Progress on the validation of the Thermal Neutron Constants

DE LA RECHERCHE À L'INDUSTRIE

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TM on Neutron Standards, IAEA, 9-13 October 2023

Validation process

Prior information
from NDS 2018

Feedback from
CONRAD analysis
Using EXFOR and
Axton data

Feedback from
integral references for
fissile actinides using
EXFOR data

Feedback from
Evaluators using
CONRAD (EXFOR data)
SAMMY (SAMMY data base)

Posterior information
for gmapy such as clean data
base for TNC and integral
values for Data Assimilation

Thermal Neutron Constant U233

	STD meeting 2017 CONRAD	NDS 2018 A.D. Carlson et al.	STD meeting 2022 I. Duran	Proposed for JEFF-4T3	Proposed for ENDF\B-VIII.1	Target values
σ_{tot}	**587.7(22)**		590.2(**17**)	588.6	590.0	≈590(2)
σ_f	530.8(23)	**533.0(22)**	533.0(**7**)	531.2	533.0	**≈533(2)**
σ_γ	44.5(11)	**44.9(9)**	44.8(19)	45.3	44.8	**≈45(1)**
σ_n	12.3(7)	**12.2(7)**	12.4(5)	12.2	12.2	**≈12.3(7)**
υ_{tot}	2.490(7)	2.487(11)		**2.497**	2.484	2.484-2.490

Add partial reaction cross sections by taking into account full covariance matrix between TNC

To be optimized if needed using Mosteller's suite

May be too small uncertainty ...

⇒ Good agreement between all the results (within the limit of the uncertainties)
⇒ Confirm STD values reported in 2018

Thermal Neutron Constant U235

	STD meeting 2017 CONRAD	NDS 2018 A.D. Carlson et al.	STD meeting 2022 Duran	EPJA 2022 Matromarco et al.	Proposed for JEFF-4T3	Proposed for ENDF\B-VIII.1	Target values
σ_{tot}	698.2(36)		700.7(13)		699.7	699.5	≈699.8(20)
σ_f	586.2(35)	**587.3(14)**	586.1(26)	586.2(33)	586.2	586.0	≈586.2(30)
σ_γ	**97.9(12)**	**99.5(13)**	100.3(27)		99.4	99.4	**≈99.5(15)**
σ_n	14.1(2)	**14.09(22)**	14.3(4)		14.1	14.1	**≈14.1(2)**
υ_{tot}	2.426(5)	2.425(11)			**2.436**	**2.414**	2.414-2.436
I_3	245.7(30)		245.7(41)		246.7	**251.9**	≈245.7(40)

Try to find the origin of this slightly lower value in the Axton data …

Problem in the GMA data base ?

Too high …

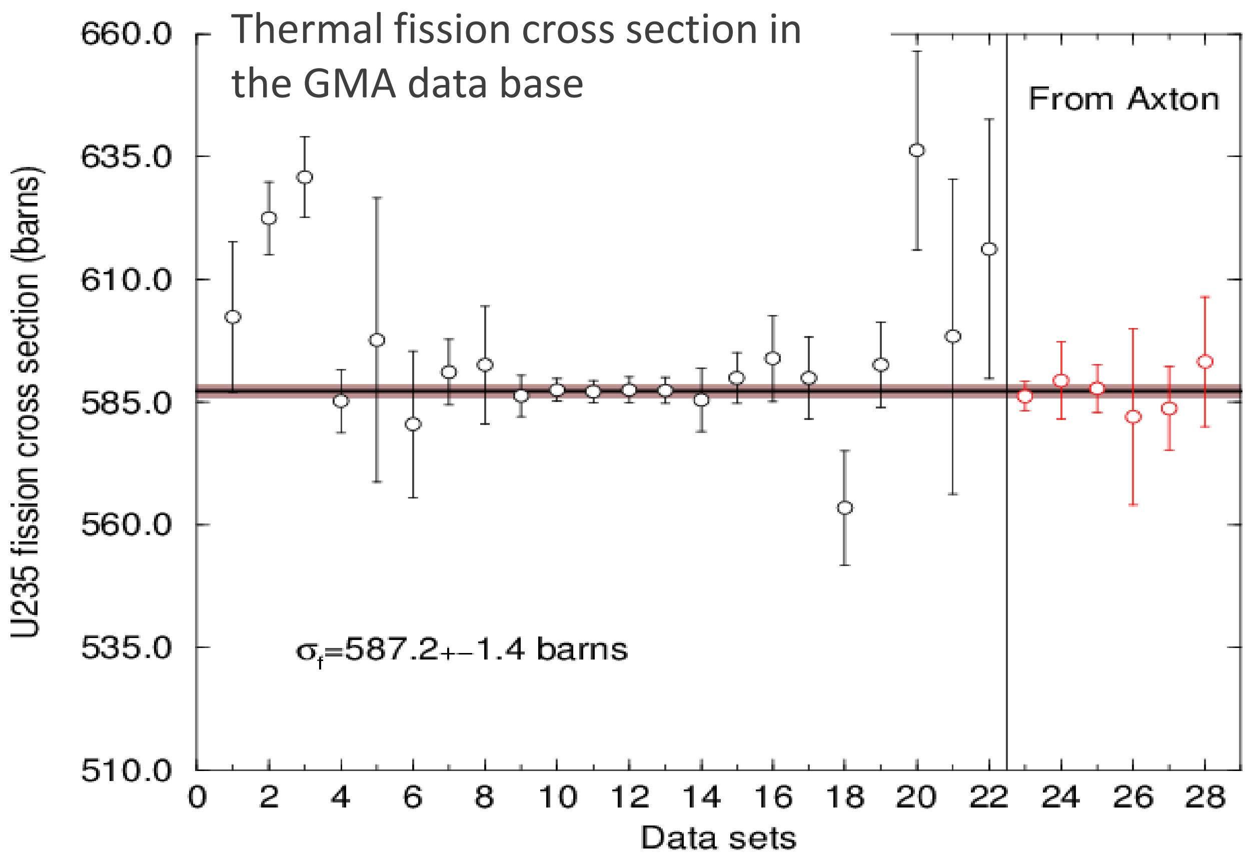
Opposite direction ?

Compensation with structures in the neutron multiplicity $\eta_p(E)$?

⇒ Good agreement between all the TNC excepted fission cross section

⇒ σ_f to be updated …

Thermal Neutron Constant U235: fission cross section



Problem in the GMA data base ?

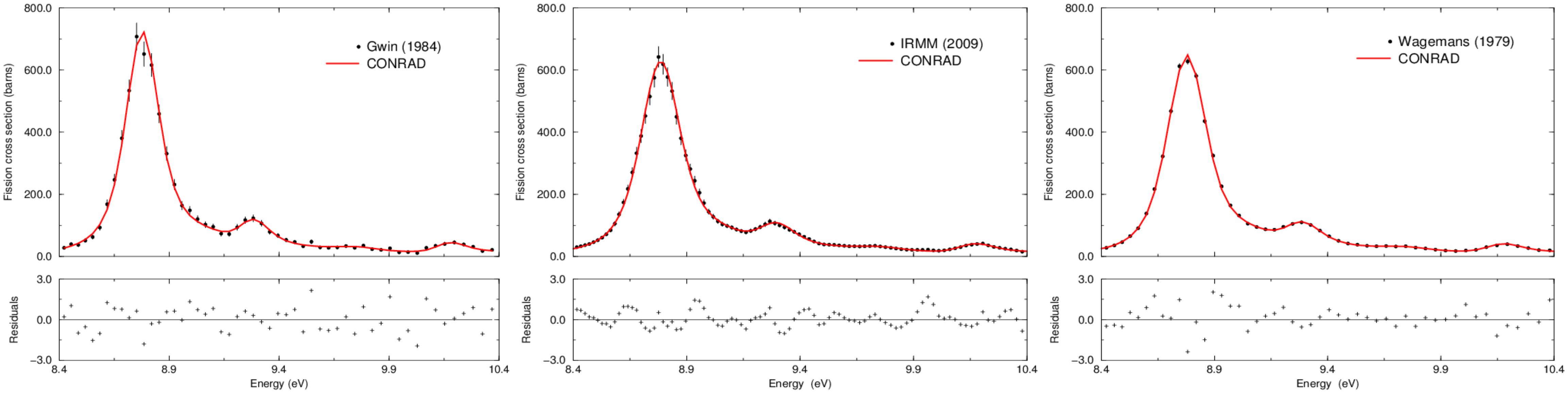
Large dispersion of the data in the GMA database
⇒ To be verified !

Thermal Neutron Constant U235: integral between 7.8 and 11 eV

Strategy to determine the average fission integral I_3 between 7.8 and 11 eV with CONRAD

Three-step calculations:

1. **GLS fit of the fission data**
2. Reliable covariance matrix calculated with the Marginalization procedure implemented in the CONRAD code
3. Average using the covariance matrix



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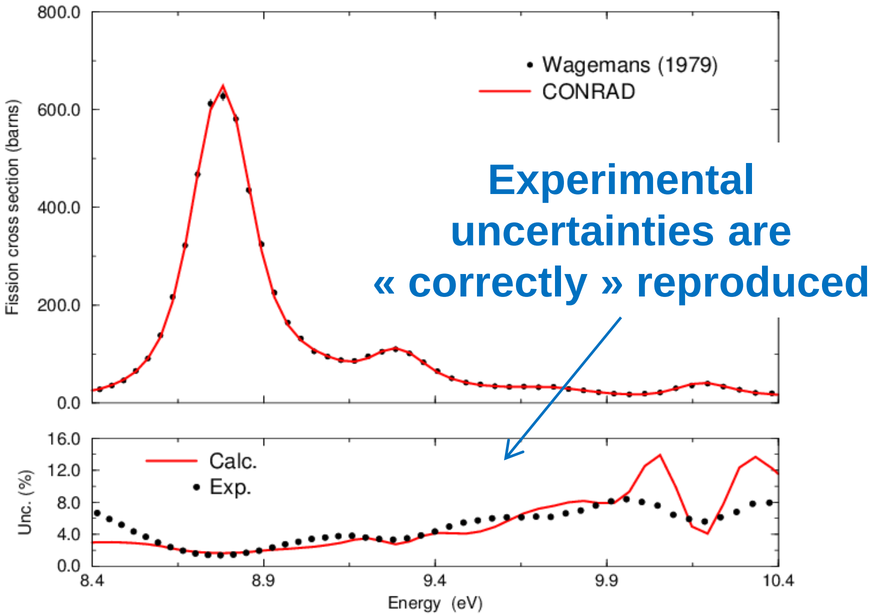
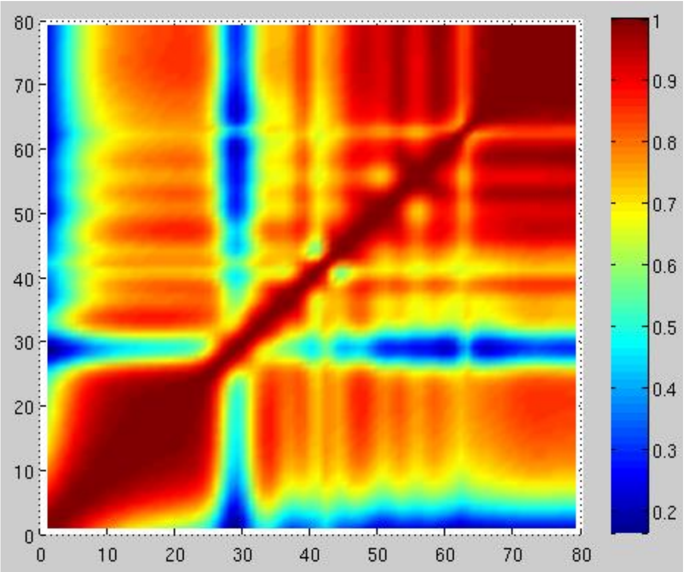
3. Average using the covariance matrix between all the data sets





Thermal Neutron Constant U235: integral between 7.8 and 11 eV

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$$I_3(U235) = 245.7(30)$$

⇒ To be compared to **245.7(41)** (I. Durand, STD meeting, 2022)

Thermal Neutron Constant Pu239

	STD meeting 2017 CONRAD	NDS 2018 A.D. Carlson et al.	STD meeting 2022 I. Duran	Linear fit EXFOR data υ_d=0.006415(50)*	Proposed for JEFF-4T3	Proposed for ENDF\B-VIII.1	Target values
σ_{tot}	1027.6(53)		1028.7(11)		1029	1029.5	≈1029(5)
σ_f	749.5(34)	**752.4(22)**	751.0(19)		749.8	751.1	≈751(2)
σ_γ	270.1(29)	**269.8(25)**	269.7(24)		269.4	270.4	**≈270(3)**
σ_n	8(1)	**7.8(10)**	8.0(8)		**9.8**	8.1	**≈8(1)**
υ_{tot}	**2.881(6)**	2.878(13)		**2.868(2)**	2.867	2.8695	2.868-2.878

Try to find the origin of this higher value in the Axton data …

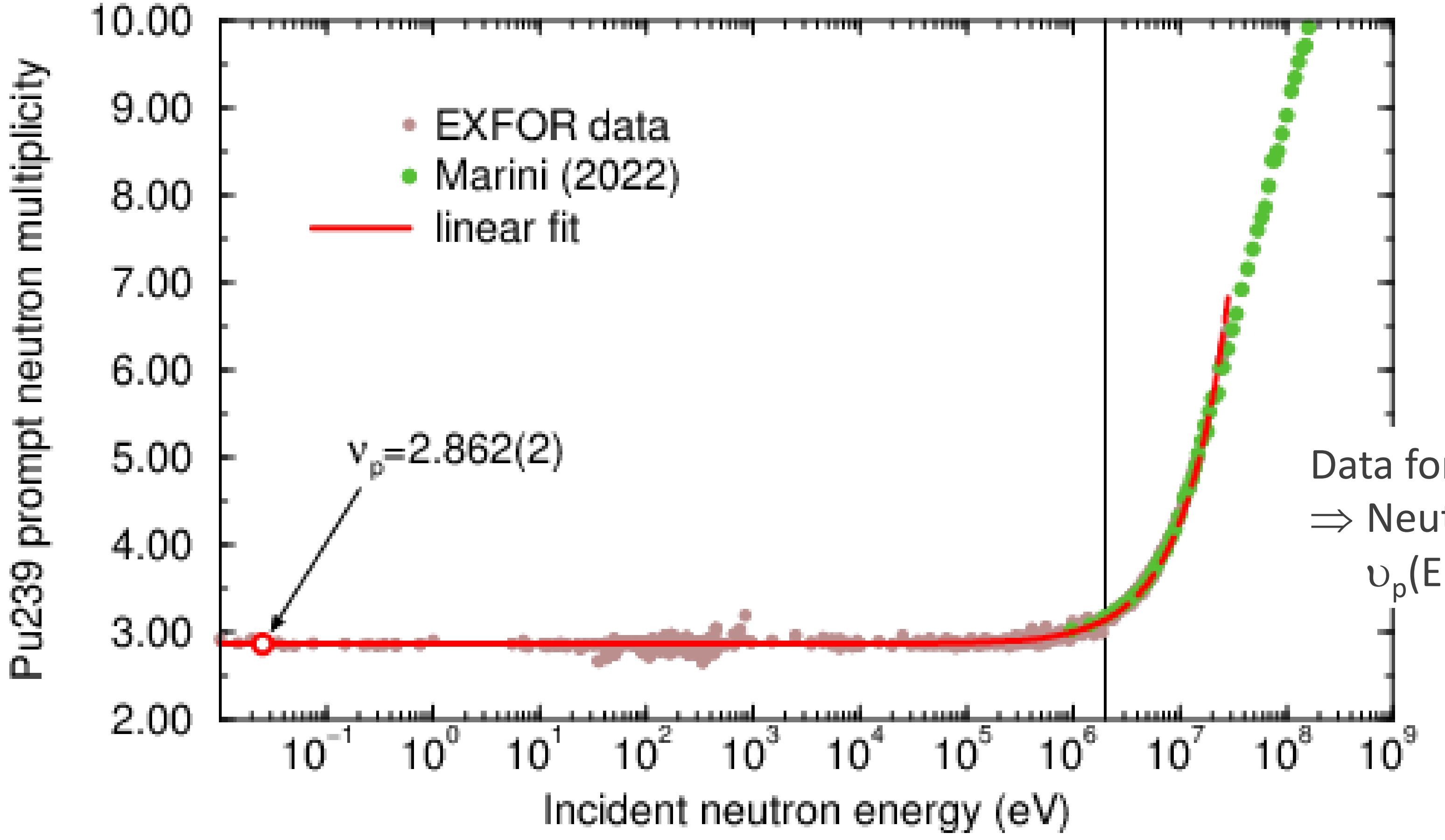
Suggest a low value for υ_{tot}

Due to a thick transmission from ORELA never used before the present analysis with the CONRAD code

⇒ Good agreement between all the TNC (within limit of uncertainties)

⇒ Slight decrease of σ_f is recommended for the next Neutron Data Standard

* P. Leconte, ALDEN experiment, prelim. value



Data for $\upsilon_p(E)$ cover a wide energy range

$\Rightarrow$ Neutron Data Standard could recommand $\upsilon_p(E)$ using the same approach than PFNS (?)

Thermal Neutron Constant Pu241

	STD meeting 2017 CONRAD	NDS 2018 A.D. Carlson et al.	STD meeting 2022 I. Duran	Proposed for JEFF-4T3	Proposed for ENDF\B-VIII.1 (=JEFF-4T3)	Target values
σ_{tot}	1400(22)		1392.1(21)	1399.4	1399.4	≈1399(2)
σ_f	1024(17)	**1023.6(108)**	1018.9(25)	1023.6	1023.6	**≈1024(2)**
σ_γ	364.3(75)	**362.3(61)**	362.3(61)	363.8	363.8	**≈363(7)**
σ_n	11.9(25)	**11.9(26)**	11.5(15)	11.9	11.9	**≈11.9(25)**
υ_{tot}	2.941(8)	2.940(13)		2.941	2.941	≈2.940(13)

$\Rightarrow$ Good agreement between all the methods

Thermal Neutron Constant Cf252

	STD meeting 2017 CONRAD (1)	NDS 2018 A.D. Carlson et al. (2)	Difference (1)-(2)
υ_{tot}	3.7660(70)	3.7637(158)	+0.0023

NDS 2018:

$\overline{\nu}_{tot}$ for ^{252}Cf from the GMAP analysis is 3.7637 (or 3.764) ± 0.42 %. This includes a 0.4 % unrecognized sys-

⇒ Reduce USU from **0.4%** to **0.25%** ?

Total delayed neutron multiplicity for U233, U235, Pu239, Pu241

Add values of the delayed neutron multiplicity υ_d in the STD report ?

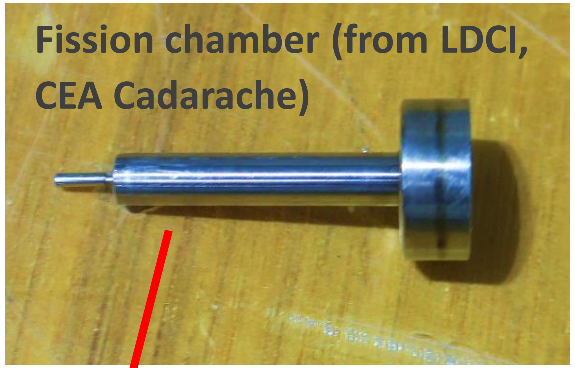
- Needed for deducing prompt neutron multiplicity from υ_{tot}
- Recommended υ_d values from CRP-AIEA
- New experimental υ_d values $\Rightarrow$ALDEN@ILL

The ALDEN program (P.Leconte, CEA Cadarache) started in 2018 at ILL (Grenoble, France) with the aim of measuring υ_d for U233, U235, Pu239 and Pu241 with the LOENIE detector

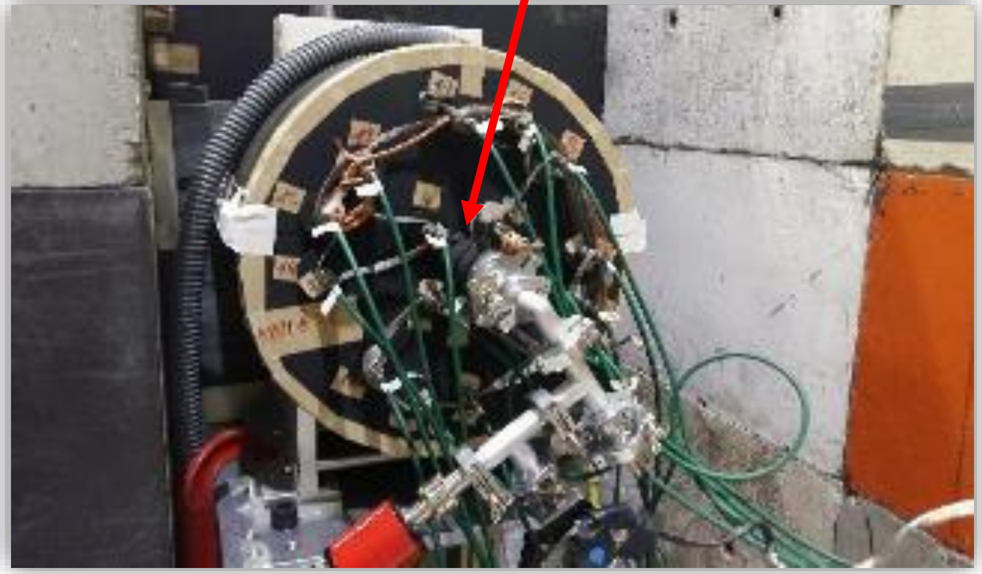
Collaboration :ILL, IRESNE, CENBG, LPSC, LPC, IRFU, GANIL

	CRP IAEA [1]	ALDEN@ILL
U233	0.667(29)%	Measurement completed
U235	1.621(50)%	1.625(10)% [2]
Pu239	0.628(38)%	Measurement completed
Pu241	1.52(11)%	Measurement planned in 2024

[1] https://www-nds.iaea.org/beta-delayed-neutron/databases/delayedn_ty.html
[2] P. Leconte et al., submitted to EPJA



LOENIE detector (PF1B area, ILL, Grenoble)



Thermal neutron capture cross section of ^{1}H

Add $^{1}H(n,\gamma)$ value in the STD report ?

- Important for reactor applications (in PWR $\Rightarrow$ 200 pcm on keff)
- Usefull for ab-initio calculations

Year	Value	Ref.
1988	≈317.7 mb	F.H. Mathiot, Few nucleons systems, mesons exchange currents and Δ excitations, J. Phys. G. Nucl. Phys. 14 S357 (1988)
2000	334.2 mb	G. Tupak, Precision calculations of np$\rightarrow$dγ cross section for big-bang nucleosynthesis, Nucl. Phys. A 678, 405 (2000)
2001	335.1 mb	S. Nakamura et al., Neutron reactions on deuteron, Phys. Rev. C 63, 034617 (2001)
2006	333.8 mb	S. Ando et al., Radiative neutron capture on a proton at big-bang nucleosynthesis energies, Phys. Rev. C 74, 025809 (2006)
2015	$334.9^{+5.2}_{-5.4}$ mb	S.R. Beane et al., Ab-initio calculation of the np$\rightarrow$dγ radiative capture process, Phys. Rev. Lett. 115, 132001 (2015)
2022	319(3) mb	W. Du et al., Calculations of the np$\rightarrow$dγ reaction in chiral effective field theory, Phys. Rev. C 106, 054608 (2022)
2022	321.0(7) mb	B. Acharya et al., Gaussian process modeling for chiral effective field theory calculations of np$\rightarrow$dγ at low energies, Phys. Lett. B 827, 137011 (2022)
	332.7(69) mb	**ENDF/B-VIII (G. Hale)**

Table provided by David Bernard, CEA Cadarcahe

Conclusions

Target values proposed for TNC agree with STD values reported in NDS 2018, however fission cross sections of U235 and Pu239 need to be updated

- σ_f(U235) ≈ 586.2(30)
- σ_f(Pu239) ≈ 751(2)

Prepare a clean TNC data base (AGS format) for gmapy data assimilation

- Differences between Axton data and EXFOR values (see Naohiko Otuka et al., proceedings ND2016)
- Correction JRC-Geel data following comments of Peter Schillebeeckx
- Verify normalization of TNC data (boron cross section, …)
- Remove redundant TNC data from GMA database
- Check consistency of the GMA data at thermal energy

⇒ Add TOF data used by Ignacio Duran in TNC data base (for consistency, easy to add new TOF data, …) ?
⇒ Provide new CONRAD results for verification

Add thermal υ_d and ^{1}H(n,γ) in the list of recommended values ?