscopic & macroscopic data 2004		Microscopic & macroscopic data 2015 (prelim.)	Microscopic data 2015 (prelim.)
SF-U5	584.4	(585)	584.4±1.0	587.2±1.4
SG-U5	99.3	(98.7)	99.3±0.7	96.8±1.7
NU-U5	2.4358		2.432±0.004	2.425±0.005
K1	721.35		719.9	722.8
Hardy	**722.7±3.9 (*)**			
SF-PU9	750		749.8±1.8	752.0±2.2
SG-PU9	271.5		271.4±2.1	270.5±3.2
NU-PU9	2.884		2.881±0.005	2.878±0.006

Luiz Leal (ISRN) RP set I(i1) RP set II(i2)

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n + ^{235}U

(n,f) from Neutron Standards

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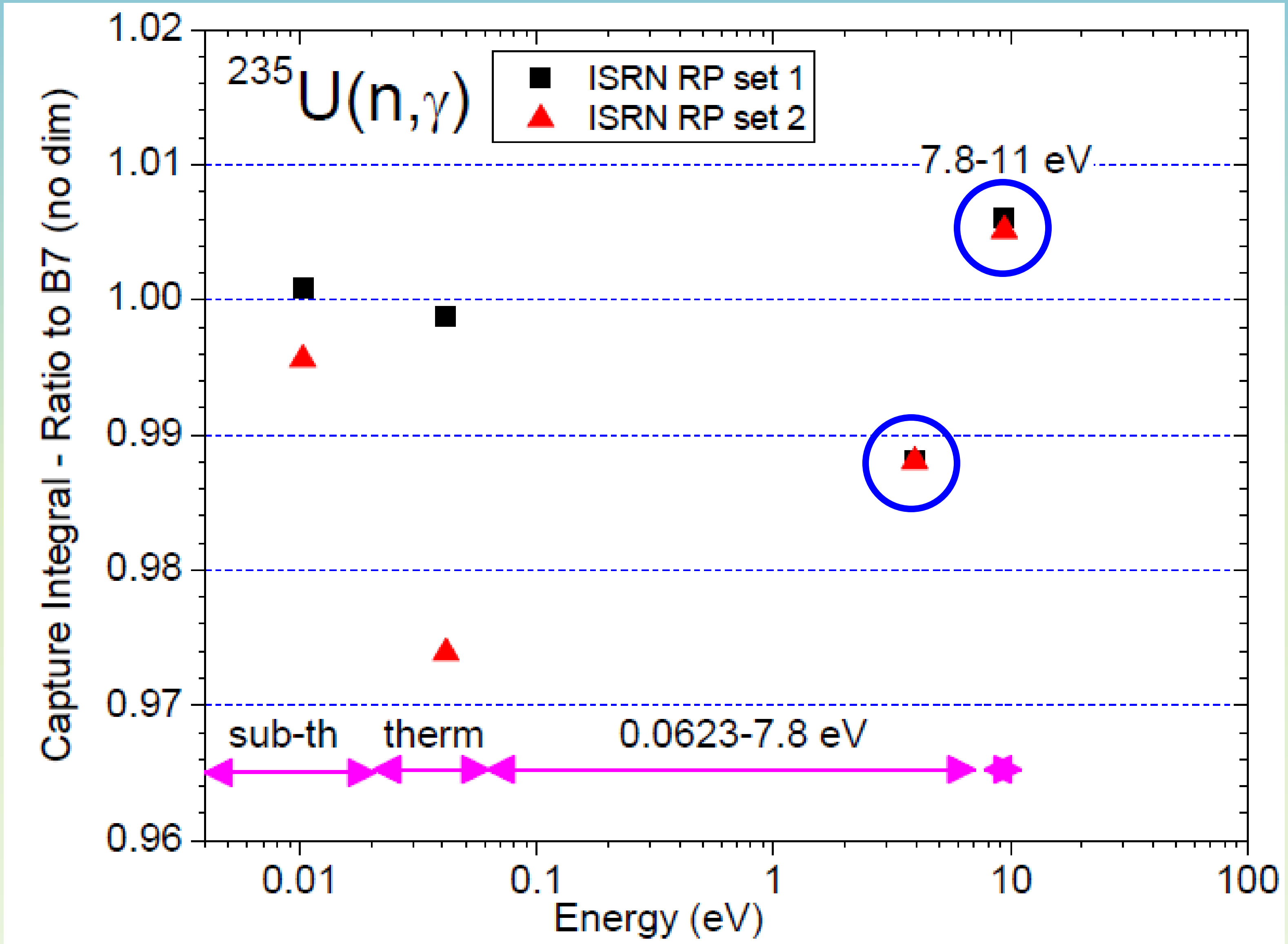
Capture integral ratio to B7 below 15 eV



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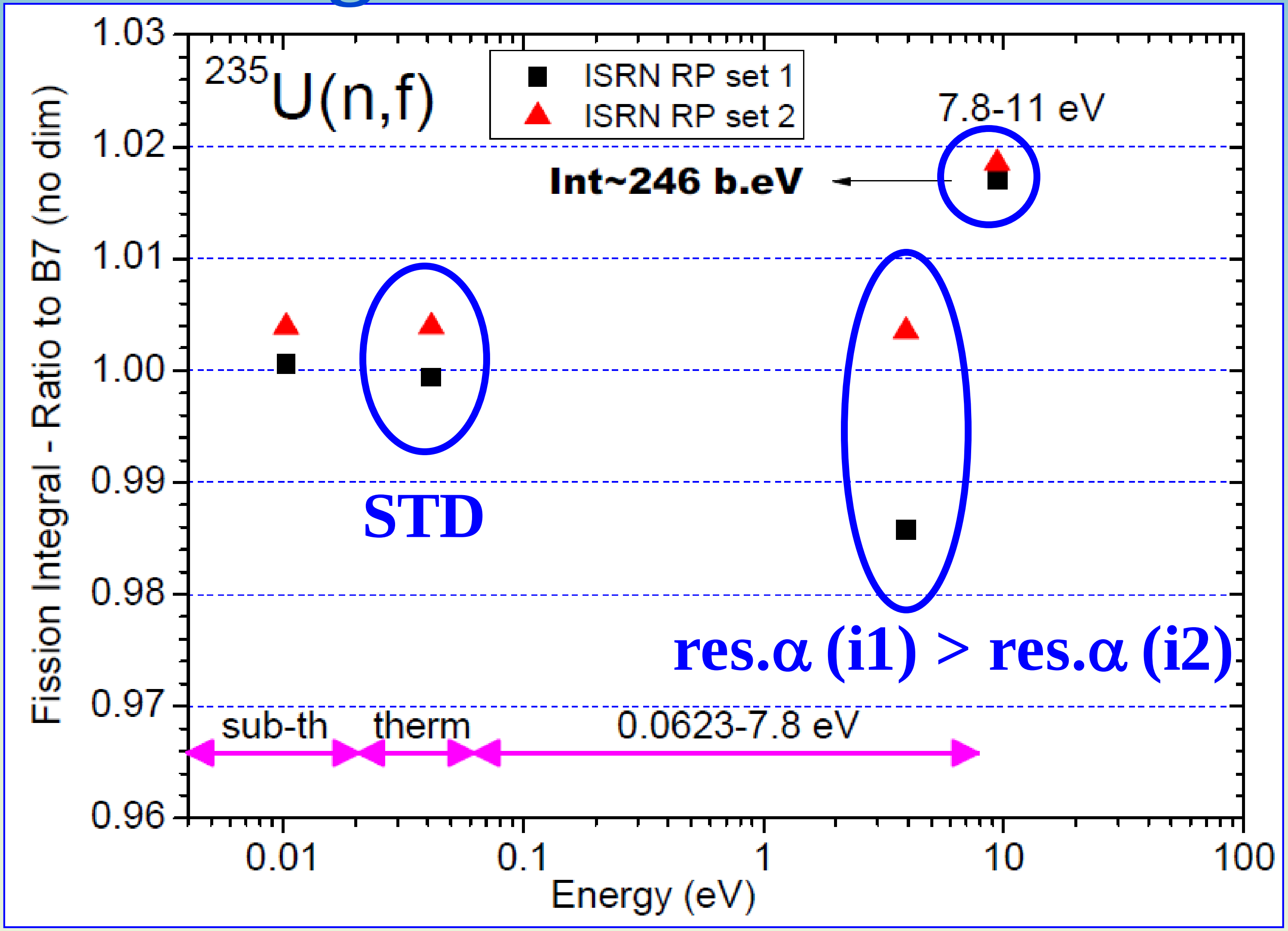
Fission integral ratio to B7 below 15 eV



C. Wagemans and A.J. Deruytter, "New results on the 235u(n,f) fission integrals"
IAEA TECDOC 335 (1984), p.155, σ_f (thermal)= 587.6 barn, Int(7.8-11eV) = 246.1 b.eV

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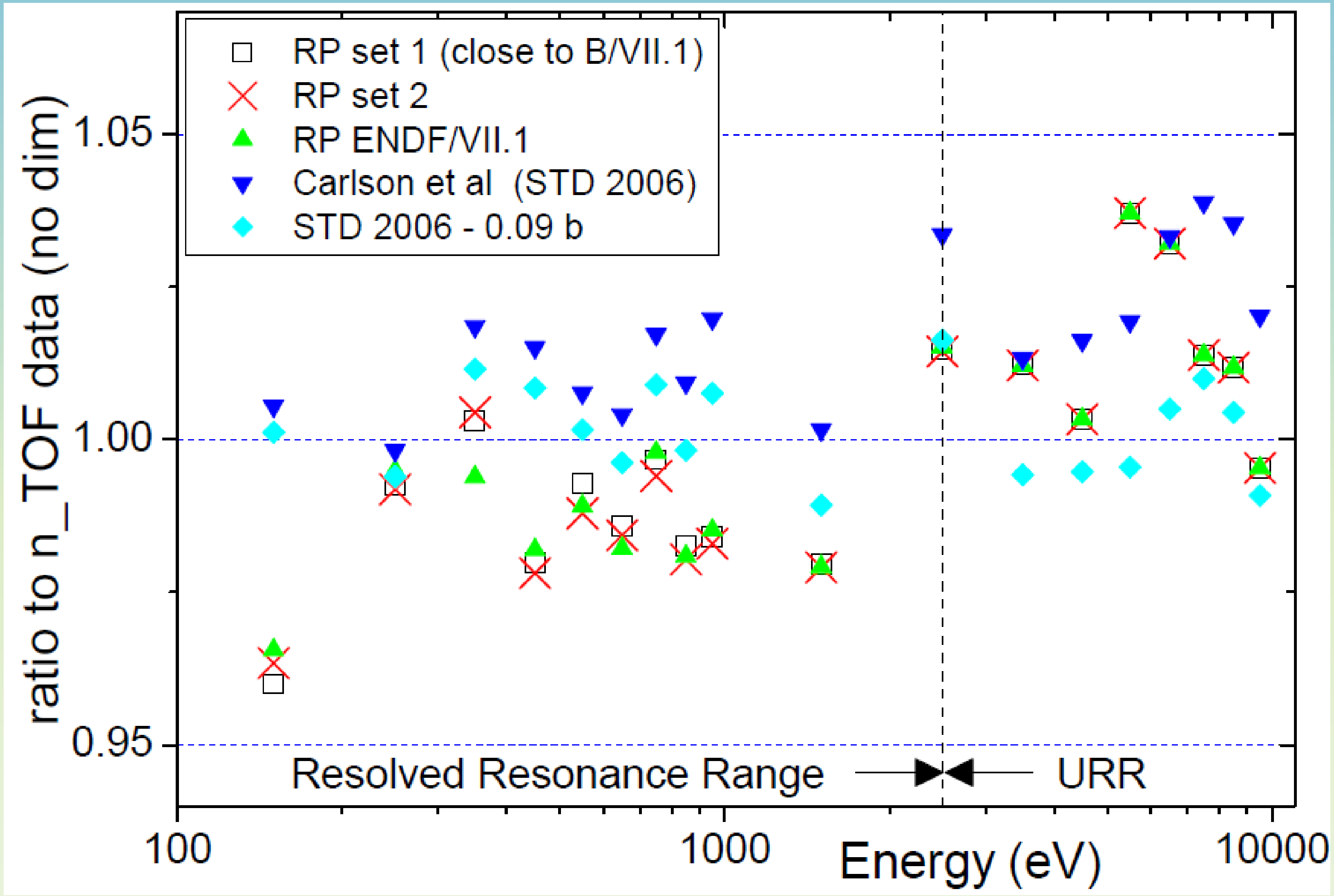
Fission XS ratio vs n_TOF: A problem?



n_TOF: Duran *et al.*, WONDER 2015, Oct. 5-8, 2015

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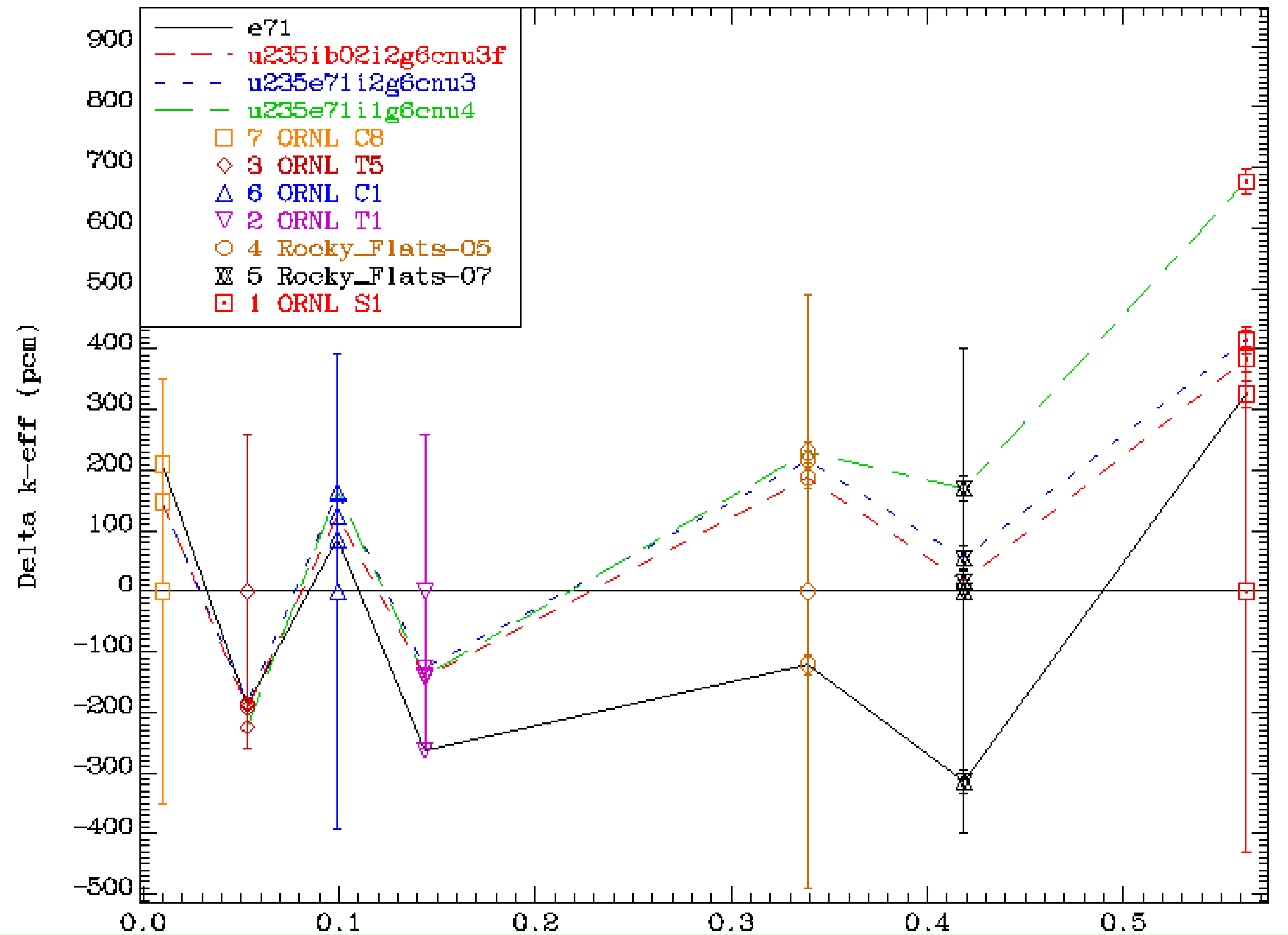
nubar fluctuations: k_{eff} vs ATLF



RP i1

RP i2

Gwin-Magnusson **ATLF** **High leakage**

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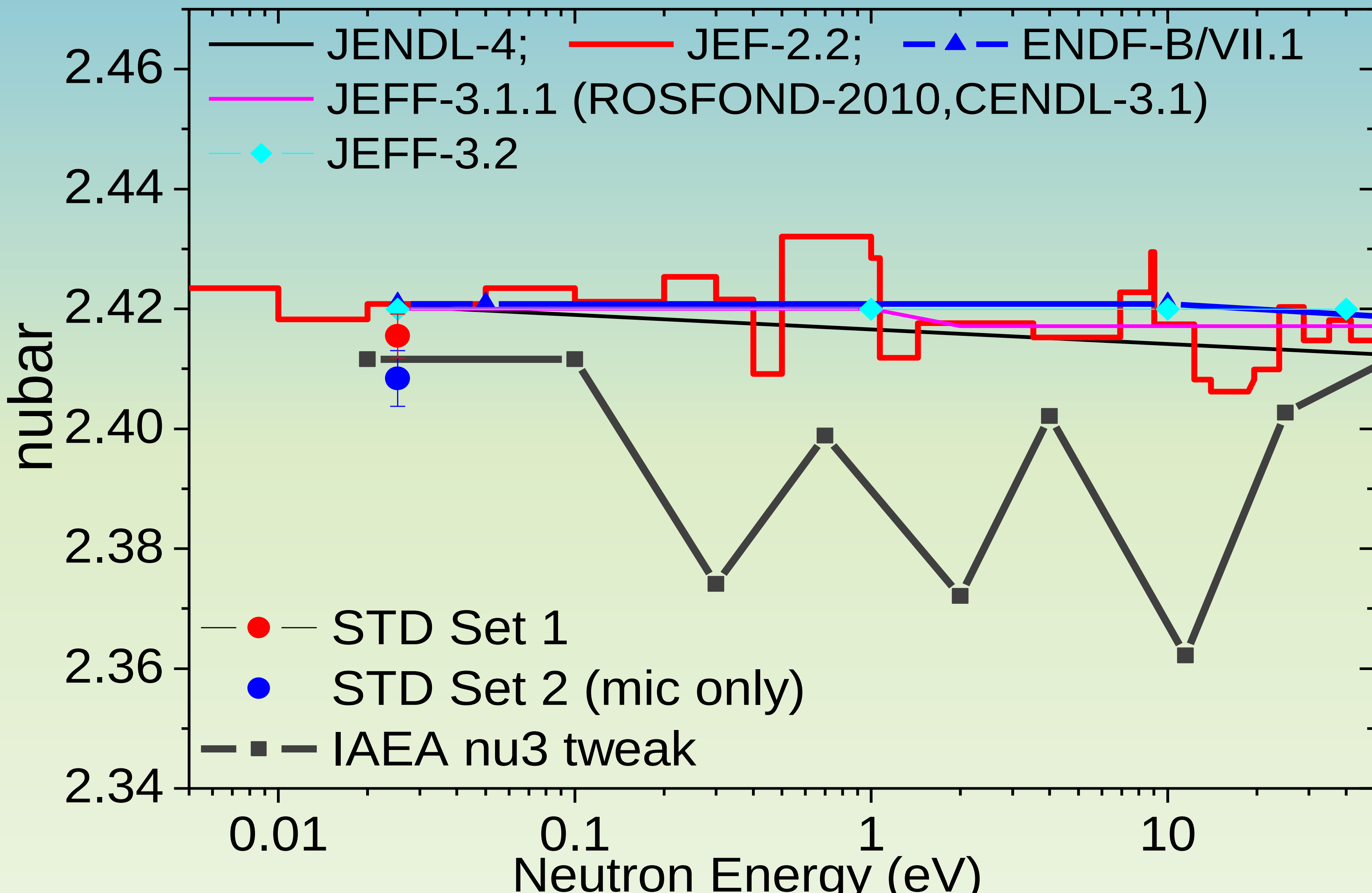
nubar fluctuations: diff. + k_{eff} vs ATLF



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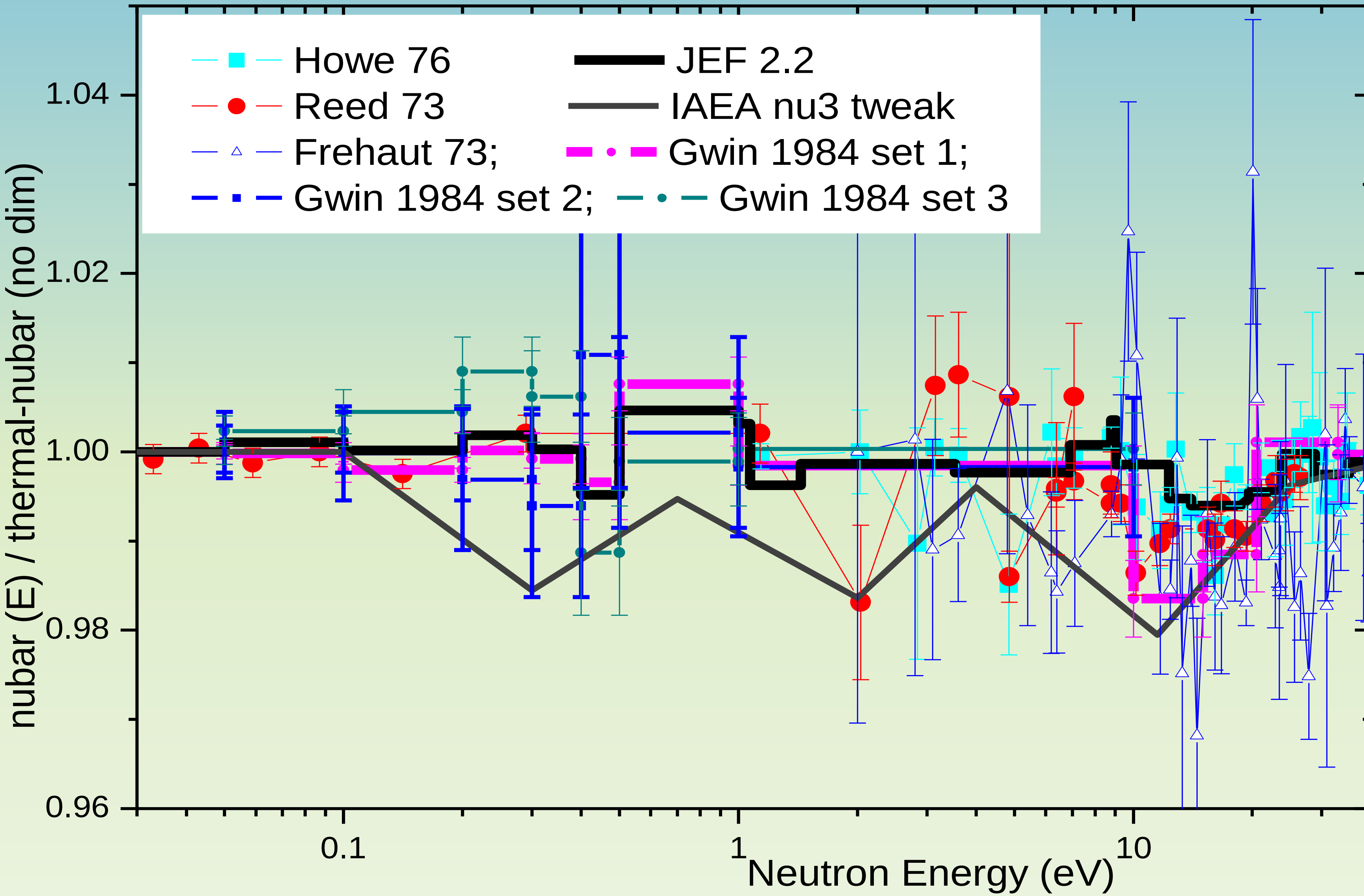
nubar fluctuations: diff. + k_{eff} vs ATLF



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$\boldsymbol{n + {}^{238}\mathrm{U}}$

(n,f) and (n,γ) from Neutron Standards

(n,2n) feedback from CEA Cadarache
(G. Noguere, D. Bernard)

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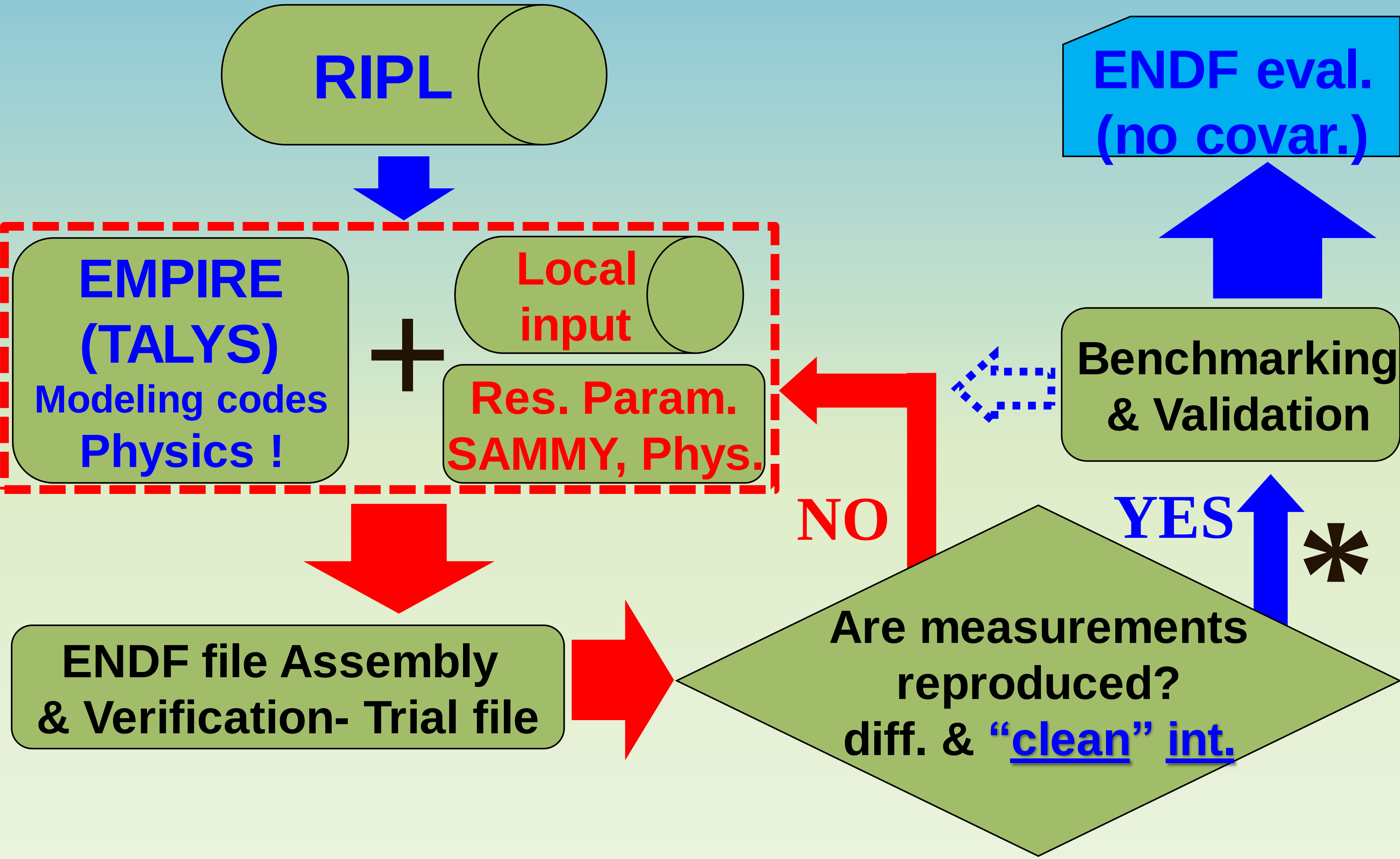
IAEA evaluation process (no covar.)



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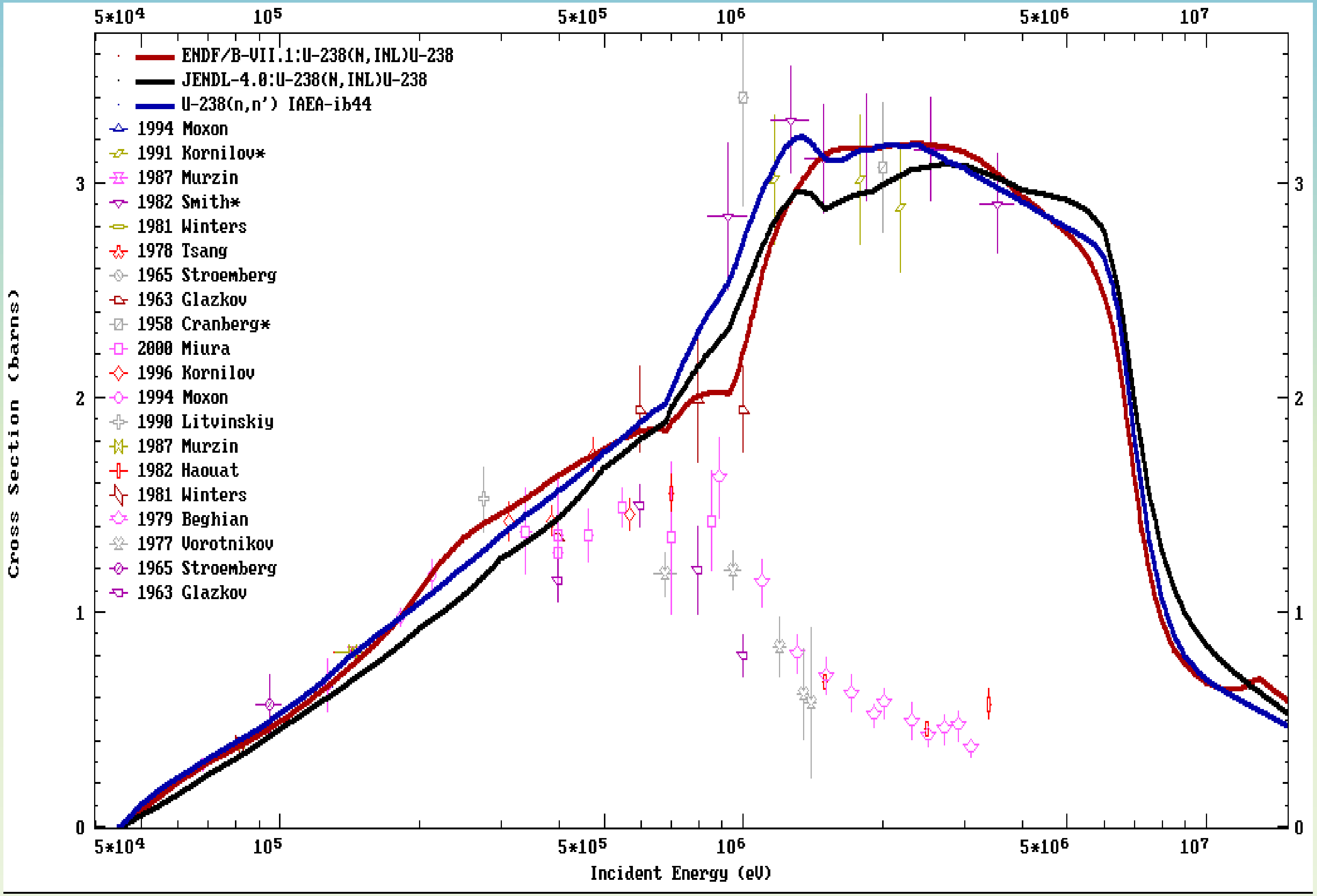
σ(inel), new physics: EW, 21-CC OMP



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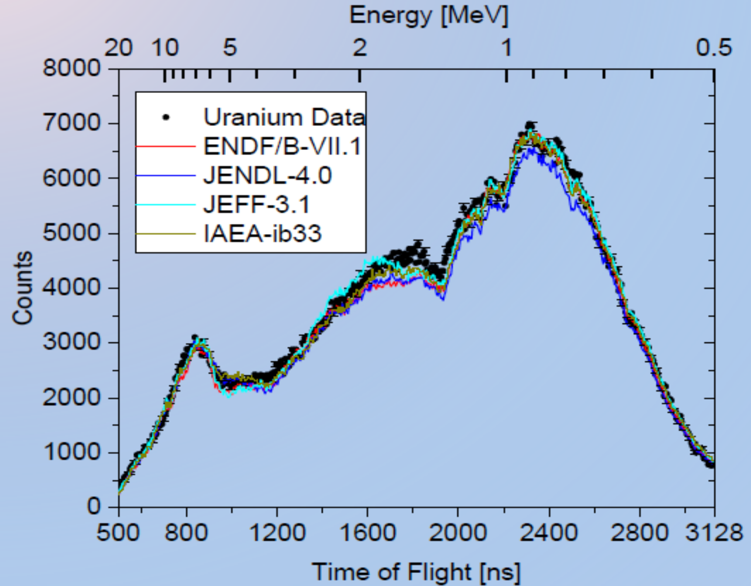
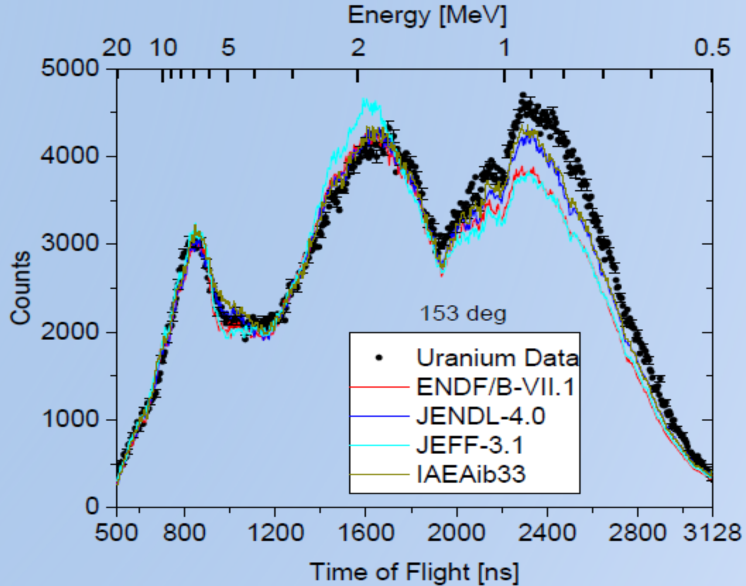
RPI exp. essential to define $d^2\sigma_{el}/dEd\Omega$

^{238}U Scattering Measurement





Library	FOM
ENDF/B-VII.1	3.8
JEFF-3.1	3.0
JENDL-4.0	5.5
IAEA-ib33	3.5

Library	FOM
ENDF/B-VII.1	18.8
JEFF-3.1	20.4
JENDL-4.0	7.7
IAEA-ib33	7.0

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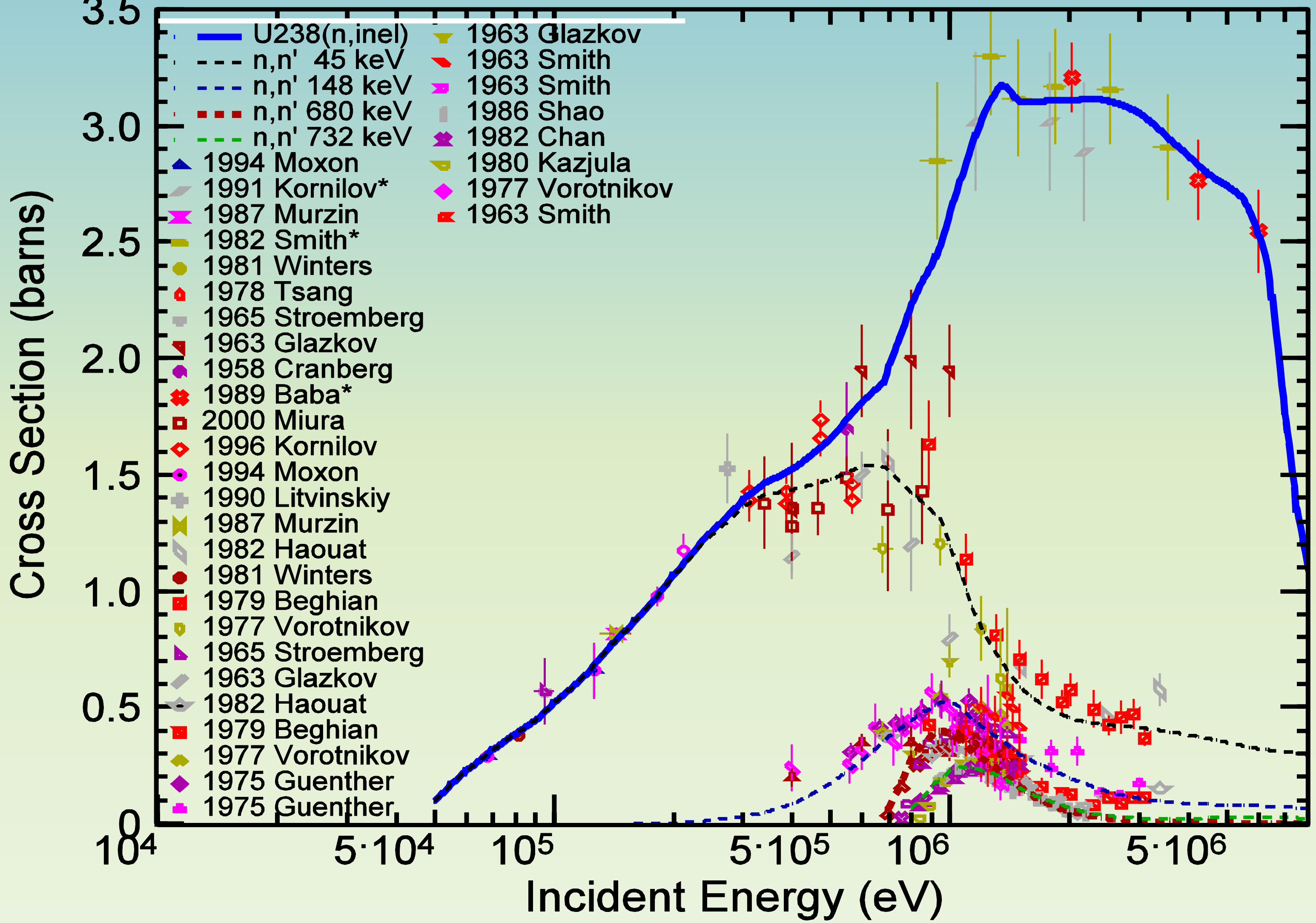
σ(inel), σ(n1), σ(n2), σ(n3) …

R. C., M. Sin, A. Trkov, M. W. Herman, D. Bernard, G. Noguere, A. Daskalakis, and Y. Danon.
NEMEA-7 proceedings, NEA SG-40 (2014) "Evaluation of neutron induced reactions on ^{238}U nucleus"



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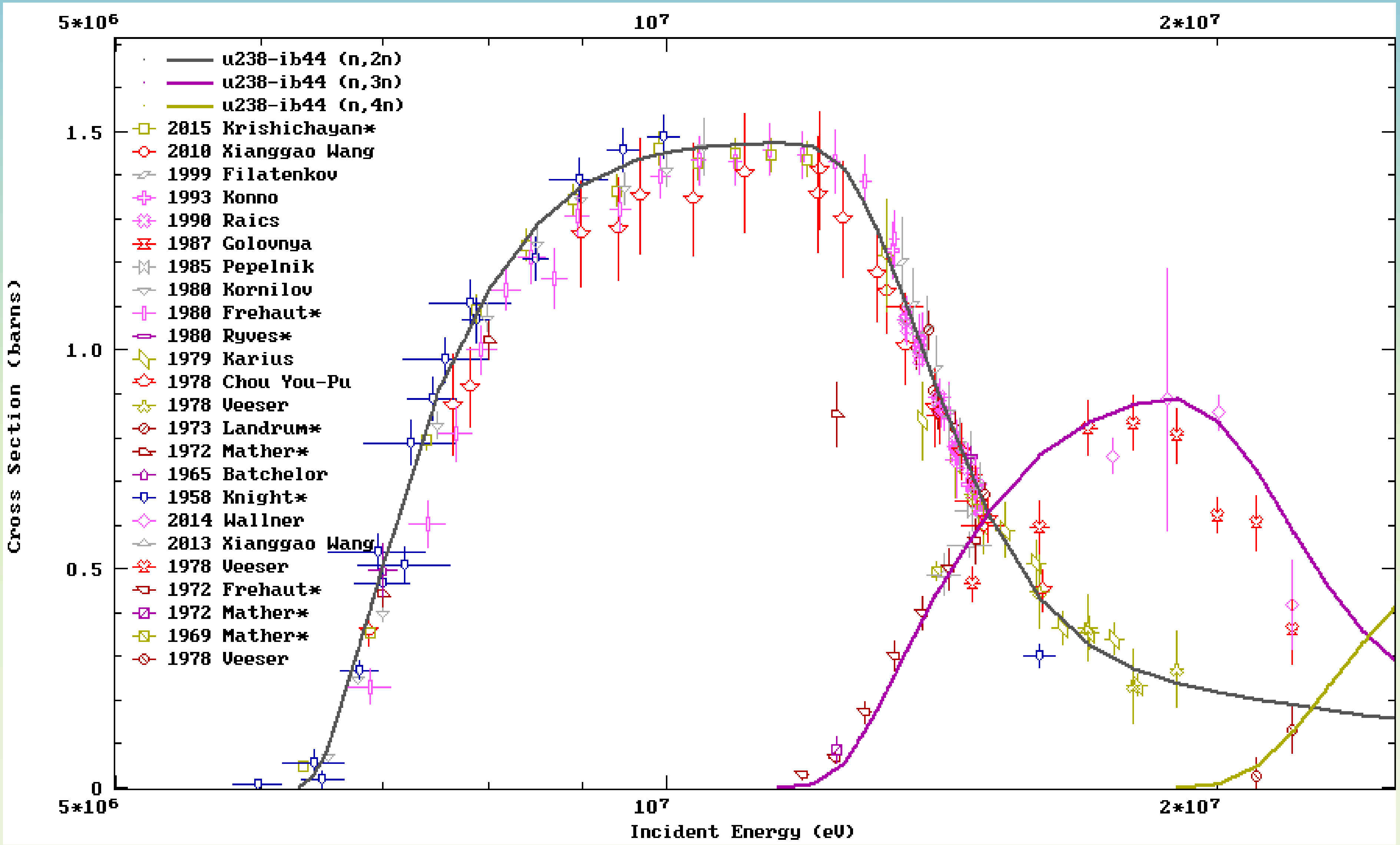
σ(n,2n), σ(n,3n), σ(n,4n)



US Nuclear Data Week, 2-6 November 2015
NNDC/BNL, Upton, NY, USA

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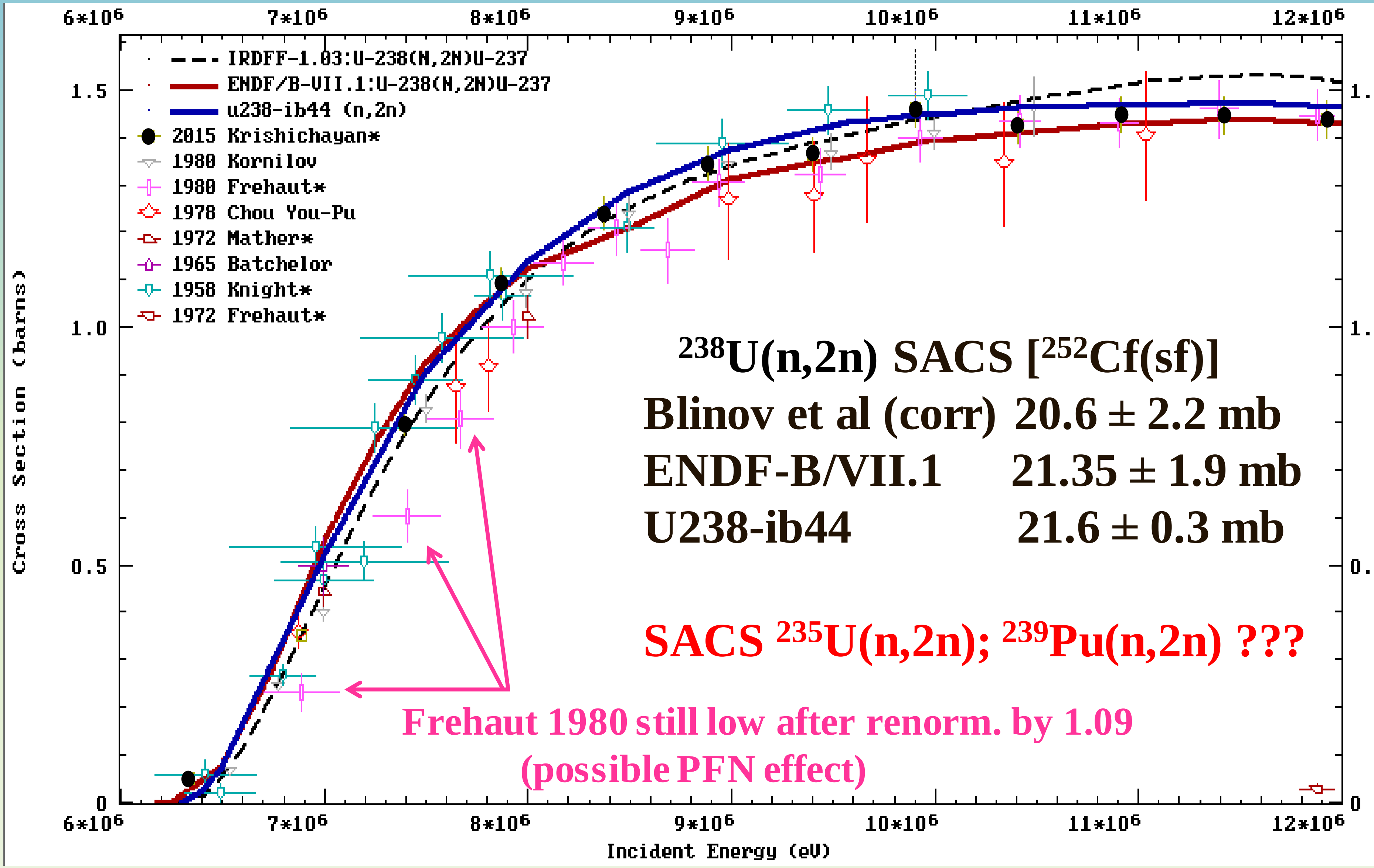
σ(n,2n) vs TUNL and SACS



^{238}U(n,2n) SACS [^{252}Cf(sf)]

Blinov et al (corr)	20.6 ± 2.2 mb
ENDF-B/VII.1	21.35 ± 1.9 mb
U238-ib44	21.6 ± 0.3 mb

SACS ^{235}U(n,2n); ^{239}Pu(n,2n) ???

Frehaut 1980 still low after renorm. by 1.09
(possible PFN effect)

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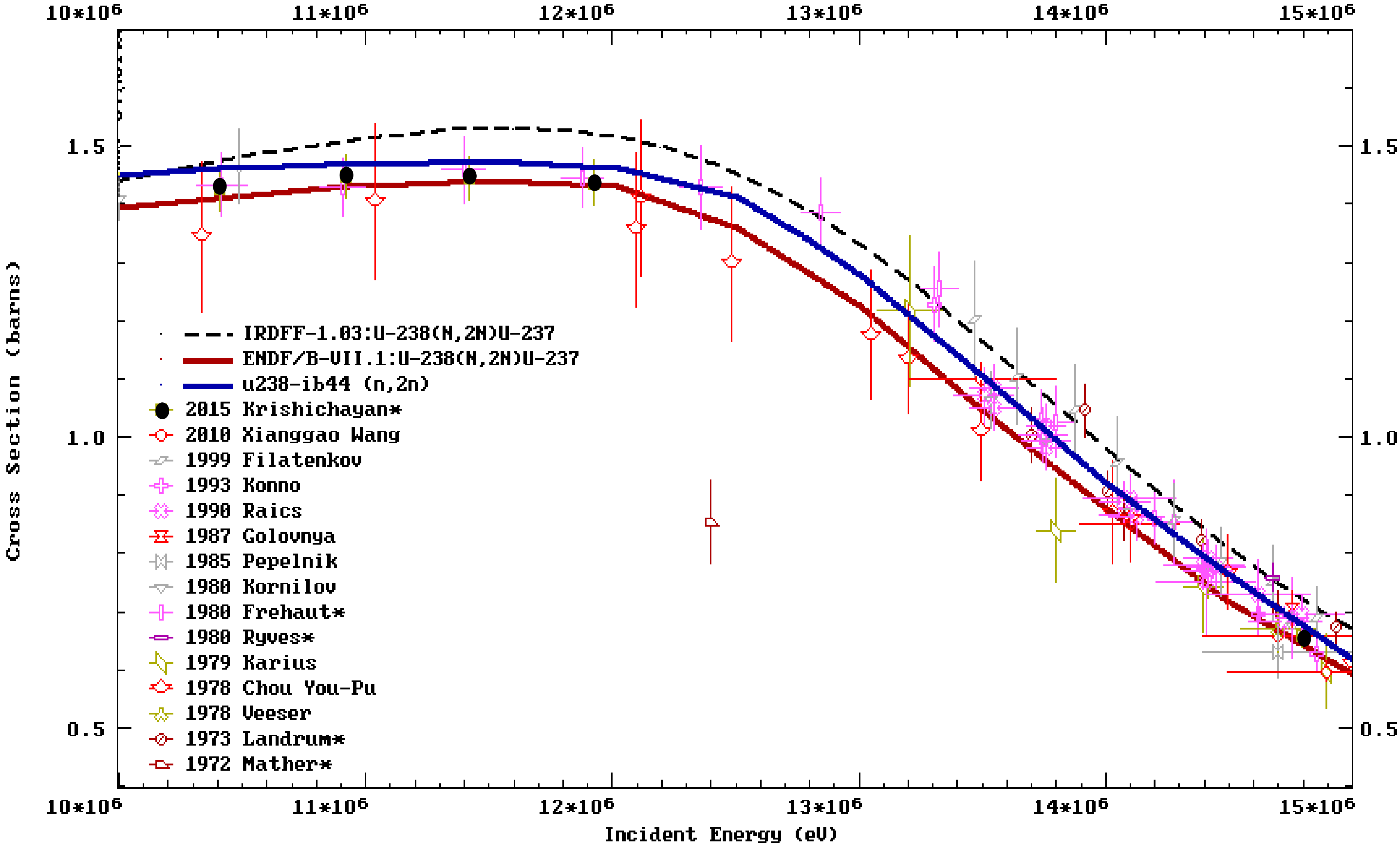
σ(n,2n) vs TUNL (above 10 MeV)



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Conclusions

- ^{235}U: new PFNS (GMA @ thermal, Talou-Rising above)
- ^{235}U: new set of thermal constants & ISRN RPs (i1 & i2)
- ^{235}U: nubar fluctuations introduced (nu3 tweak)

^{235}U: σ(inel), σ(el) (new RPI data?), σ(2n) (^{252}Cf(sf) SACS data?)

^{235}U challenges: resonance alpha, RR->URR discontinuity

- ^{238}U: new evaluation, elastic/inel. changes (better physics)
- ^{238}U: RPI quasi-diff. data - a big help
- ^{238}U: better n,2n

  (CEA Cadarache feedback, inelastic + TUNL data)

^{238}U: addit. inelastic/elastic fine-tuning with RPI and crit. benchmarks

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