NUCLEAR DATA EVALUATION:

Impact of n_TOF measurements on nuclear applications

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Nuclear Data Section

International Atomic Energy Agency

OUTLINE

- ❑ Nuclear data evaluation in a nutshell
- ❑ Overview of n_TOF results and their impact
- ❑ Summary and outlook

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Definition of (ND) Evaluation

A properly weighted combination (usually by GLSQ fit) of selected experimental data (and nuclear reaction modelling results).

Bayesian approaches:

- ❑ "Non-model" GLSQ fit: neutron standards
- ❑ R-matrix (non-model fit) – RR evaluations
- ❑ Model prior + GLSQ fit

  - ✓ Experimental nuclear physicists
  - ✓ Theoreticians and reaction modellers
  - ✓ Evaluators

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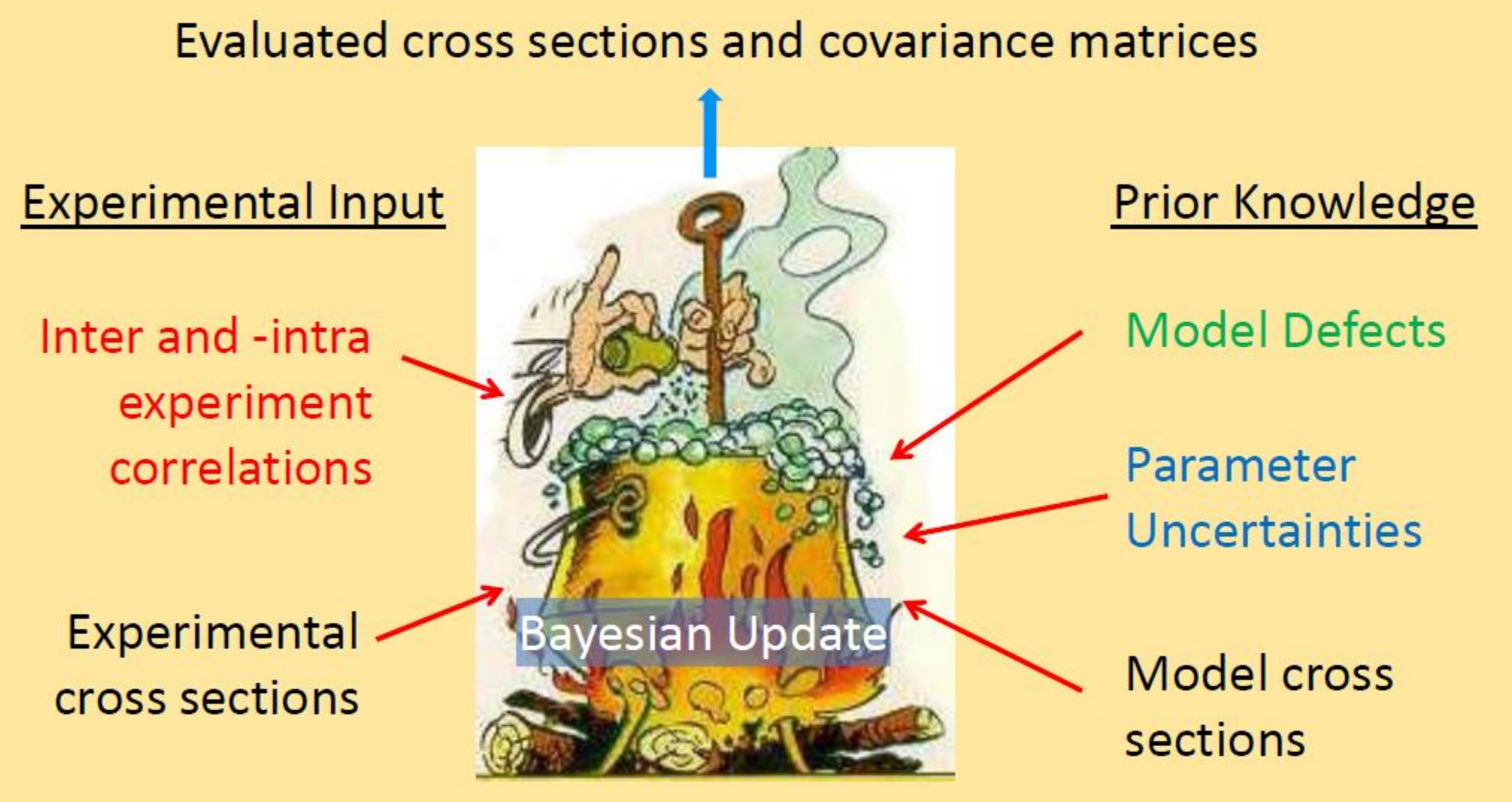
Nuclear Data Evaluation



From D. Neudecker, S. Gundacker, H. Leeb *et al.*, ND2010, Jeju Isl., Korea

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n_TOF data
impact on evaluations

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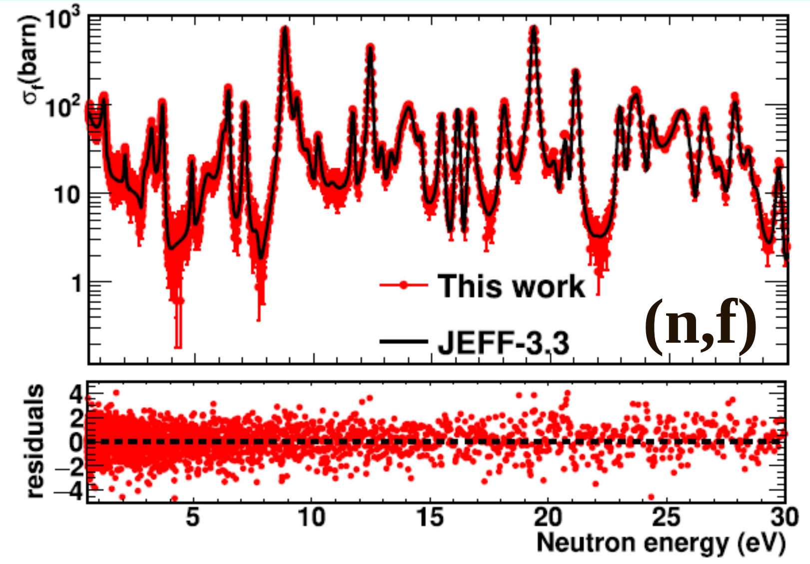
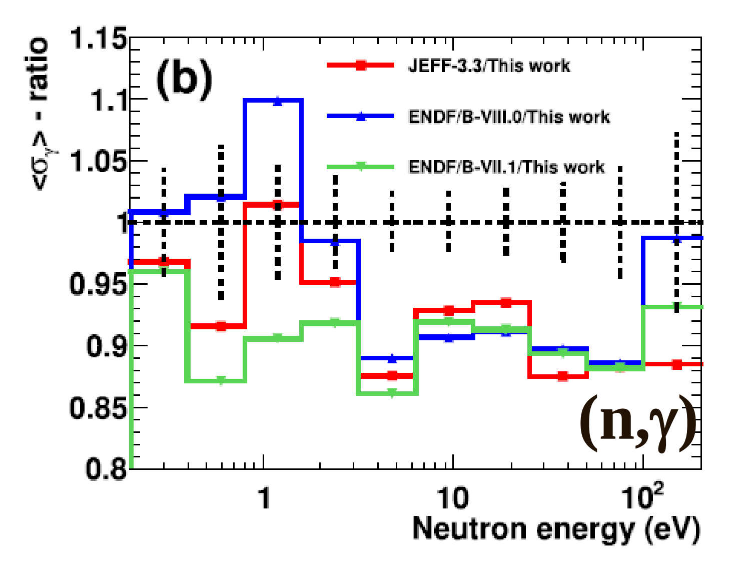
Capture on ^{235}U below 200 eV





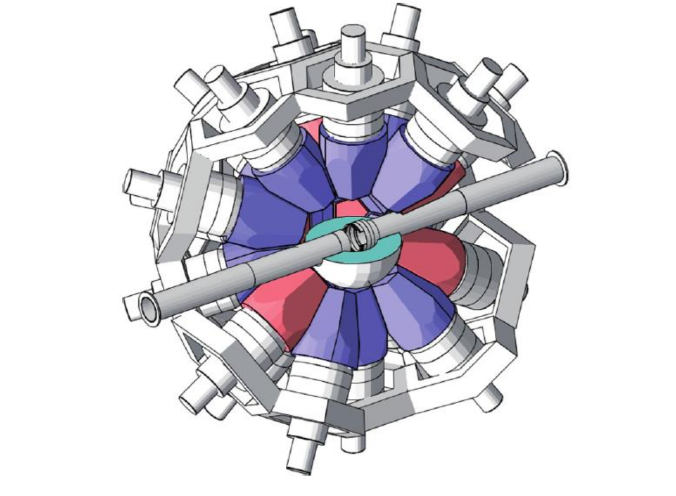


FIG. 1. Schematic view of part of the n_TOF TAC, together with

Phys Rev C102 (2020) 044615

Measurement of the α ratio and (n, γ) cross section of ^{235}U from 0.2 to 200 eV at n_TOF

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(n_TOF Collaboration)

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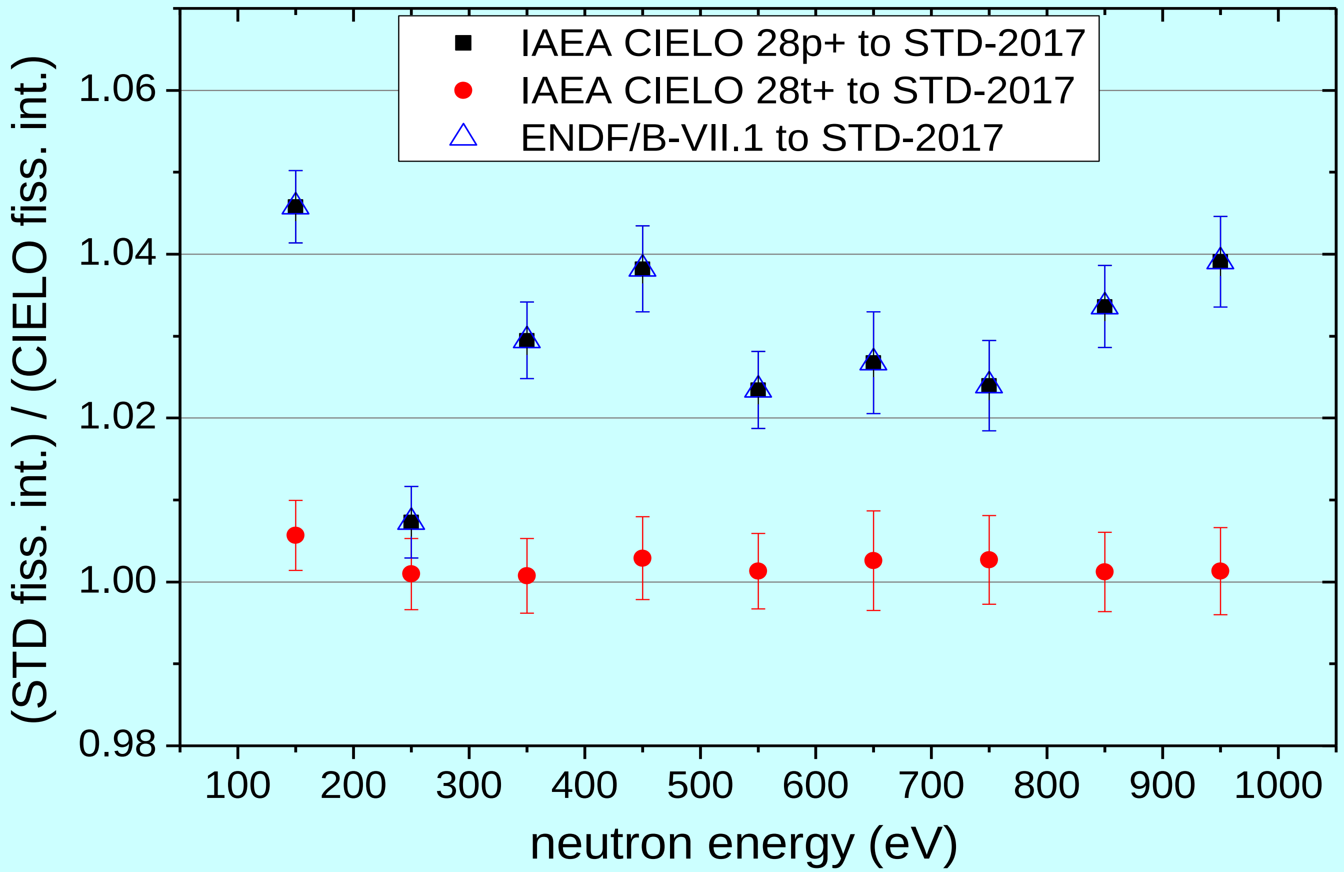
Reference $^{235}U(n,f)$ resonance integrals validated by n_TOF



Duran et al, WONDER 2015, EPJ WoC 111(2016) 02003

High accuracy $^{235}U(n,f)$ data in the resonance energy region

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IAEA Neutron Standards evaluation (2017)

https://nds.iaea.org/standards

Nucl. Data Sheets 148 (2018) 143-188

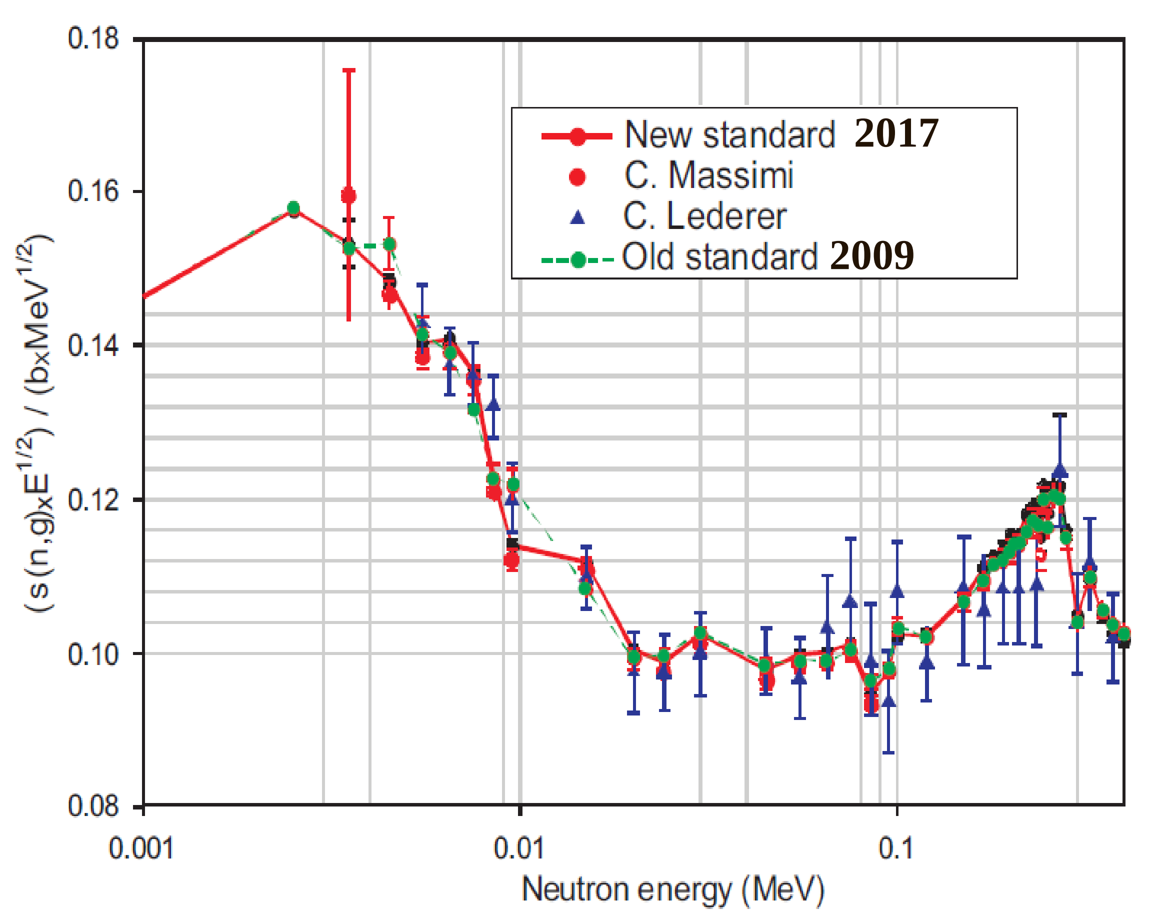
Evaluation of the Neutron Data Standards

A.D. Carlson,[1,*] V.G. Pronyaev,[2] R. Capote,[3] G.M. Hale,[4] Z.-P. Chen,[5] I. Duran,[6] F.-J. Hambsch,[7] S. Kunieda,[8] W. Mannhart,[9] B. Marcinkevicius,[3,10] R.O. Nelson,[4] D. Neudecker,[4] G. Noguere,[11] M. Paris,[4] S.P. Simakov,[12] P. Schillebeeckx,[7] D.L. Smith,[13] X. Tao,[14] A. Trkov,[3] A. Wallner,[15,16] and W. Wang[14]

#	Reaction	Energy Range
1	H(n,n)	1 keV to 20 MeV
2	^{6}Li(n,t)	1e-5 eV to 4 MeV (Standard range up to 1 MeV)
3	^{10}B(n,α);(n,$\alpha_1\gamma$)	1e-5 eV to 1 MeV
4	^{nat}C(n,n)	up to 6.45 MeV
5	^{197}Au(n,γ)	2.5 keV to 2.8 MeV
6	^{235}U(n,f)	150 eV to 200 MeV
7	^{238}U(n,f)	0.5 to 200 MeV
8	Thermal Neutron Constants: ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu, ^{252}Cf	0.0253 eV (2200 m/s)
9	^{197}Au(n,γ)	MACS (30 keV)= 620(11) mb
10	^{235}U(n,f)	Integral from 7.8 eV to 11 eV = 247.5(3.3) b*eV

Neutron Standards: ^{197}Au(n,γ)

Nucl. Data Sheets 148 (2018) 143-188 @ **nds.iaea.org/standards**



^{197}Au(n,γ) cross section in the unresolved resonance region

C. Lederer et al (n_TOF), Phys Rev C83 (2011) 034608

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Neutron Standards: $^{235}U(n,f)$, $^{238}U(n,f)$

Nucl. Data Sheets 148 (2018) 143-188 @ **nds.iaea.org/standards**

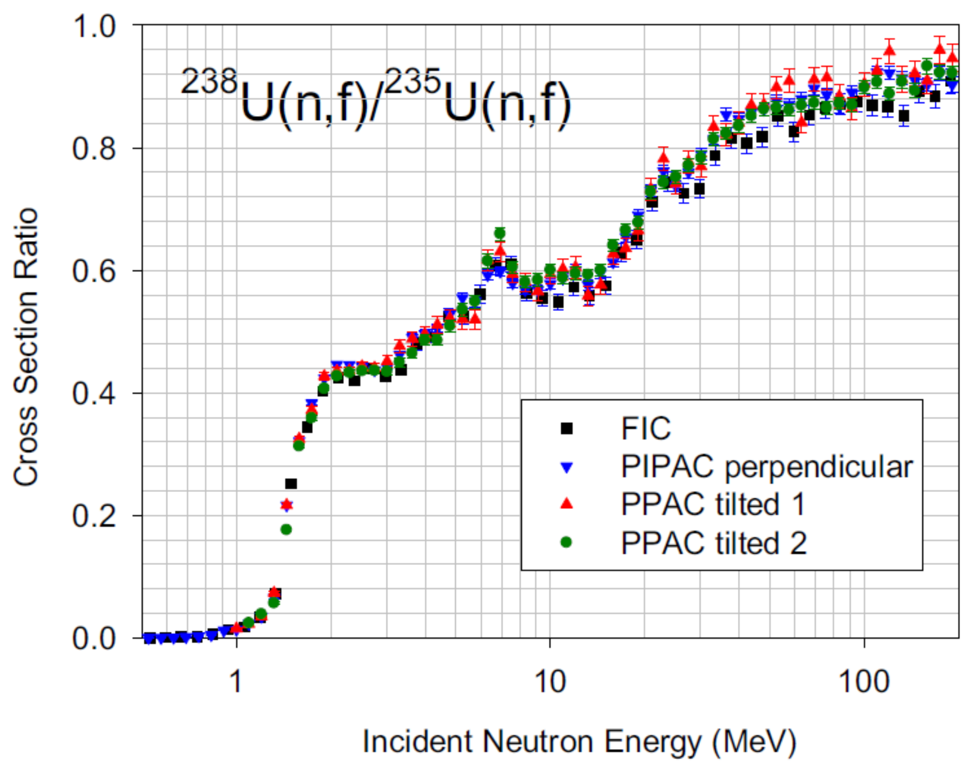

FIG. 6. (Color online) Measurements of the $^{238}U(n,f)/$ $^{235}U(n,f)$ cross section ratio by Paradela *et al.*

High-accuracy determination of the $^{238}U/^{235}U$ fission cross section ratio up to ≈ 1 GeV at n_TOF (CERN)

C. Paradela et al (n_TOF), Phys Rev C91 (2015) 024602

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Neutron References: $^{nat}Pb(n,f)$

Nucl. Data Sheets 148 (2018) 143-188 @ **nds.iaea.org/standards**

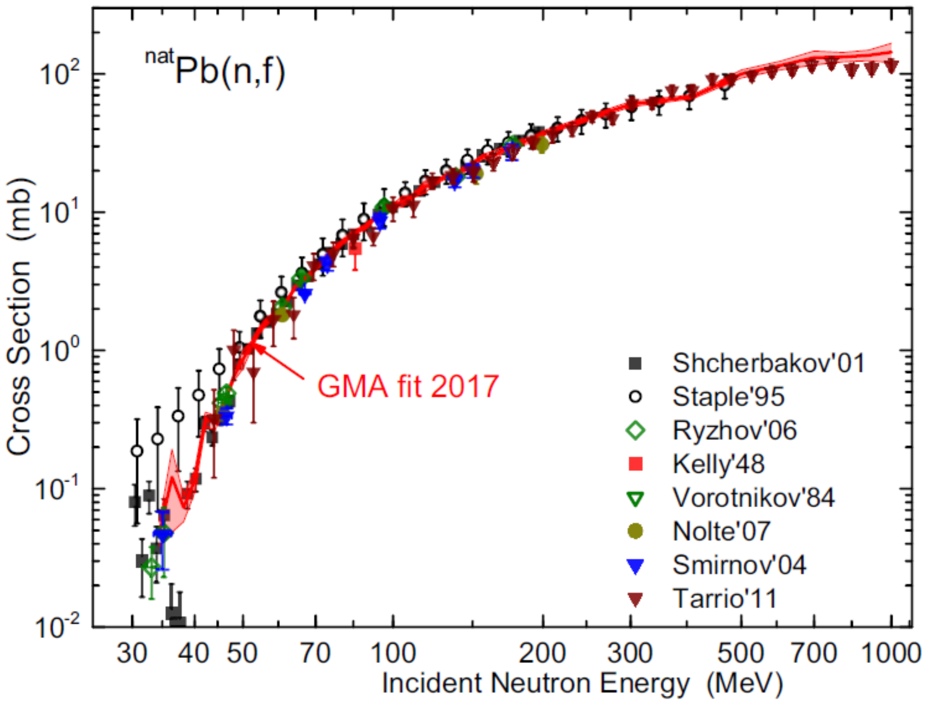

FIG. 25. (Color online) ^{nat}Pb(n,f) cross section from threshold up to 1 GeV: known measurements selected for the GMA evaluation (symbols) and GMA fit 2017 with uncertainties (red curve).

Neutron-induced fission cross section of ^{nat}Pb and ^{209}Bi from threshold to 1 GeV: An improved parametrization

D. Tarrio et al (n_TOF), Phys Rev C83 (2011) 044620

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Neutron References: ^{235}U(n,f) up to 1GeV

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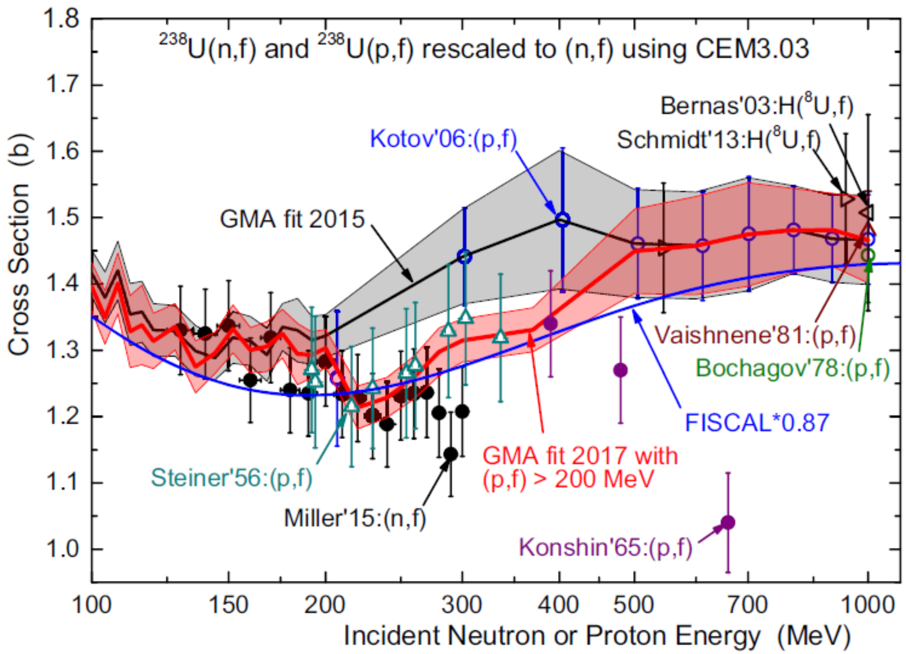

FIG. 24. (Color online) ^{238}U(n,f) cross section from 100 MeV to 1 GeV. Symbols: recent measurement of Miller [50] and selected known (p,f) experiments above 200 MeV after rescaling to (n,f) using CEM3.03 model. Curves: GMA fit made in 2015 [90] (black) and current fit (red) with uncertainties; FISCAL parameterization scaled by factor 0.87 (blue). Note that we quote the results of the FISCAL parameterization by Fukahori *et al.* [94] as the JENDL-HE values from 300 to 1000 MeV.

Extensively discussed by Duran, Ventura and n_TOF collaborators @ IAEA meet.

^{235}U(n,f) 200MeV -1GeV

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Neutron Standards: ^{6}Li(n,t) and ^{10}B(n,α)

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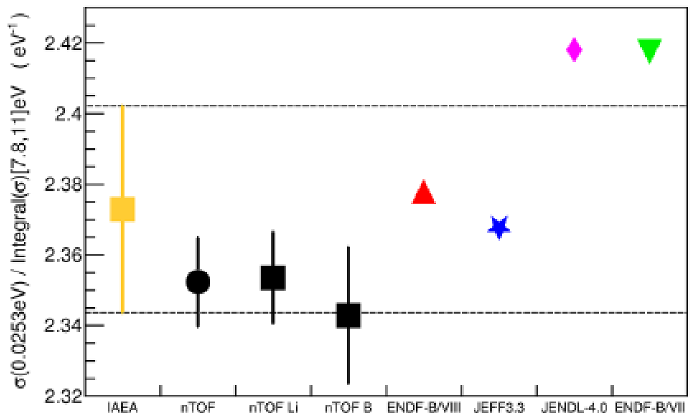

Fig. 13. Ratio between the ^{235}U(n, f) cross section at the thermal point and the integrated cross section in the 7.8–11.0 eV neutron energy interval for several evaluations and the data of this work, separately with respect to Li and B, and their weighted average. The error bars for our data only include statistical uncertainty.

IAEA standards validated !!

Measurement of the ^{235}U(n,f) cross section relative to the ^{6}Li(n,t) and ^{10}B(n,α) standards from thermal to 170 keV neutron energy range at n_TOF

Table 2. Comparison of the relevant standard values between IAEA and the present work computed using ^{6}Li and ^{10}B reference fluxes.

	Ratio σ (0.025 meV)/integral (σ) [7.8, 11] eV [eV^{-1}]	integral (σ) [7.8, 11] eV [b · eV]
IAEA	2.373 ± 0.029	247.5 ± 3
^{6}Li ref. flux	2.353 ± 0.013(stat) ± 0.007(syst)	249.6 ± 1.4(stat) ± 0.94(syst)
^{10}B ref. flux	2.343 ± 0.019(stat) ± 0.007(syst)	250.7 ± 2.0(stat) ± 0.95(syst)
(^{6}Li + ^{10}B) ref. flux	2.352 ± 0.013(stat) ± 0.007(syst)	249.7 ± 1.4(stat) ± 0.94(syst)

S. Amaducci et al (n_TOF), Eur. Phys J.A55 (2019) 120

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Neutron Standards: ^{6}Li(n,t) and ^{10}B(n,α)

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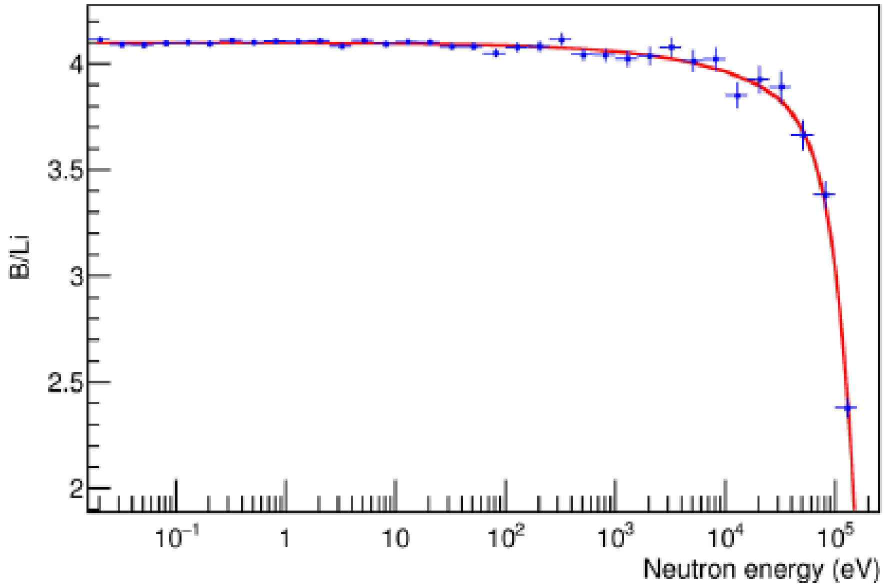

Fig. 12. Ratio of the corrected ^{10}B to ^{6}Li count rates (dots), along with the corresponding ratio between the standard cross sections from the evaluated data files [31] (line).

IAEA standards validated !!

Measurement of the ^{235}U(n,f) cross section relative to the ^{6}Li(n,t) and ^{10}B(n,α) standards from thermal to 170 keV neutron energy range at n_TOF

S. Amaducci et al (n_TOF), Eur. Phys J.A55 (2019) 120

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Neutron References: ^{235}U(n,f) resonances

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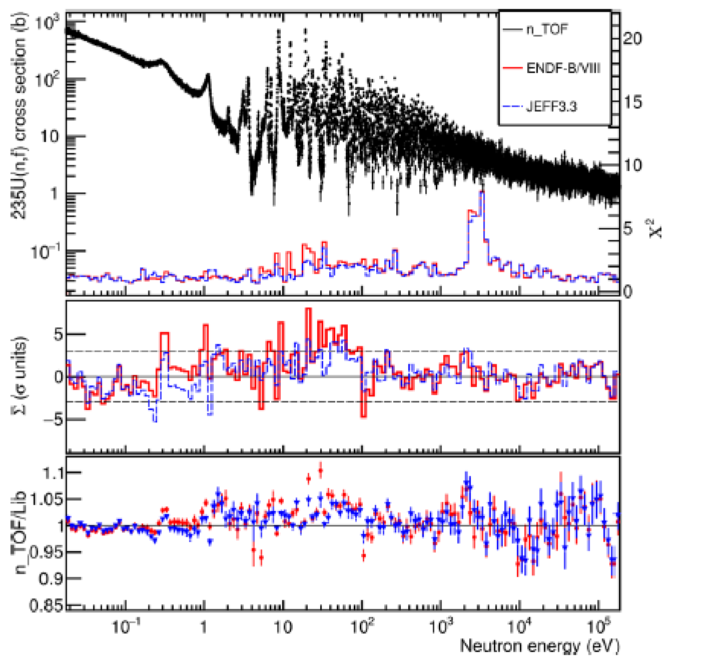

Fig. 15. Top panel: the final measured ^{235}U(n, f) cross section of this work, obtained from the ratio method relative to the weighted average of the ^{6}Li(n, t) and ^{10}B(n, α) data; in the lower part the reduced χ^2 with respect to the ENDF-B/VIII and the JEFF3.3 evaluations is shown. Middle panel: the normalized deviation Σ between the current data and the two libraries; the dashed lines indicate the $\pm 3\,\sigma$ level. Bottom panel: the ratio of the current data to the two libraries.

Measurement of the ^{235}U(n,f) cross section relative to the ^{6}Li(n,t) and ^{10}B(n,α) standards from thermal to 170 keV neutron energy range at n_TOF

Evaluations validated

Improvement not possible till data are available

S. Amaducci et al (n_TOF), Eur. Phys J.A55 (2019) 120

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TAKE HOME MESSAGE

- n_TOF provided **excellent** data for evaluations, in particular for the IAEA Standard project: $^{235}U(n,f)/^{238}U(n,f)$, $^{235}U(n,f)$, $Au(n,\gamma)$, $^{6}Li(n,t)$ and $^{10}B(n,\alpha)$

Congratulations for the 20 years! keep going…

- A very friendly reminder:

  Job is not finished till **ALL** data are in EXFOR

  - **Please submit the data to EXFOR with the paper to the journal**
  - **Discuss data submission to IAEA expert committees, it may speed up the use of excellent n_TOF data in international evaluations**

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