New Fit of Thermal Neutron Constants for Standards

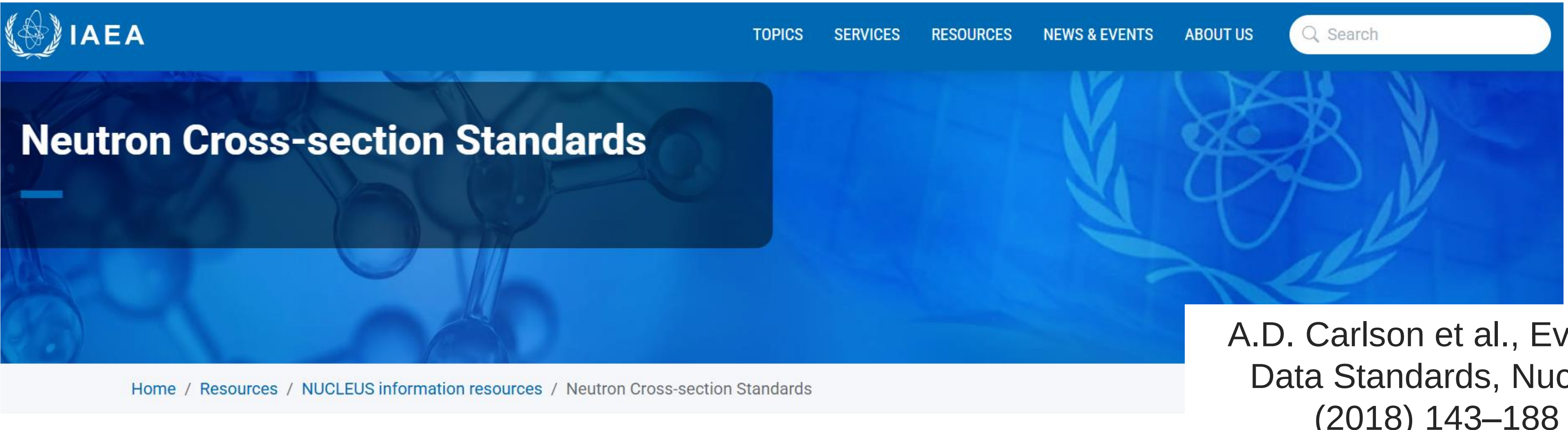
G. Schnabel (IAEA), R. Capote (Suncoast Data Evaluation), A.D. Carlson (NIST), I. Duran (USC), G. Noguere (CEA Cadarache), V.G. Pronyaev (IAEA consultant)

WONDER 2026, Aix en Provence, July 2026

IAEA

Coordinated by the
International Atomic
Energy Agency

Context



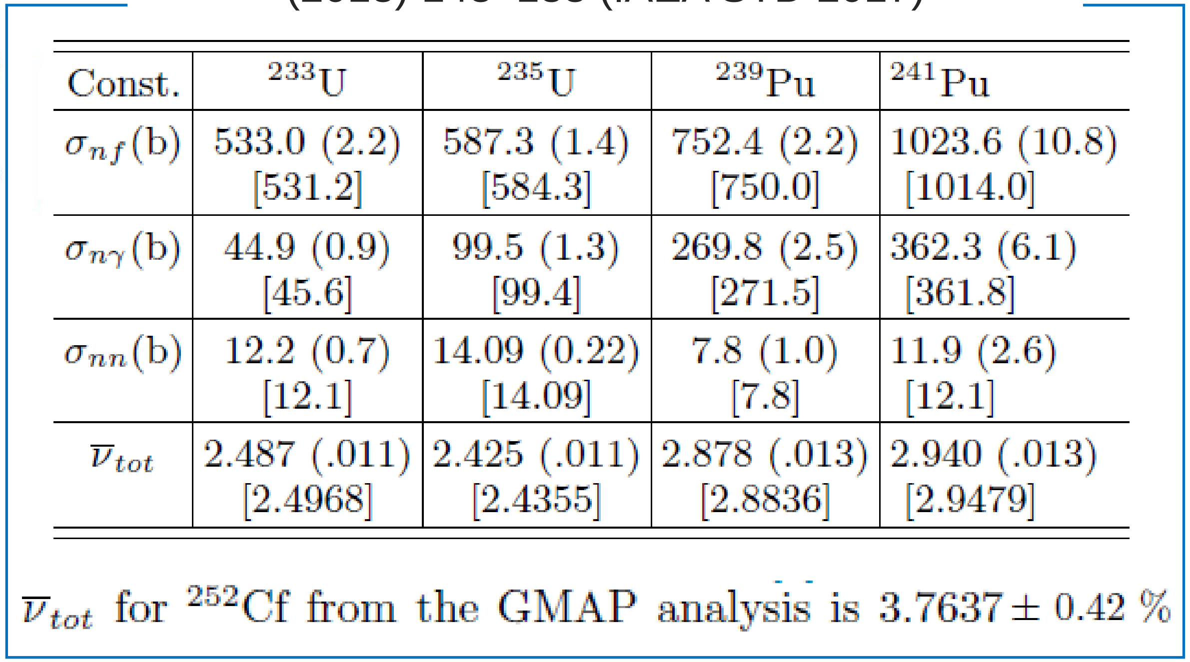
Neutron Cross-section Standards

Home / Resources / NUCLEUS information resources / Neutron Cross-section Standards

Neutron cross section standards are important in the measurement and evaluation of all other neutron reaction cross sections.

Not many cross sections can be defined as absolute - most are measured relative to the cross section standards. The most recent evaluations were completed in 2017. Further information can be found in Nuclear Data Sheets Volume 148, February 2018, Pages 143-188.

A.D. Carlson et al., Evaluation of the Neutron Data Standards, Nuclear Data Sheets 148 (2018) 143–188 (IAEA STD 2017)



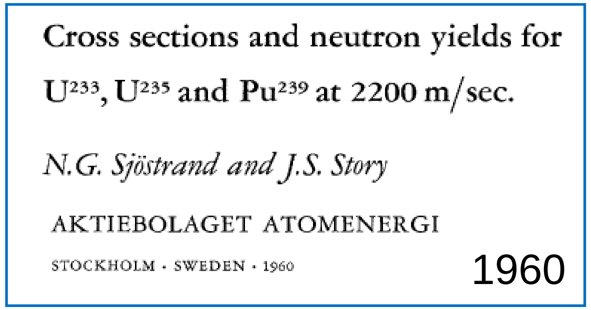
Const.	^{233}U	^{235}U	^{239}Pu	^{241}Pu
σ_{nf}(b)	533.0 (2.2) [531.2]	587.3 (1.4) [584.3]	752.4 (2.2) [750.0]	1023.6 (10.8) [1014.0]
$\sigma_{n\gamma}$(b)	44.9 (0.9) [45.6]	99.5 (1.3) [99.4]	269.8 (2.5) [271.5]	362.3 (6.1) [361.8]
σ_{nn}(b)	12.2 (0.7) [12.1]	14.09 (0.22) [14.09]	7.8 (1.0) [7.8]	11.9 (2.6) [12.1]
$\overline{\nu}_{tot}$	2.487 (.011) [2.4968]	2.425 (.011) [2.4355]	2.878 (.013) [2.8836]	2.940 (.013) [2.9479]

$\overline{\nu}_{tot}$ for ^{252}Cf from the GMAP analysis is 3.7637 ± 0.42 %

Thermal Neutron Constants (TNC) are evaluated in the framework of the Neutron Data Standard group of IAEA

Context

Continuous evaluation process of the Thermal Neutron Constants is underway since the late 1950's
Long tradition at the IAEA (Hanna, Westcott, Lemmel)


Cross sections and neutron yields for
U²³³, U²³⁵ and Pu²³⁹ at 2200 m/sec.

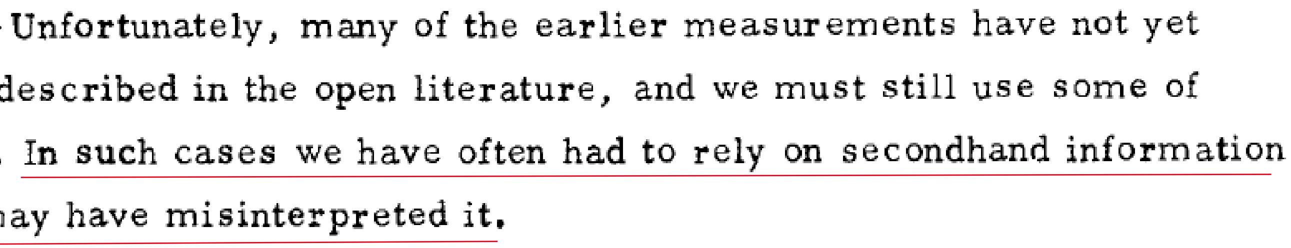
N.G. Sjöstrand and J.S. Story

AKTIEBOLAGET ATOMENERGI

STOCKHOLM · SWEDEN · 1960

1960

Before 1960 ⇒

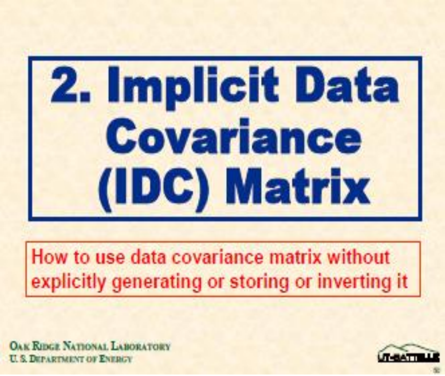

Unfortunately, many of the earlier measurements have not yet been described in the open literature, and we must still use some of them. In such cases we have often had to rely on secondhand information and may have misinterpreted it.

1984

- Divadeenam and Stehn, A least-squares fit of thermal data for fissile nuclei, ANE 11 (1984) 375-404 [1]

After 1986

- Significant progress has been made thanks to the compilation work carried out by Axton [2], who reports experimental TNC values with **full experimental covariance matrix** using the IDC format [3] developed at JRC-Geel (AGS code/method)


2. Implicit Data Covariance (IDC) Matrix

How to use data covariance matrix without explicitly generating or storing or inverting it

Oak Ridge National Laboratory
U.S. Department of Energy

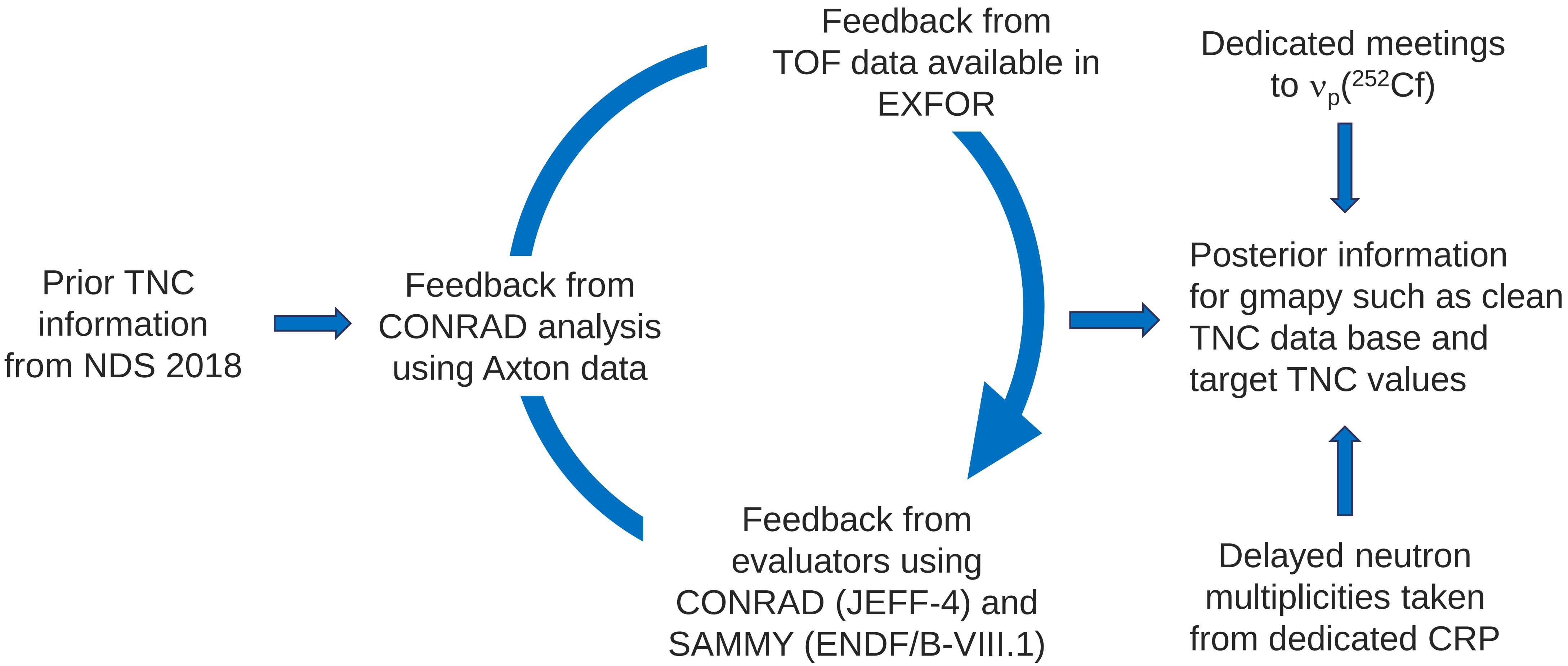
UT-Battelle

New release in 2026

- A new evaluation code has been developed by G. Schnabel (**gmapy**)
- **Axton data base has been significantly revised and extended**

[1] https://doi.org/10.1016/0306-4549(84)90002-1
[2] E.J Axton, Evaluation of the thermal constants, CBNM report, Geel, Belgium, GE/PH/01/86, 1986
[3] N.M. Larson, A concise method for storing and communicating the Experimental Covariance Matrix, ORNL/TM-2008/104, 2008

Schematic evaluation process



Prior TNC information from NDS 2018

Feedback from CONRAD analysis using Axton data

Feedback from TOF data available in EXFOR

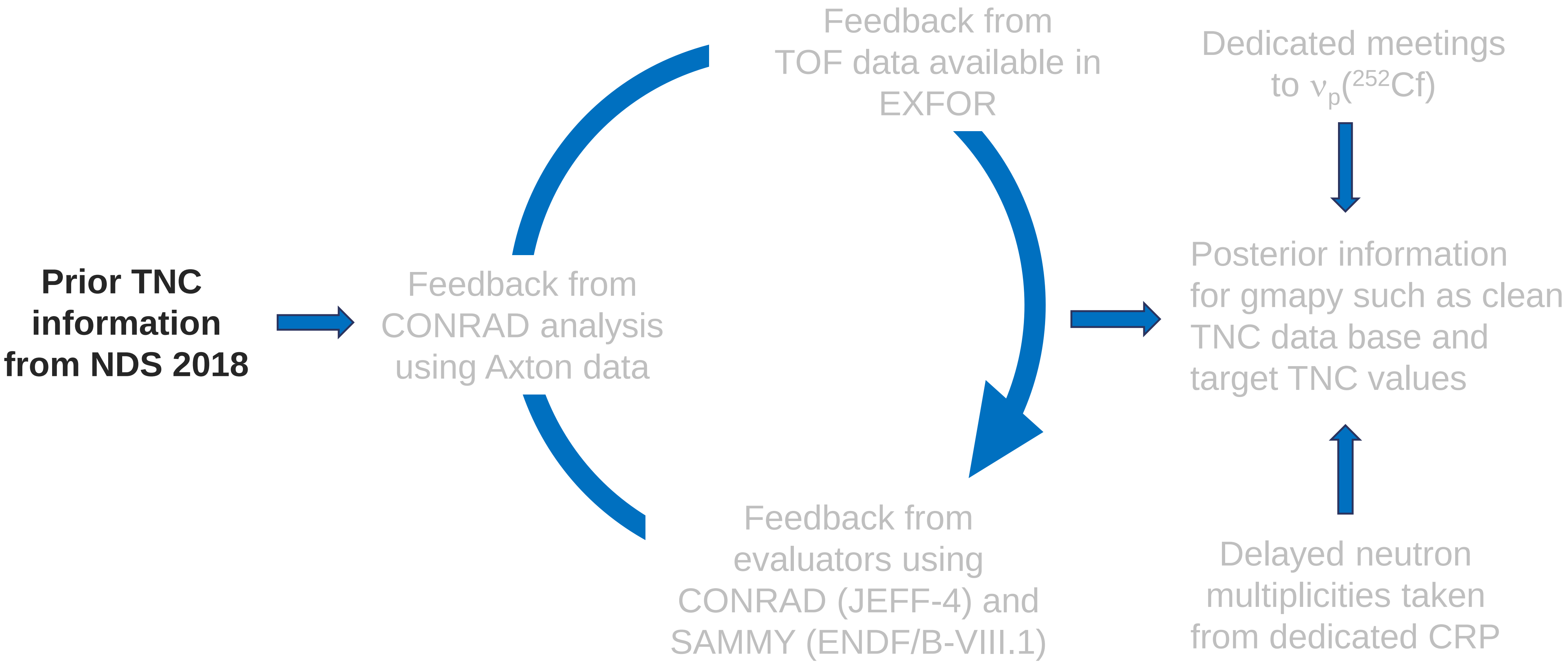
Feedback from evaluators using CONRAD (JEFF-4) and SAMMY (ENDF/B-VIII.1)

Dedicated meetings to $\nu_p(^{252}\mathrm{Cf})$

Posterior information for gmapy such as clean TNC data base and target TNC values

Delayed neutron multiplicities taken from dedicated CRP

Schematic evaluation process



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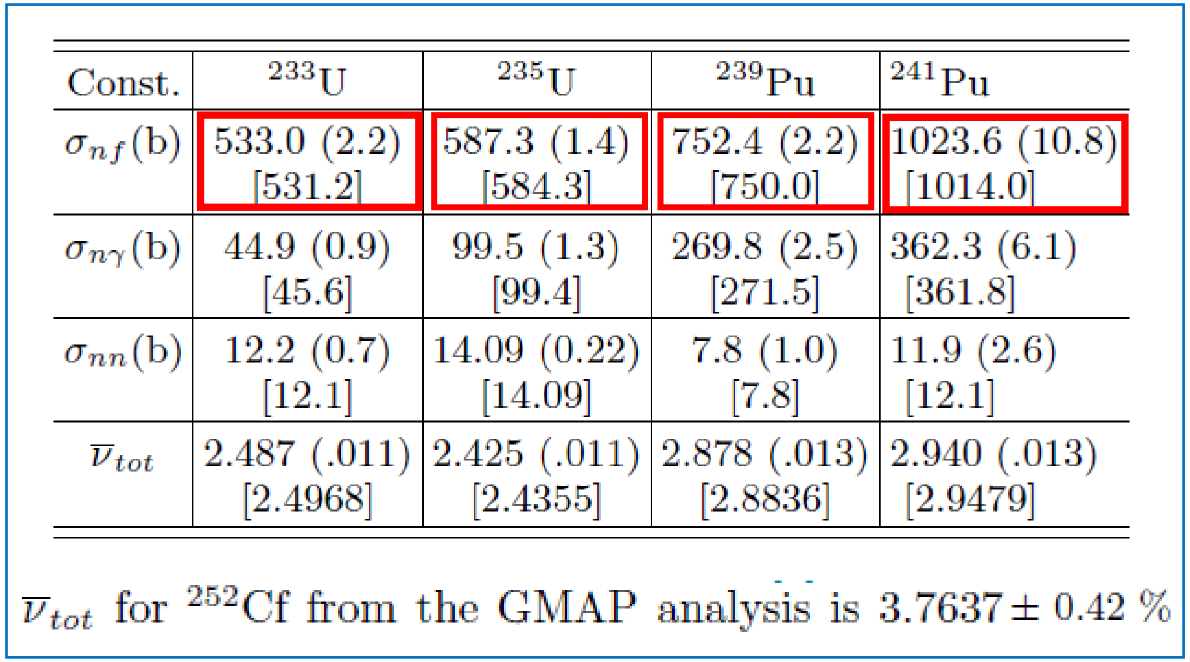

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$\overline{\nu}_{tot}$ for ^{252}Cf from the GMAP analysis is 3.7637 ± 0.42 %

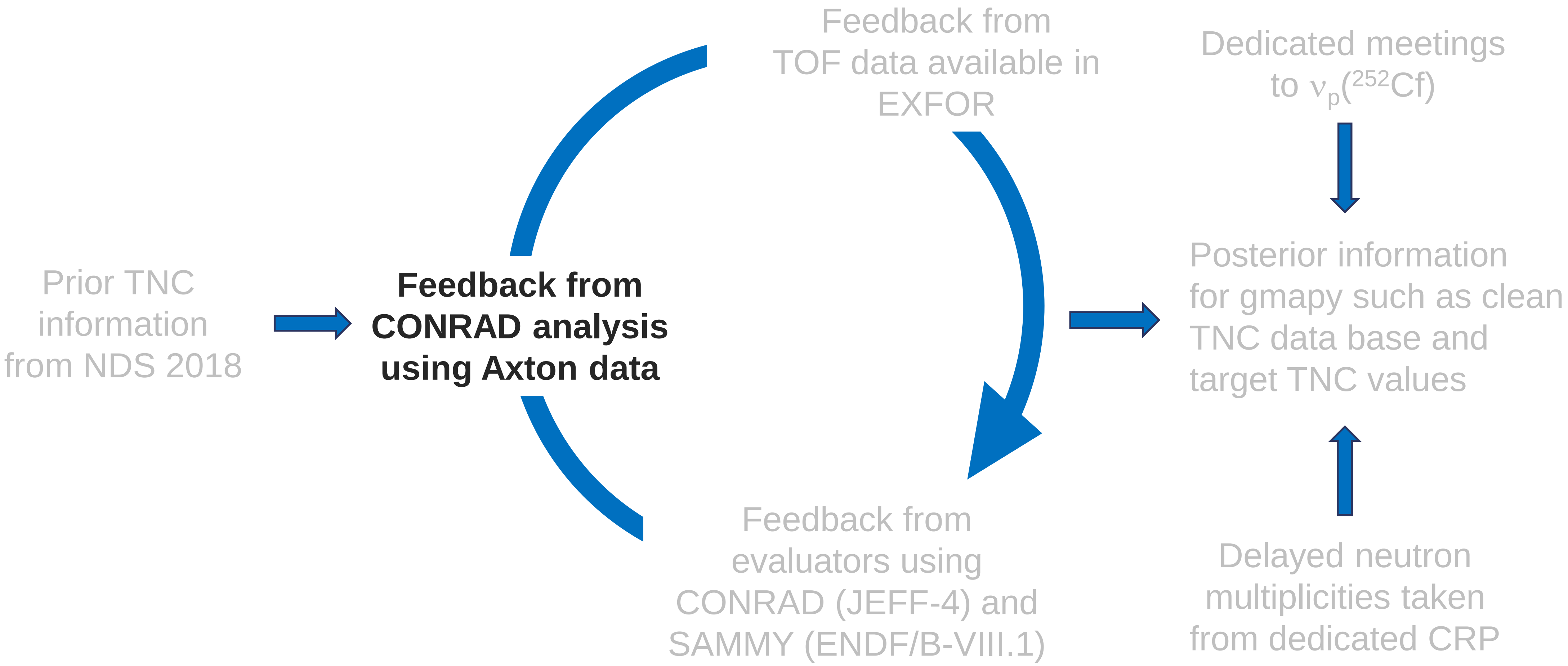
For the past release:

- TNC and high-energy standard cross sections were simultaneously evaluated with the GMA code
- For the GMA fit, prior TNC values and covariances came from Axton’s report
- **No new prior TNC values established since Axton work**

Compared to TNC published in 2006 (2nd row), those released in 2018 show a systematic increase in ALL thermal fission cross sections

Needs to improve the evaluation strategy !

Schematic evaluation process



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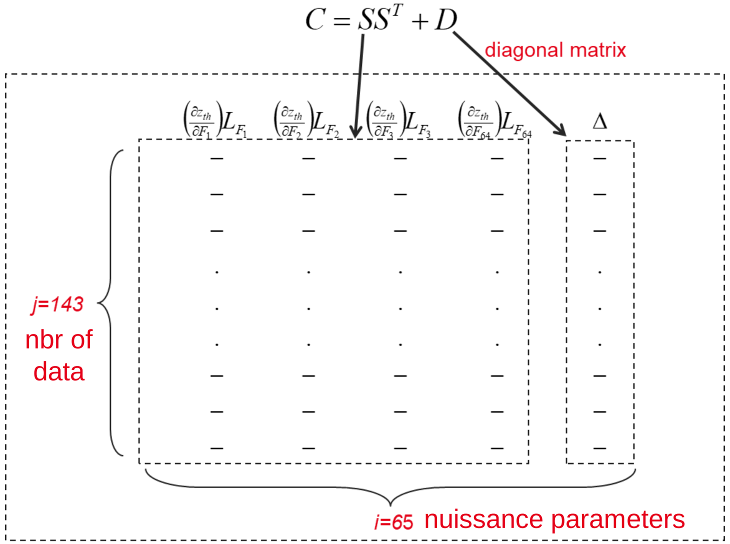
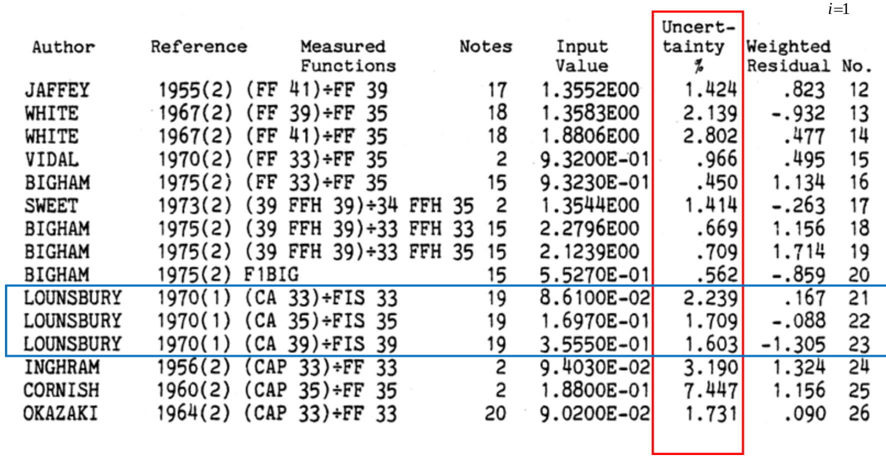
Generic form of the experimental covariance matrix *C* in IDC format



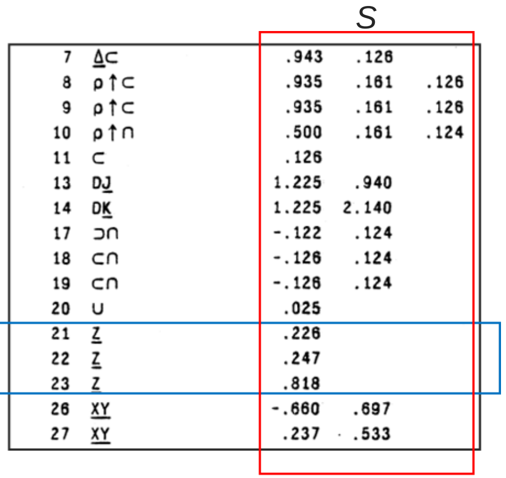
$$C = SS^T + D$$

$$\left(\Delta z_j\right)^2 = \Delta_j^2 + \sum_{i=1}^{64} \delta_{ij}^2$$



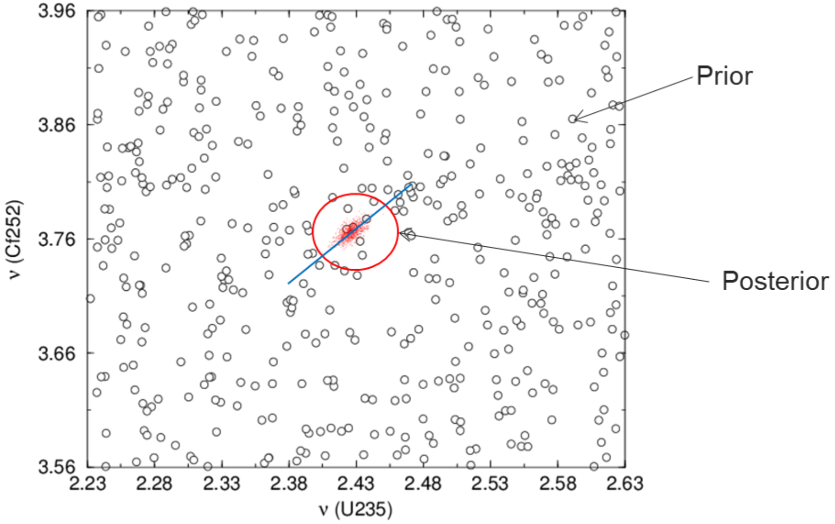
Author	Reference	Measured Functions	Notes	Input Value	Uncert-tainty %	Weighted Residual	No.
JAFFEY	1955(2)	(FF 41)÷FF 39	17	1.3552E00	1.424	.823	12
WHITE	1967(2)	(FF 39)÷FF 35	18	1.3583E00	2.139	-.932	13
WHITE	1967(2)	(FF 41)÷FF 35	18	1.8806E00	2.802	.477	14
VIDAL	1970(2)	(FF 33)÷FF 35	2	9.3200E-01	.966	.495	15
BIGHAM	1975(2)	(FF 33)÷FF 35	15	9.3230E-01	.450	1.134	16
SWEET	1973(2)	(39 FFH 39)÷34 FFH 35	2	1.3544E00	1.414	-.263	17
BIGHAM	1975(2)	(39 FFH 39)÷33 FFH 33	15	2.2796E00	.669	1.156	18
BIGHAM	1975(2)	(39 FFH 39)÷33 FFH 35	15	2.1239E00	.709	1.714	19
BIGHAM	1975(2)	F1BIG	15	5.5270E-01	.562	-.859	20
LOUNSBURY	1970(1)	(CA 33)÷FIS 33	19	8.6100E-02	2.239	.167	21
LOUNSBURY	1970(1)	(CA 35)÷FIS 35	19	1.6970E-01	1.709	-.088	22
LOUNSBURY	1970(1)	(CA 39)÷FIS 39	19	3.5550E-01	1.603	-1.305	23
INGHRAM	1956(2)	(CAP 33)÷FF 33	2	9.4030E-02	3.190	1.324	24
CORNISH	1960(2)	(CAP 35)÷FF 35	2	1.8800E-01	7.447	1.156	25
OKAZAKI	1964(2)	(CAP 33)÷FF 33	20	9.0200E-02	1.731	.090	26

S



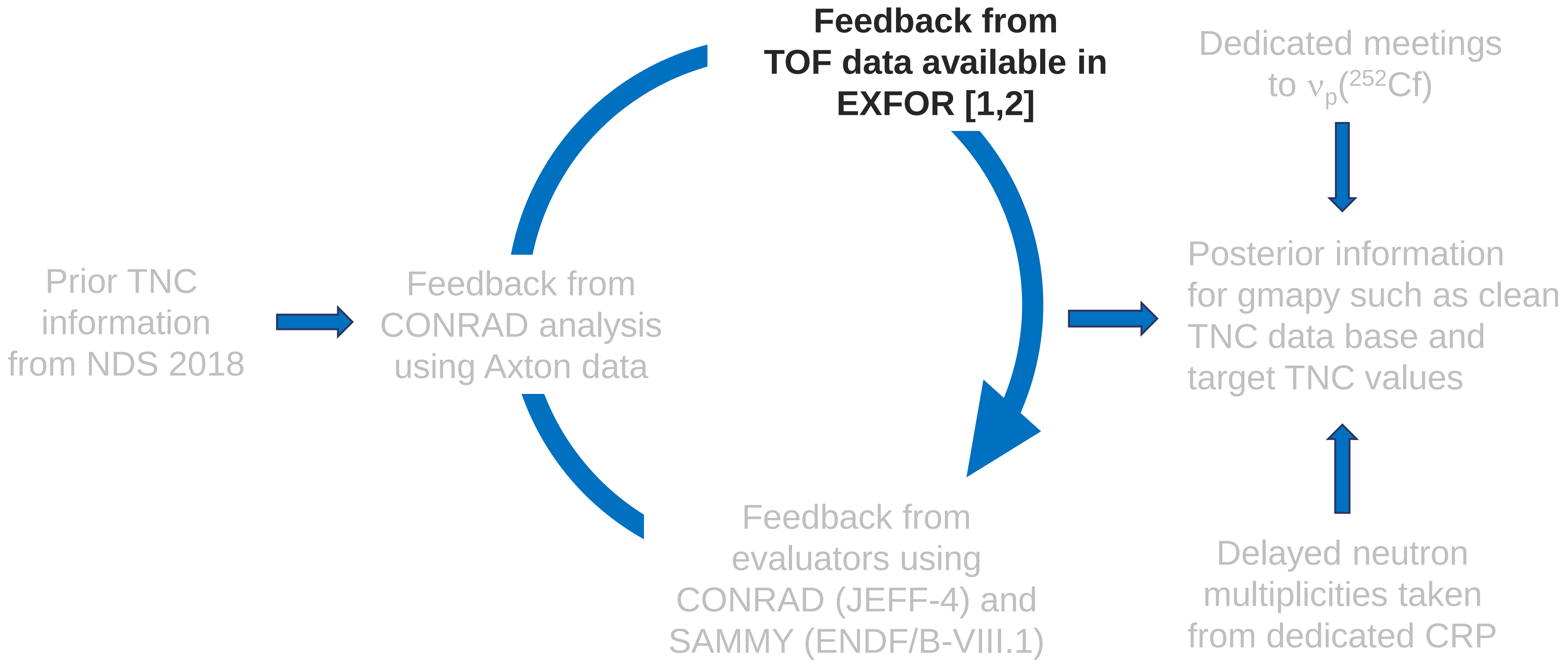
7	Δ⊂	.943	.126	
8	ρ↑⊂	.935	.161	.126
9	ρ↑⊂	.935	.161	.126
10	ρ↑∩	.500	.161	.124
11	⊂	.126		
13	DJ	1.225	.940	
14	DK	1.225	2.140	
17	⊃∩	-.122	.124	
18	⊂∩	-.126	.124	
19	⊂∩	-.126	.124	
20	∪	.025		
21	Z	.226		
22	Z	.247		
23	Z	.818		
26	XY	-.660	.697	
27	XY	.237	.533	

GLS fit coupled to an analytic or Monte-Carlo marginalization of the uncertainties



- Non-informative prior values were introduced in the fitting procedure (prior relative uncertainties of 100%, uniform sampling of the priors)
- Example of reliable posterior correlation between the U235 and Cf252 neutron multiplicities (red dot) obtained after a Monte-Carlo data assimilation procedure.

Schematic evaluation process



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Feedback from CONRAD analysis using Axton data

Feedback from TOF data available in EXFOR [1,2]

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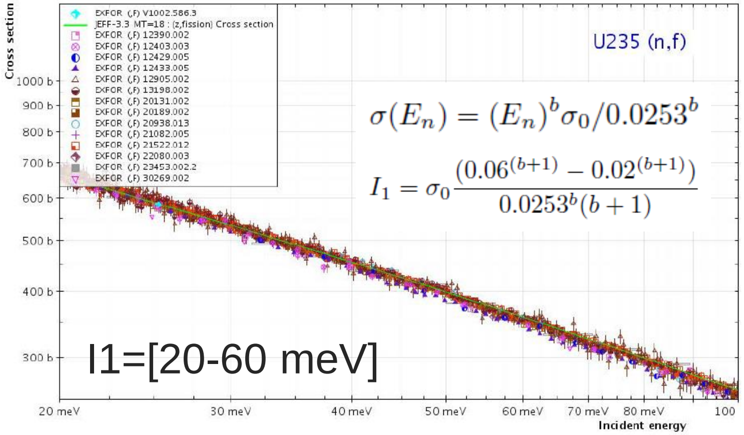
Delayed neutron multiplicities taken from dedicated CRP

[1] Duran et al, NDS 193 (2024) 95
[2] Duran et al, ND2025, Madrid, submitted

Feedback from high-resolution TOF data available in EXFOR



$$\sigma(E_n) = (E_n)^b \sigma_0 / 0.0253^b$$

$$I_1 = \sigma_0 \frac{(0.06^{(b+1)} - 0.02^{(b+1)})}{0.0253^b (b+1)}$$

I1=[20-60 meV]

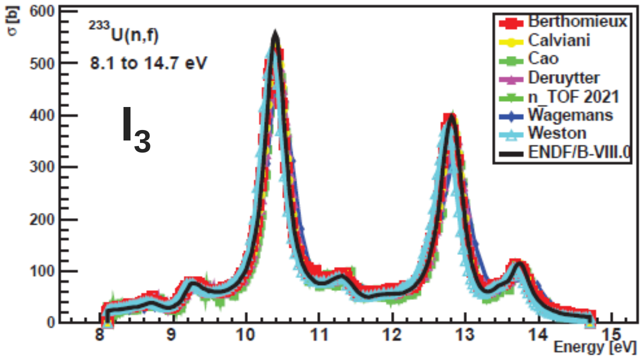
- **Total** and **fission** neutron cross sections at thermal energy and ratio **σ_{th}/I1** determined from time-of-flight data available in EXFOR

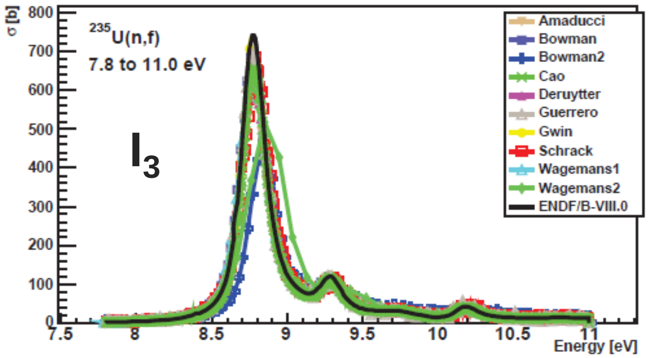
- **Capture** cross sections and ratio **σ_{th}/I1** deduced from the total cross sections by substracting the fission and elastic scattering contributions

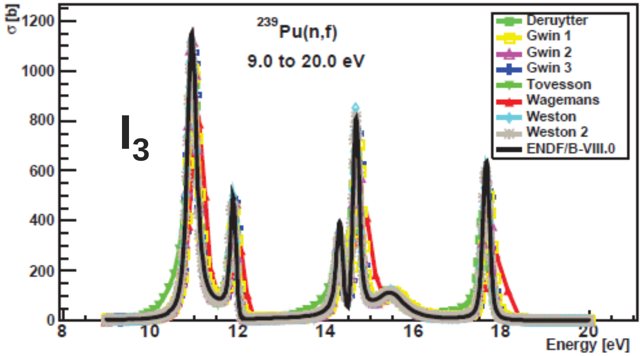
- Integral ratio **I3/I1** for U233, U235, Pu239, and Pu241 also revisited thanks to EXFOR data

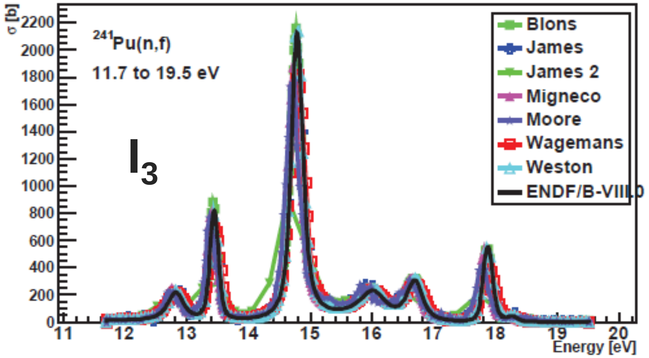
σ_{th}/I1 and I3/I1 are independent of normalization issues

- Reference integral I3 is a useful quantity to normalize TOF data if thermal value not measured (or not precise enough)

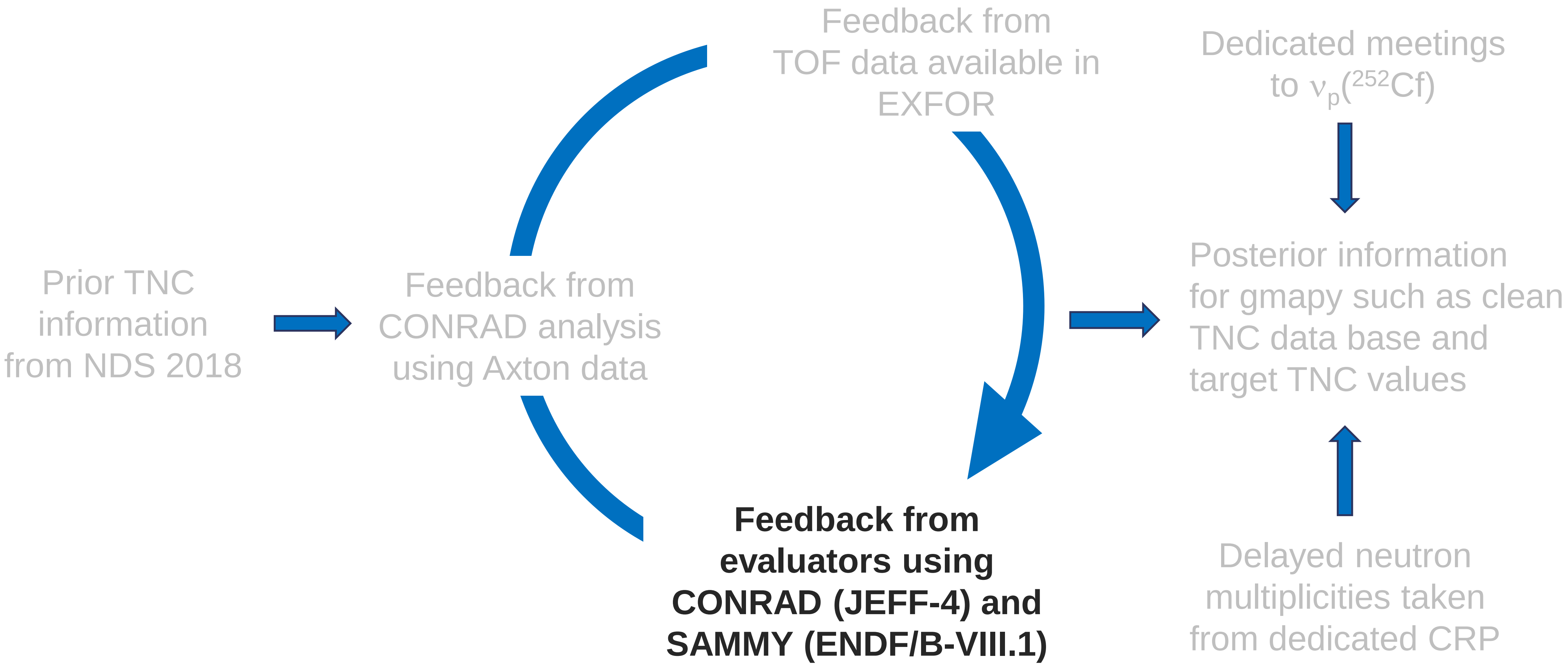








Schematic evaluation process



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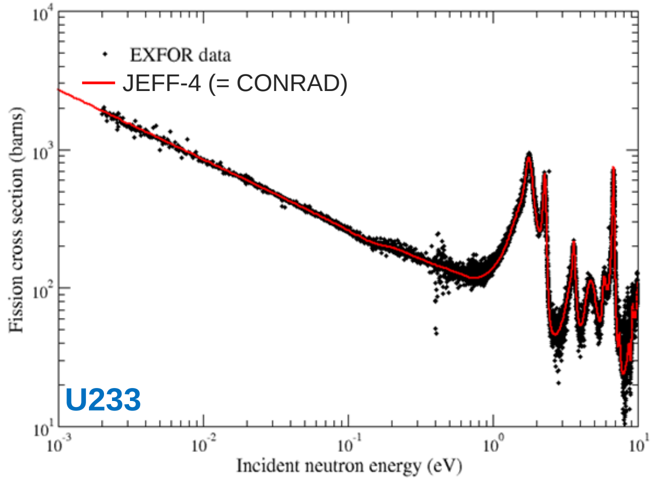
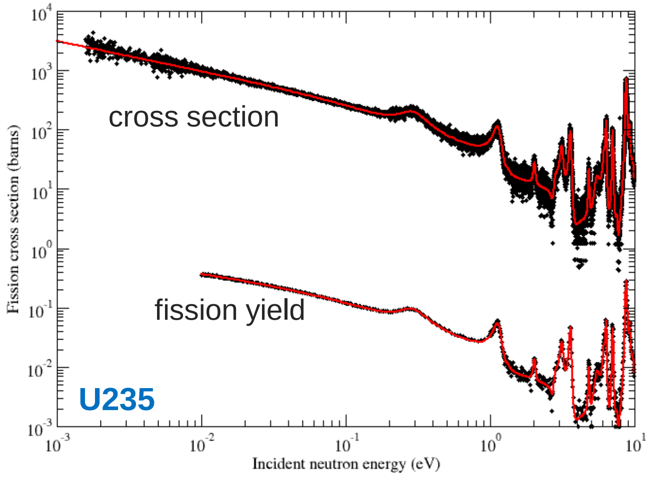
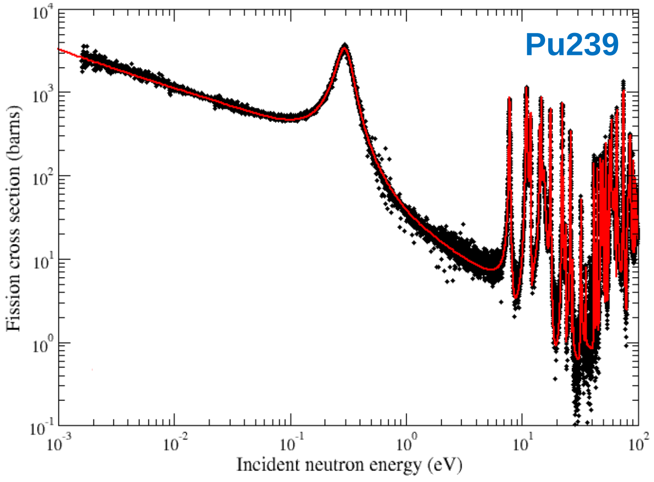
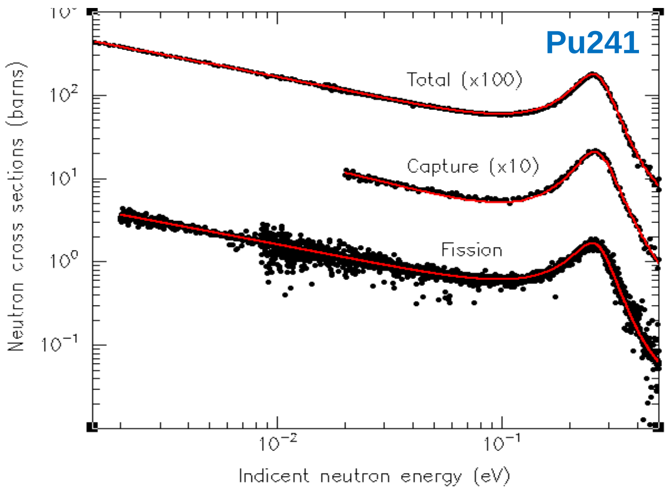
Delayed neutron multiplicities taken from dedicated CRP

Feedback from JEFF and ENDF/B participants

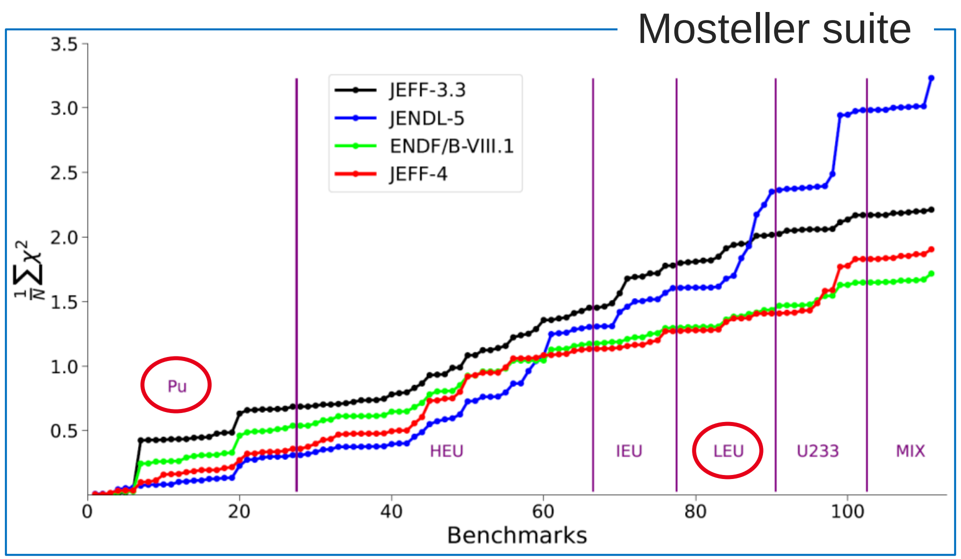




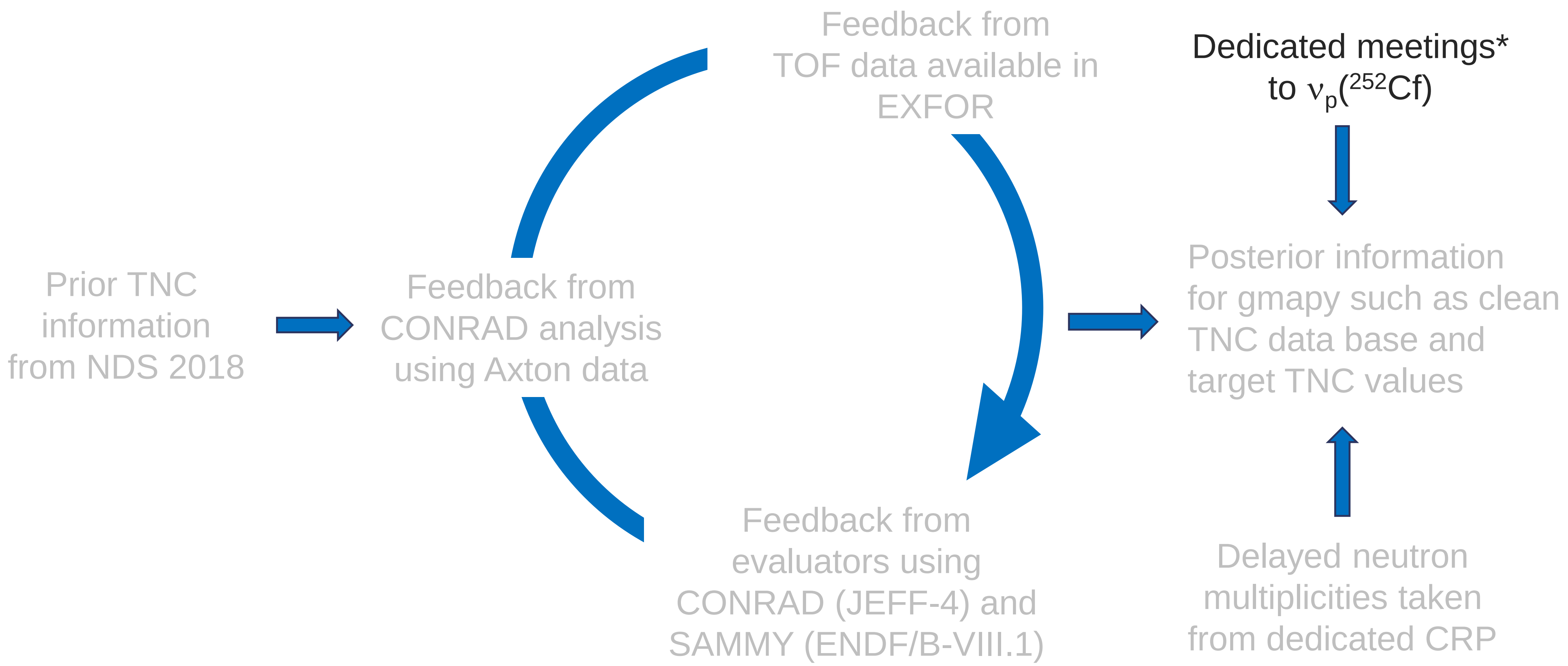




« online » evaluation and integral validation by taking into account evolution of the TNC during the production of JEFF-4 and ENDF/B-VIII.1 libraries



Schematic evaluation process



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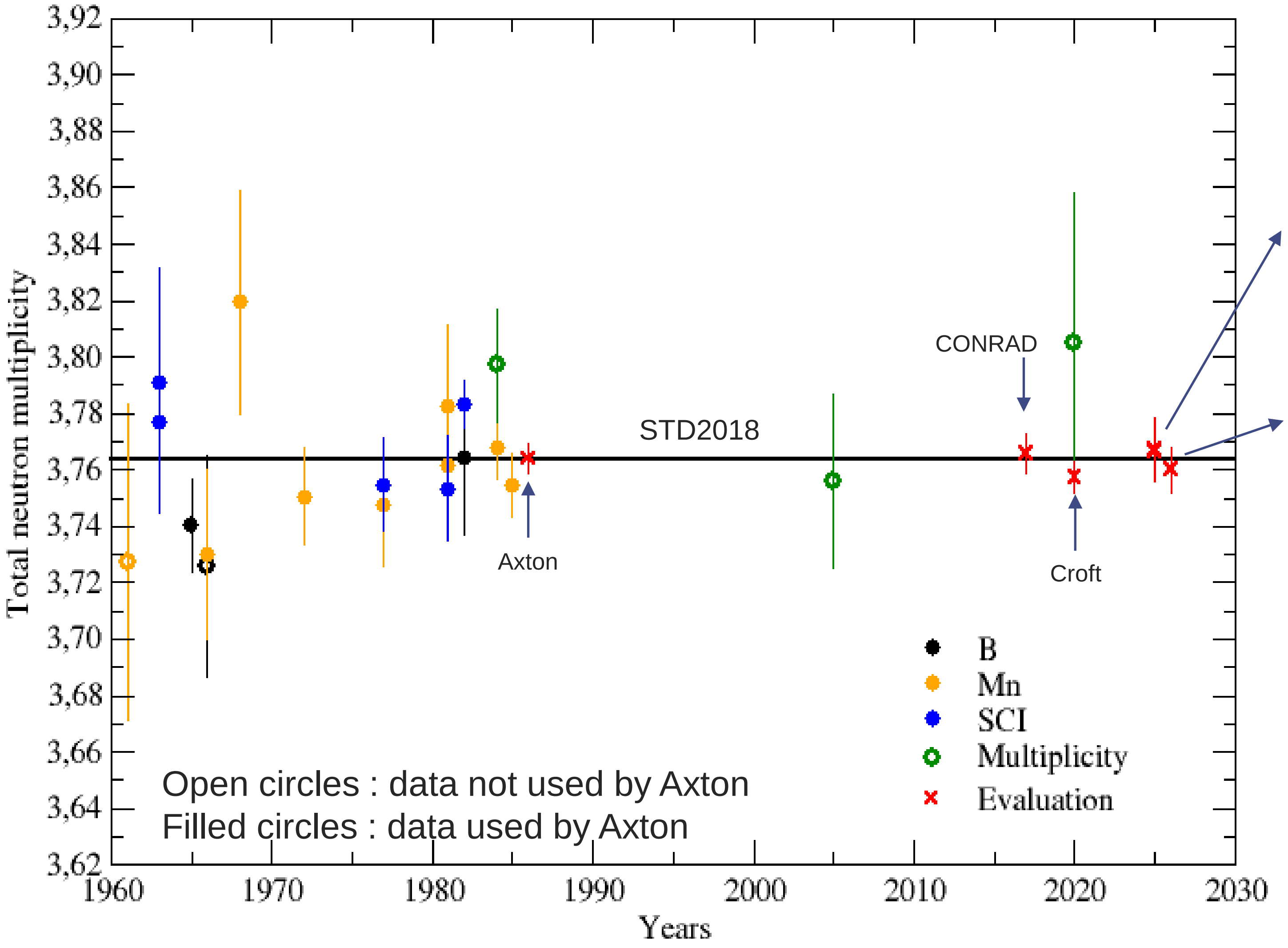
Delayed neutron multiplicities taken from dedicated CRP

*participants : Neudeker (LANL), Morgan, Croft (Lancaster University), Kelly (LANL), Bellier (CEA), Talou (LANL), Taieb (CEA)

Review υ_t(Cf252)



2025 (CONRAD, gmapy) ⇒ **±0.3%** by marginalizing standard deviation for each type of measurement (**±0.7%** for Mn, **±0.3%** for SCI and **±0.5%** for B)

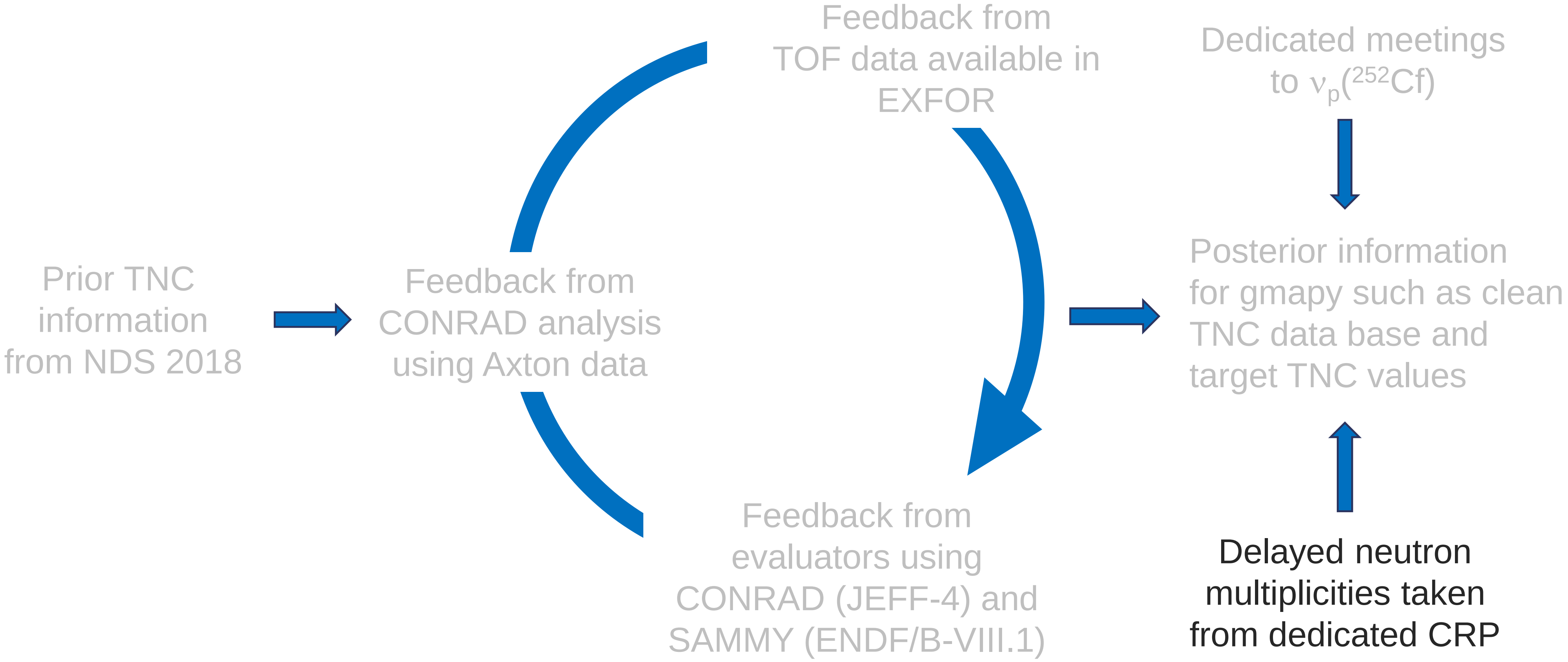
2026 (CONRAD) ⇒ **±0.2%** by updating correlated and uncorrelated sources of uncertainties following dedicated discussions chaired by D. Neudecker

New evaluated results are all close to the value reported by Axton in 1986 (and agree within smaller uncertanties)

For the next release, no revision of the **υ_t(Cf252)** experimental values available in the Axton data base !

New evaluation of ^{252}Cf(sf) total multiplicity on-going led by Neudecker (LANL) in the longer term

Schematic evaluation process



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Delayed neutron multiplicities

Delayed neutron multiplicities are needed to derive the **prompt** contribution from the **total** neutron multiplicities derived from the TNC evaluation work

IAEA 2013-2018

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ScienceDirect

Nuclear Data Sheets 173 (2021) 144–238

Nuclear Data Sheets

www.elsevier.com/locate/nds

Development of a Reference Database for Beta-Delayed Neutron Emission

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X. Huang,[16] T. Marketin,[17] F. Minato,[18] G. Mukherjee,[8] B.C. Rasco,[19,6,15,20] A. Sonzogni,[21] M. Verpelli,[1]
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K.V. Mitrofanov,[5] M. Narbonne,[13] P. Romojaro,[11] A. Sanchez-Caballero,[11] and N.D. Scielzo[22]

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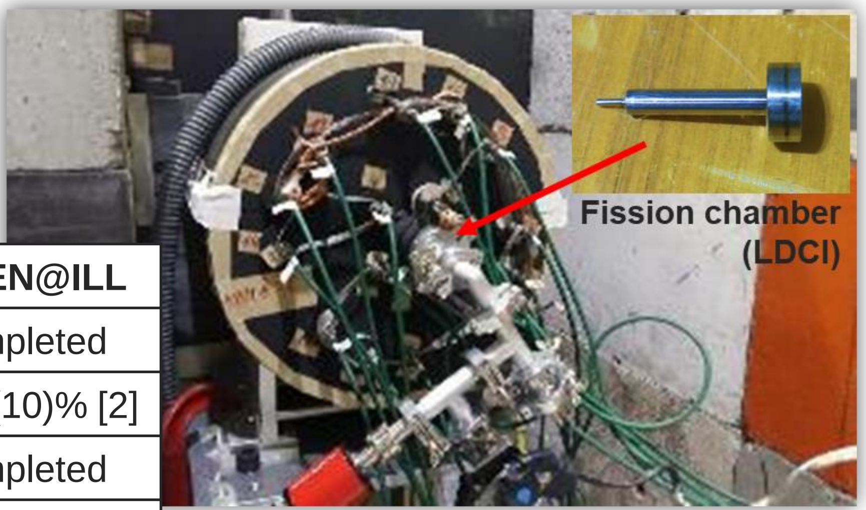
Beta-delayed neutron emission is important for nuclear structure and astrophysics as well
reactor applications. Significant advances in nuclear experimental techniques in the past two de
have led to a wealth of new measurements that remain to be incorporated in the databases.
We report on a coordinated effort to compile and evaluate all the available β-delayed neutron
sion data. The different measurement techniques have been assessed and the data have been
pared with semi-microscopic and microscopic-macroscopic models. The new microscopic data
has been tested against aggregate total delayed neutron yields, time-dependent group param
in 6-and 8-group re-presentation, and aggregate delayed neutron spectra. New recommendati
macroscopic delayed-neutron data for fissile materials of interest to applications are also prese
The new Reference Database for Beta-Delayed Neutron Emission Data is available onli
`http://www-nds.iaea.org/beta-delayed-neutron/database.html.`

ALDEN program started in 2018 at ILL with the aim of measuring υ_d for U233, U235, Pu239 and Pu241 with the LOENIE detector

Collaboration: ILL, IRESNE, LP2I, LPSC, LPC, IRFU, GANIL

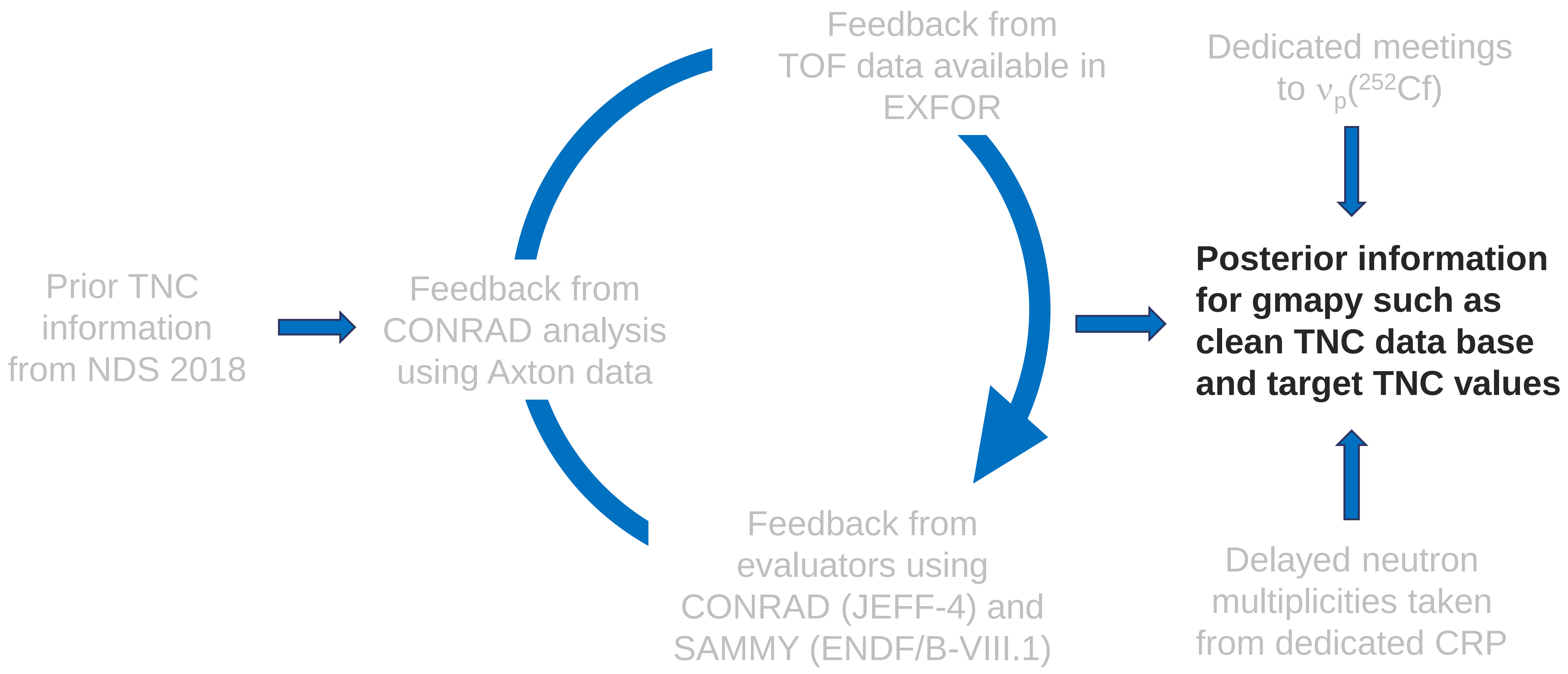
LOENIE detector (PF1B area, ILL, Grenoble)



	IAEA [1]	ALDEN@ILL
U233	0.667(29)%	Completed
U235	1.621(50)%	1.625(10)% [2]
Pu239	0.628(38)%	Completed
Pu241	1.52(11)%	Completed

[1] https://www-nds.iaea.org/beta-delayed-neutron/databases/delayedn_ty.html
[2] P. Leconte et al., EPJA (2024) 60:197

Schematic evaluation process



Prior TNC information from NDS 2018

Feedback from CONRAD analysis using Axton data

Feedback from TOF data available in EXFOR

Feedback from evaluators using CONRAD (JEFF-4) and SAMMY (ENDF/B-VIII.1)

Dedicated meetings to $\nu_p(^{252}\mathrm{Cf})$

Posterior information for gmapy such as clean TNC data base and target TNC values

Delayed neutron multiplicities taken from dedicated CRP

gmapy code and fitting method

High-energy part

- Fortran GMAP code (Poenitz, Pronyaev) translated to Python (gmapy), modernized and validated
- TensorFlow backend enables various evaluation strategies (GLS, ChiSquare Minimization, Maximum Likelihood, Bayesian Markov Chain Monte Carlo)
- Standards committee decided to continue using GLS as evaluation method but integrate other evaluation techniques to assess uncertainty related to evaluation method
- New code supports original database format as well as JSON format (FAIR principles)

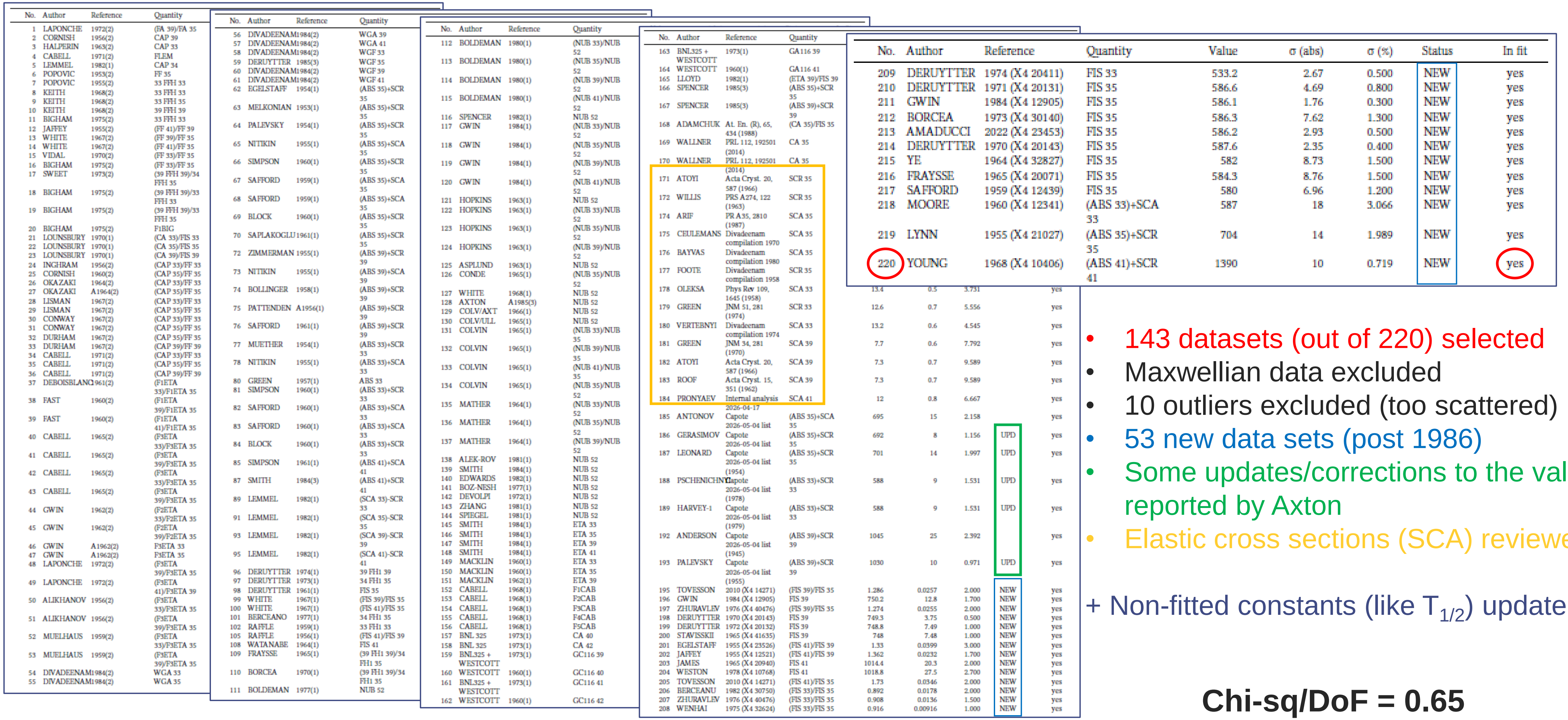
TNC part

- AI-accelerated creation of evaluation pipeline for the reproduction of Axton 1986 evaluation
- Evaluation approach uses TensorFlow to implement GLS method
- Creation of JSON database closely following IDC format and covariance specification approach in Axton report
- Update and revision of TNC database

Upcoming integration of TNC part into gmapy

- TensorFlow graphs for high-energy and TNC part will be combined for a joint (TNC+high-energy) GLS evaluation
- In case of unresolvable tensions between TNC and high-energy part, the cut posterior approach will be applied (fixing TNC but rigorous uncertainty propagation to high-energy part)

Gmapy experimental data base



No.	Author	Reference	Quantity
1	LAPONCHE	1972(2)	(FA 39)/FA 35
2	CORNISH	1956(2)	CAP 39
3	HALPERIN	1963(2)	CAP 33
4	CABELL	1971(2)	FLEM
5	LEMMEL	1982(1)	CAP 34
6	POPOVIC	1953(2)	FF 35
7	POPOVIC	1955(2)	33 FFH 33
8	KEITH	1968(2)	33 FFH 33
9	KEITH	1968(2)	33 FFH 35
10	KEITH	1968(2)	39 FFH 39
11	BIGHAM	1975(2)	33 FFH 33
12	JAFFEY	1955(2)	(FF 41)/FF 39
13	WHITE	1967(2)	(FF 39)/FF 35
14	WHITE	1967(2)	(FF 41)/FF 35
15	VIDAL	1970(2)	(FF 33)/FF 35
16	BIGHAM	1975(2)	(FF 33)/FF 35
17	SWEET	1973(2)	(39 FFH 39)/34 FFH 35
18	BIGHAM	1975(2)	(39 FFH 39)/33 FFH 33
19	BIGHAM	1975(2)	(39 FFH 39)/33 FFH 35
20	BIGHAM	1975(2)	F1BIG
21	LOUNSBURY	1970(1)	(CA 33)/FIS 33
22	LOUNSBURY	1970(1)	(CA 35)/FIS 35
23	LOUNSBURY	1970(1)	(CA 39)/FIS 39
24	INGHRAM	1956(2)	(CAP 33)/FF 33
25	CORNISH	1960(2)	(CAP 35)/FF 35
26	OKAZAKI	1964(2)	(CAP 33)/FF 33
27	OKAZAKI	A1964(2)	(CAP 35)/FF 35
28	LISMAN	1967(2)	(CAP 33)/FF 33
29	LISMAN	1967(2)	(CAP 35)/FF 35
30	CONWAY	1967(2)	(CAP 33)/FF 33
31	CONWAY	1967(2)	(CAP 35)/FF 35
32	DURHAM	1967(2)	(CAP 35)/FF 35
33	DURHAM	1967(2)	(CAP 39)/FF 39
34	CABELL	1971(2)	(CAP 33)/FF 33
35	CABELL	1971(2)	(CAP 35)/FF 35
36	CABELL	1971(2)	(CAP 39)/FF 39
37	DEBOISBLANC	1961(2)	(F1ETA 33)/F1ETA 35
38	FAST	1960(2)	(F1ETA 39)/F1ETA 35
39	FAST	1960(2)	(F1ETA 41)/F1ETA 35
40	CABELL	1965(2)	(F3ETA 33)/F3ETA 35
41	CABELL	1965(2)	(F3ETA 39)/F3ETA 35
42	CABELL	1965(2)	(F3ETA 33)/F3ETA 35
43	CABELL	1965(2)	(F3ETA 39)/F3ETA 35
44	GWIN	1962(2)	(F2ETA 33)/F2ETA 35
45	GWIN	1962(2)	(F2ETA 39)/F2ETA 35
46	GWIN	A1962(2)	F3ETA 33
47	GWIN	A1962(2)	F3ETA 35
48	LAPONCHE	1972(2)	(F3ETA 39)/F3ETA 35
49	LAPONCHE	1972(2)	(F3ETA 41)/F3ETA 39
50	ALIKHANOV	1956(2)	(F3ETA 33)/F3ETA 35
51	ALIKHANOV	1956(2)	(F3ETA 39)/F3ETA 35
52	MUELHAUS	1959(2)	(F3ETA 33)/F3ETA 35
53	MUELHAUS	1959(2)	(F3ETA 39)/F3ETA 35
54	DIVADEENAM	1984(2)	WGA 33
55	DIVADEENAM	1984(2)	WGA 35
56	DIVADEENAM	1984(2)	WGA 39
57	DIVADEENAM	1984(2)	WGA 41
58	DIVADEENAM	1984(2)	WGF 33
59	DERUYTTER	1985(3)	WGF 35
60	DIVADEENAM	1984(2)	WGF 39
61	DIVADEENAM	1984(2)	WGF 41
62	EGELSTAFF	1954(1)	(ABS 35)+SCR 35
63	MELKONIAN	1953(1)	(ABS 35)+SCR 35
64	PALEVSKY	1954(1)	(ABS 35)+SCR 35
65	NITIKIN	1955(1)	(ABS 35)+SCA 35
66	SIMPSON	1960(1)	(ABS 35)+SCR 35
67	SAFFORD	1959(1)	(ABS 35)+SCA 35
68	SAFFORD	1959(1)	(ABS 35)+SCA 35
69	BLOCK	1960(1)	(ABS 35)+SCR 35
70	SAPLAKOGLU	1961(1)	(ABS 35)+SCR 35
72	ZIMMERMAN	1955(1)	(ABS 39)+SCR 39
73	NITIKIN	1955(1)	(ABS 39)+SCA 39
74	BOLLINGER	1958(1)	(ABS 39)+SCR 39
75	PATTENDEN	A1956(1)	(ABS 39)+SCR 39
76	SAFFORD	1961(1)	(ABS 39)+SCR 39
77	MUETHER	1954(1)	(ABS 33)+SCR 33
78	NITIKIN	1955(1)	(ABS 33)+SCA 33
80	GREEN	1957(1)	ABS 33
81	SIMPSON	1960(1)	(ABS 33)+SCR 33
82	SAFFORD	1960(1)	(ABS 33)+SCA 33
83	SAFFORD	1960(1)	(ABS 33)+SCA 33
84	BLOCK	1960(1)	(ABS 33)+SCR 33
85	SIMPSON	1961(1)	(ABS 41)+SCA 41
87	SMITH	1984(3)	(ABS 41)+SCR 41
89	LEMMEL	1982(1)	(SCA 33)-SCR 33
91	LEMMEL	1982(1)	(SCA 35)-SCR 35
93	LEMMEL	1982(1)	(SCA 39)-SCR 39
95	LEMMEL	1982(1)	(SCA 41)-SCR 41
96	DERUYTTER	1974(1)	39 FH1 39
97	DERUYTTER	1973(1)	34 FH1 35
98	DERUYTTER	1961(1)	FIS 35
99	WHITE	1967(1)	(FIS 39)/FIS 35
100	WHITE	1967(1)	(FIS 41)/FIS 35
101	BERCEANO	1977(1)	34 FH1 35
102	RAFFLE	1959(1)	33 FH1 33
105	RAFFLE	1956(1)	(FIS 41)/FIS 39
108	WATANABE	1964(1)	FIS 41
109	FRAYSSE	1965(1)	(39 FH1 39)/34 FH1 35
110	BORCEA	1970(1)	(39 FH1 39)/34 FH1 35
111	BOLDEMAN	1977(1)	NUB 52
112	BOLDEMAN	1980(1)	(NUB 33)/NUB 52
113	BOLDEMAN	1980(1)	(NUB 35)/NUB 52
114	BOLDEMAN	1980(1)	(NUB 39)/NUB 52
115	BOLDEMAN	1980(1)	(NUB 41)/NUB 52
116	SPENCER	1982(1)	NUB 52
117	GWIN	1984(1)	(NUB 33)/NUB 52
118	GWIN	1984(1)	(NUB 35)/NUB 52
119	GWIN	1984(1)	(NUB 39)/NUB 52
120	GWIN	1984(1)	(NUB 41)/NUB 52
121	HOPKINS	1963(1)	NUB 52
122	HOPKINS	1963(1)	(NUB 33)/NUB 52
123	HOPKINS	1963(1)	(NUB 35)/NUB 52
124	HOPKINS	1963(1)	(NUB 39)/NUB 52
125	ASPLUND	1963(1)	NUB 52
126	CONDE	1965(1)	(NUB 35)/NUB 52
127	WHITE	1968(1)	NUB 52
128	AXTON	A1985(3)	NUB 52
129	COLV/AXT	1966(1)	NUB 52
130	COLV/ULL	1965(1)	NUB 52
131	COLVIN	1965(1)	(NUB 33)/NUB 35
132	COLVIN	1965(1)	(NUB 39)/NUB 35
133	COLVIN	1965(1)	(NUB 41)/NUB 35
134	COLVIN	1965(1)	(NUB 35)/NUB 52
135	MATHER	1964(1)	(NUB 33)/NUB 52
136	MATHER	1964(1)	(NUB 35)/NUB 52
137	MATHER	1964(1)	(NUB 39)/NUB 52
138	ALEK-ROV	1981(1)	NUB 52
139	SMITH	1984(1)	NUB 52
140	EDWARDS	1982(1)	NUB 52
141	BOZ-NESH	1977(1)	NUB 52
142	DEVOLPI	1972(1)	NUB 52
143	ZHANG	1981(1)	NUB 52
144	SPIEGEL	1981(1)	NUB 52
145	SMITH	1984(1)	ETA 33
146	SMITH	1984(1)	ETA 35
147	SMITH	1984(1)	ETA 39
148	SMITH	1984(1)	ETA 41
149	MACKLIN	1960(1)	ETA 33
150	MACKLIN	1960(1)	ETA 35
151	MACKLIN	1962(1)	ETA 39
152	CABELL	1968(1)	F1CAB
153	CABELL	1968(1)	F2CAB
154	CABELL	1968(1)	F3CAB
155	CABELL	1968(1)	F4CAB
156	CABELL	1968(1)	F5CAB
157	BNL 325	1973(1)	CA 40
158	BNL 325	1973(1)	CA 42
159	BNL325 + WESTCOTT	1973(1)	GC116 39
160	WESTCOTT	1960(1)	GC116 40
161	BNL325 + WESTCOTT	1973(1)	GC116 41
162	WESTCOTT	1960(1)	GC116 42

No.	Author	Reference	Quantity					
163	BNL325 + WESTCOTT	1973(1)	GA116 39					
164	WESTCOTT	1960(1)	GA116 41					
165	LLOYD	1982(1)	(ETA 39)/FIS 39					
166	SPENCER	1985(3)	(ABS 35)+SCR 35					
167	SPENCER	1985(3)	(ABS 39)+SCR 39					
168	ADAMCHUK	At. En. (R), 65, 434 (1988)	(CA 35)/FIS 35					
169	WALLNER	PRL 112, 192501 (2014)	CA 35					
170	WALLNER	PRL 112, 192501 (2014)	CA 35					
171	ATOYI	Acta Cryst. 20, 587 (1966)	SCR 35					
172	WILLIS	PRS A274, 122 (1963)	SCR 35					
174	ARIF	PR A35, 2810 (1987)	SCA 35					
175	CEULEMANS	Divadeenam compilation 1970	SCA 35					
176	BAYVAS	Divadeenam compilation 1980	SCA 35					
177	FOOTE	Divadeenam compilation 1958	SCR 35					
178	OLEKSA	Phys Rev 109, 1645 (1958)	SCA 33	13.4	0.5	3.731		yes
179	GREEN	JNM 51, 281 (1974)	SCR 33	12.6	0.7	5.556		yes
180	VERTEBNYI	Divadeenam compilation 1974	SCA 33	13.2	0.6	4.545		yes
181	GREEN	JNM 34, 281 (1970)	SCA 39	7.7	0.6	7.792		yes
182	ATOYI	Acta Cryst. 20, 587 (1966)	SCA 39	7.3	0.7	9.589		yes
183	ROOF	Acta Cryst. 15, 351 (1962)	SCA 39	7.3	0.7	9.589		yes
184	PRONYAEV	Internal analysis 2026-04-17	SCA 41	12	0.8	6.667		yes
185	ANTONOV	Capote 2026-05-04 list	(ABS 35)+SCA 35	695	15	2.158		yes
186	GERASIMOV	Capote 2026-05-04 list	(ABS 35)+SCR 35	692	8	1.156	UPD	yes
187	LEONARD	Capote 2026-05-04 list (1954)	(ABS 35)+SCR 35	701	14	1.997	UPD	yes
188	PSCHENICHNYI	Capote 2026-05-04 list (1978)	(ABS 33)+SCR 33	588	9	1.531	UPD	yes
189	HARVEY-1	Capote 2026-05-04 list (1979)	(ABS 33)+SCR 33	588	9	1.531	UPD	yes
192	ANDERSON	Capote 2026-05-04 list (1945)	(ABS 39)+SCR 39	1045	25	2.392		yes
193	PALEVSKY	Capote 2026-05-04 list (1955)	(ABS 39)+SCR 39	1030	10	0.971	UPD	yes
195	TOVESSON	2010 (X4 14271)	(FIS 39)/FIS 35	1.286	0.0257	2.000	NEW	yes
196	GWIN	1984 (X4 12905)	FIS 39	750.2	12.8	1.700	NEW	yes
197	ZHURAVLEV	1976 (X4 40476)	(FIS 39)/FIS 35	1.274	0.0255	2.000	NEW	yes
198	DERUYTTER	1970 (X4 20143)	FIS 39	749.3	3.75	0.500	NEW	yes
199	DERUYTTER	1972 (X4 20132)	FIS 39	748.8	7.49	1.000	NEW	yes
200	STAVISSKII	1965 (X4 41635)	FIS 39	748	7.48	1.000	NEW	yes
201	EGELSTAFF	1955 (X4 23526)	(FIS 41)/FIS 39	1.33	0.0399	3.000	NEW	yes
202	JAFFEY	1955 (X4 12521)	(FIS 41)/FIS 39	1.362	0.0232	1.700	NEW	yes
203	JAMES	1965 (X4 20940)	FIS 41	1014.4	20.3	2.000	NEW	yes
204	WESTON	1978 (X4 10768)	FIS 41	1018.8	27.5	2.700	NEW	yes
205	TOVESSON	2010 (X4 14271)	(FIS 41)/FIS 35	1.73	0.0346	2.000	NEW	yes
206	BERCEANU	1982 (X4 30750)	(FIS 33)/FIS 35	0.892	0.0178	2.000	NEW	yes
207	ZHURAVLEV	1976 (X4 40476)	(FIS 33)/FIS 35	0.908	0.0136	1.500	NEW	yes
208	WENHAI	1975 (X4 32624)	(FIS 33)/FIS 35	0.916	0.00916	1.000	NEW	yes

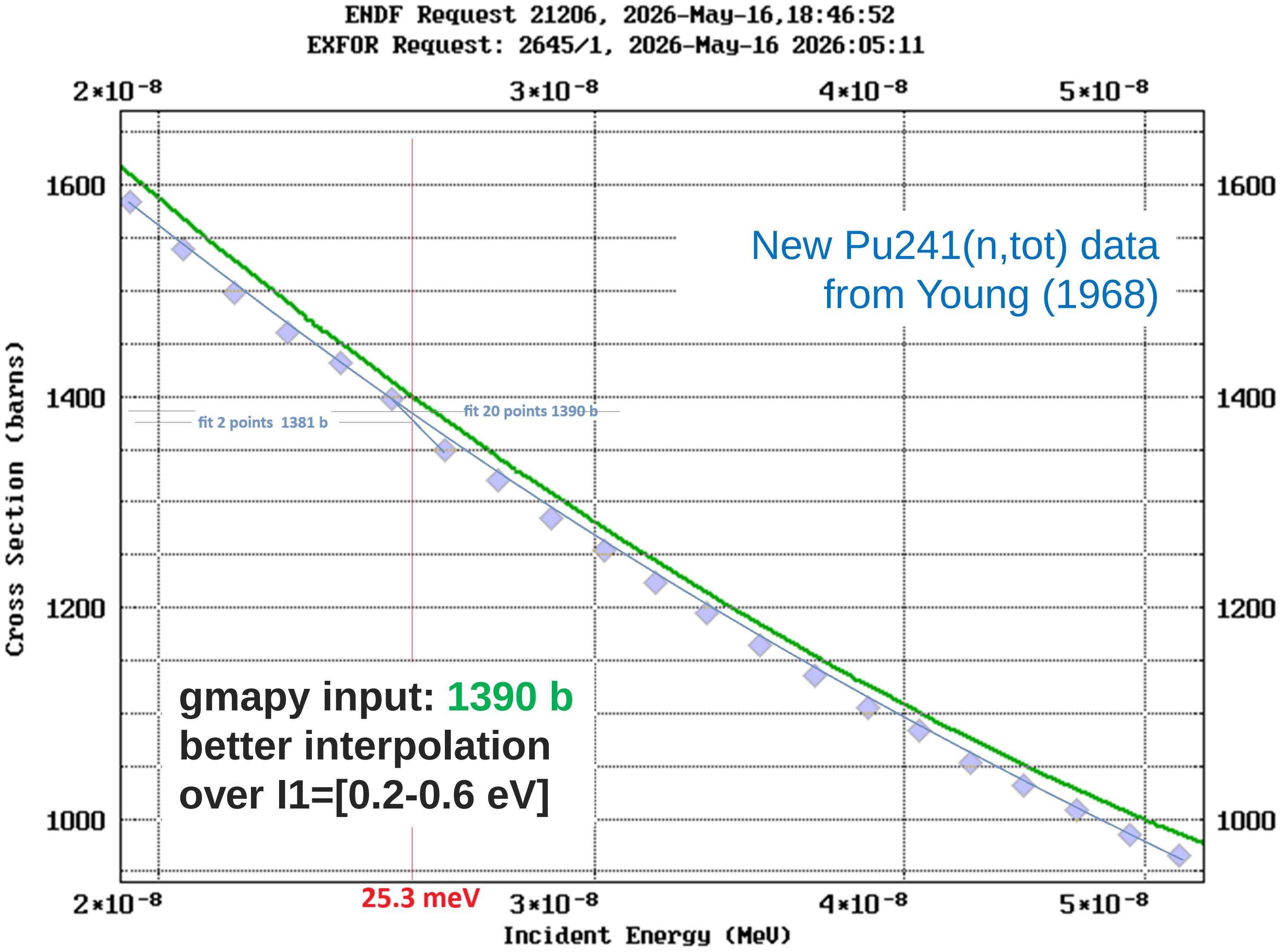
No.	Author	Reference	Quantity	Value	σ (abs)	σ (%)	Status	In fit
209	DERUYTTER	1974 (X4 20411)	FIS 33	533.2	2.67	0.500	NEW	yes
210	DERUYTTER	1971 (X4 20131)	FIS 35	586.6	4.69	0.800	NEW	yes
211	GWIN	1984 (X4 12905)	FIS 35	586.1	1.76	0.300	NEW	yes
212	BORCEA	1973 (X4 30140)	FIS 35	586.3	7.62	1.300	NEW	yes
213	AMADUCCI	2022 (X4 23453)	FIS 35	586.2	2.93	0.500	NEW	yes
214	DERUYTTER	1970 (X4 20143)	FIS 35	587.6	2.35	0.400	NEW	yes
215	YE	1964 (X4 32827)	FIS 35	582	8.73	1.500	NEW	yes
216	FRAYSSE	1965 (X4 20071)	FIS 35	584.3	8.76	1.500	NEW	yes
217	SAFFORD	1959 (X4 12439)	FIS 35	580	6.96	1.200	NEW	yes
218	MOORE	1960 (X4 12341)	(ABS 33)+SCA 33	587	18	3.066	NEW	yes
219	LYNN	1955 (X4 21027)	(ABS 35)+SCR 35	704	14	1.989	NEW	yes
220	YOUNG	1968 (X4 10406)	(ABS 41)+SCR 41	1390	10	0.719	NEW	yes

- 143 datasets (out of 220) selected
- Maxwellian data excluded
- 10 outliers excluded (too scattered)
- 53 new data sets (post 1986)
- Some updates/corrections to the values reported by Axton
- Elastic cross sections (SCA) reviewed

+ Non-fitted constants (like $T_{1/2}$) updated

Chi-sq/DoF = 0.65

Example of new data

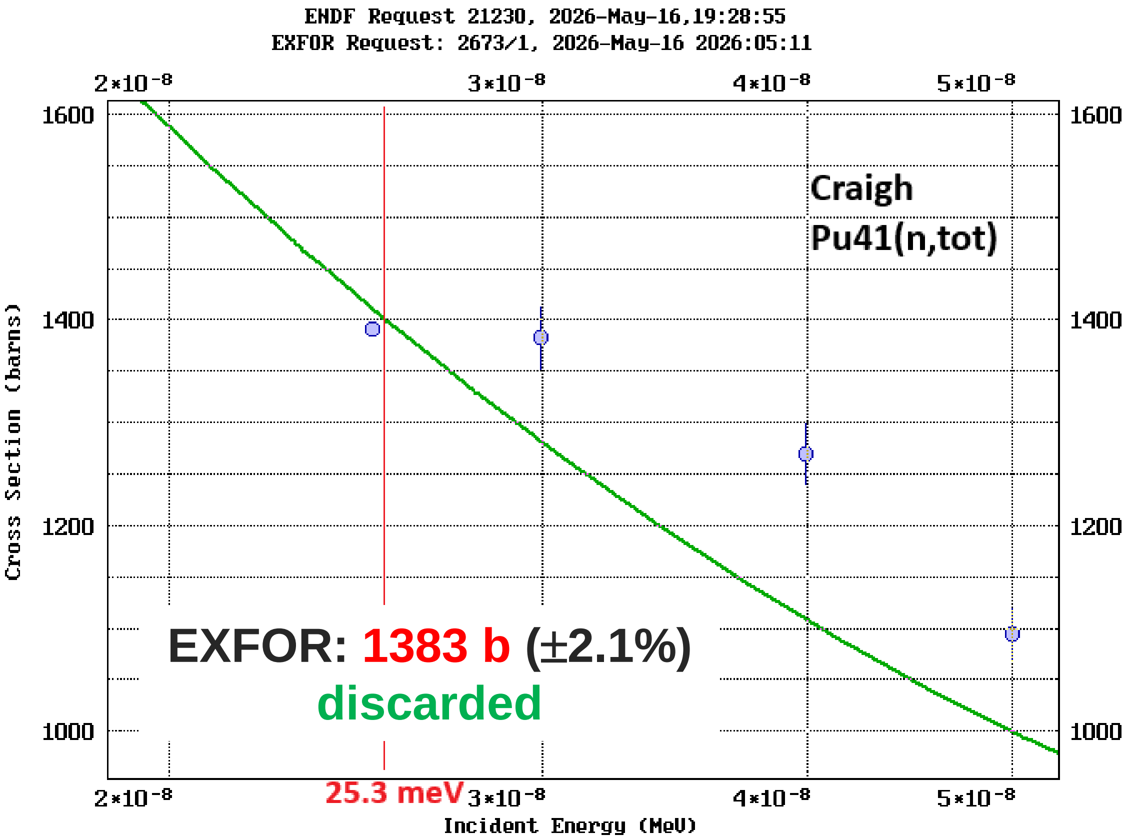


New Pu241(n,tot) data
from Young (1968)

gmapy input: 1390 b
better interpolation
over I1=[0.2-0.6 eV]

Example of rejected Axton data

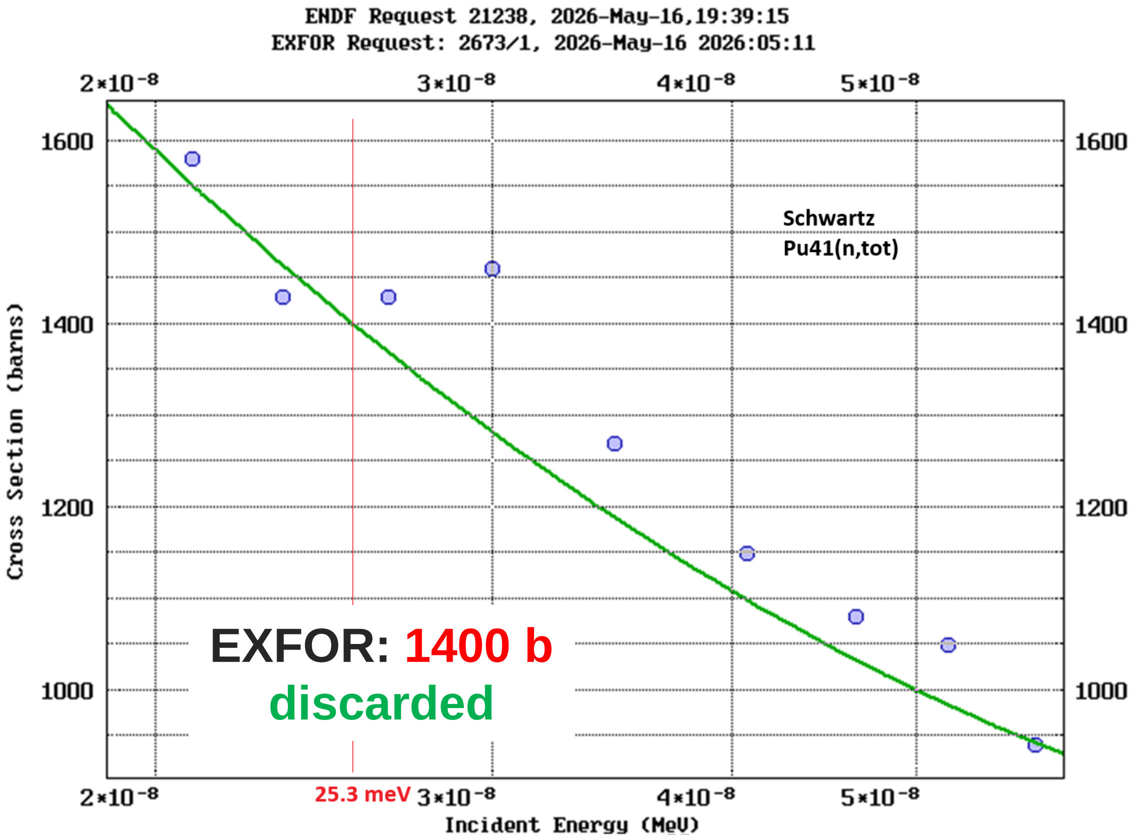
Axton Pu241(n,tot) data from Craig (1964) and Schwartz (1958) ⇒ Discarded



Craigh Pu41(n,tot)

EXFOR: 1383 b (±2.1%) discarded

25.3 meV

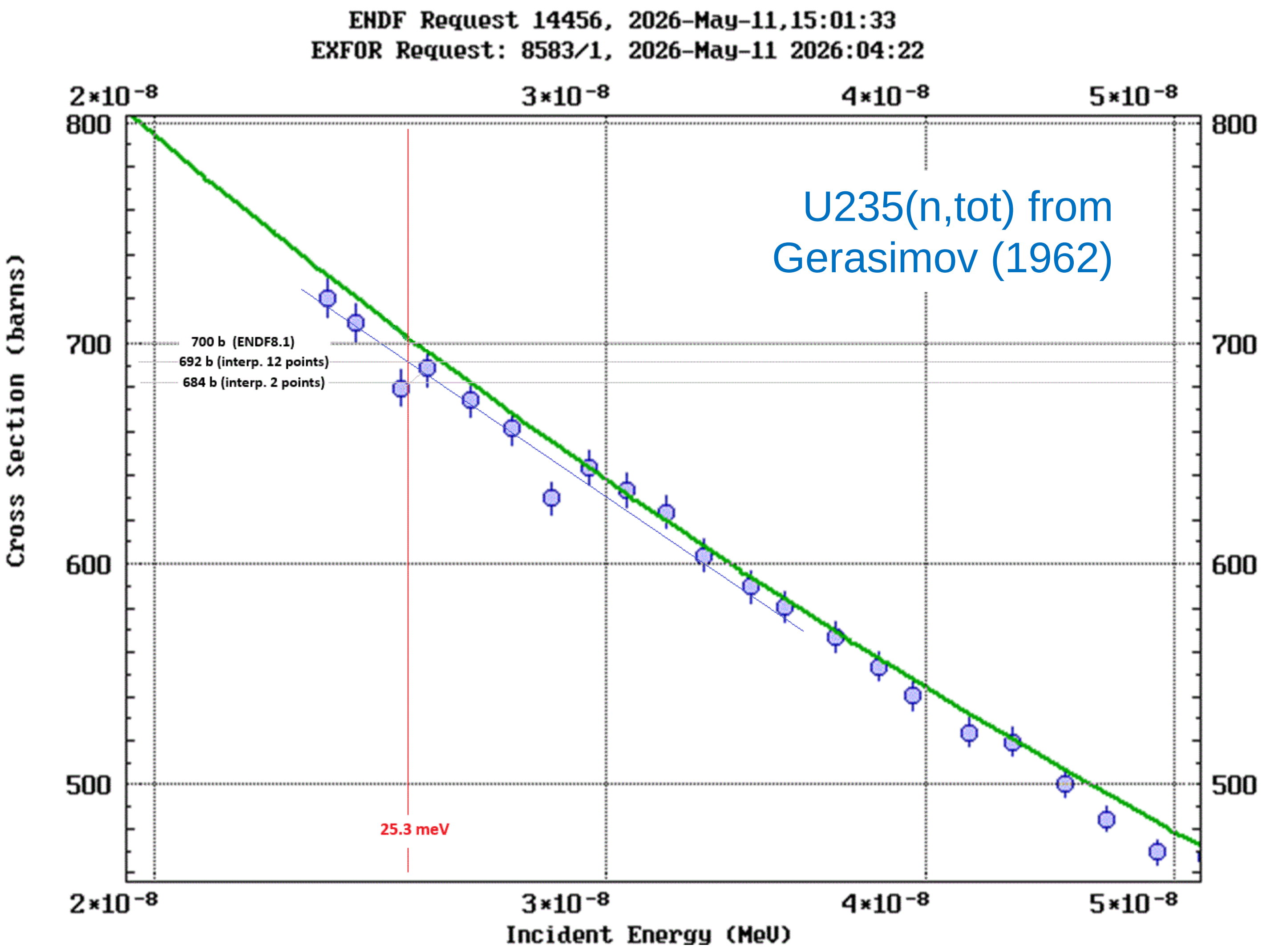


Schwartz Pu41(n,tot)

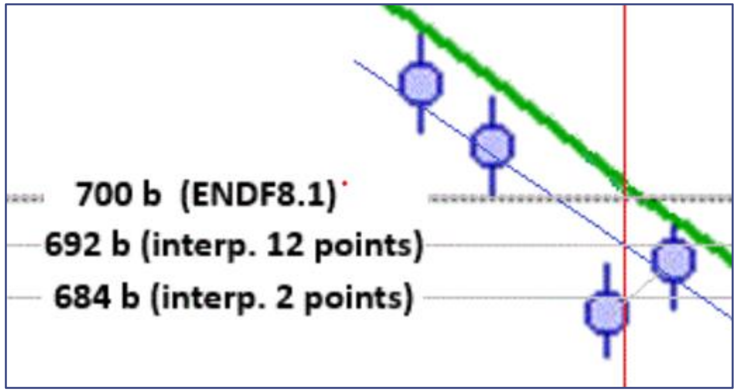
EXFOR: 1400 b discarded

25.3 meV

Example of updated Axton data



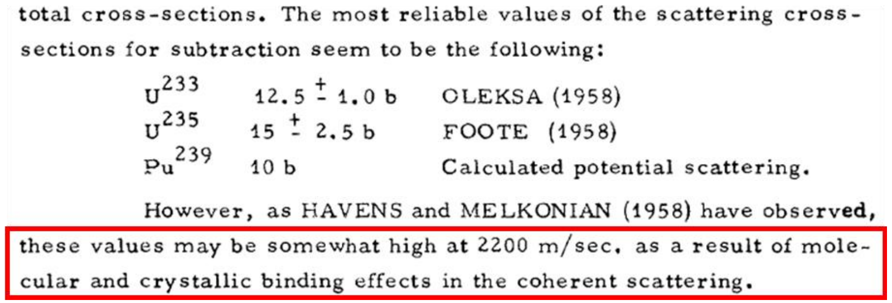
U235(n,tot) from Gerasimov (1962)



EXFOR: 684 b (±1.2%)
gmapy input: 692 b (±1.2%)
⇒ better interpolation
in a broader energy region !

Focus on issues with neutron scattering cross section

Sjostrand (1960)

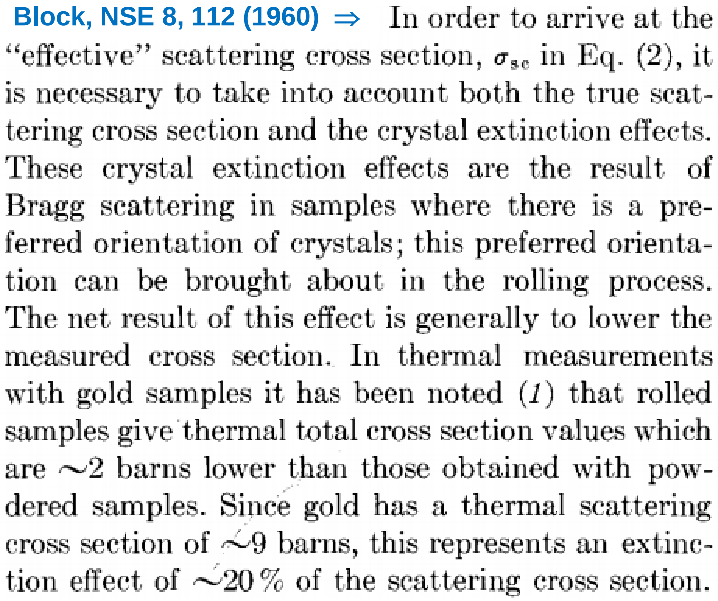


total cross-sections. The most reliable values of the scattering cross-sections for subtraction seem to be the following:

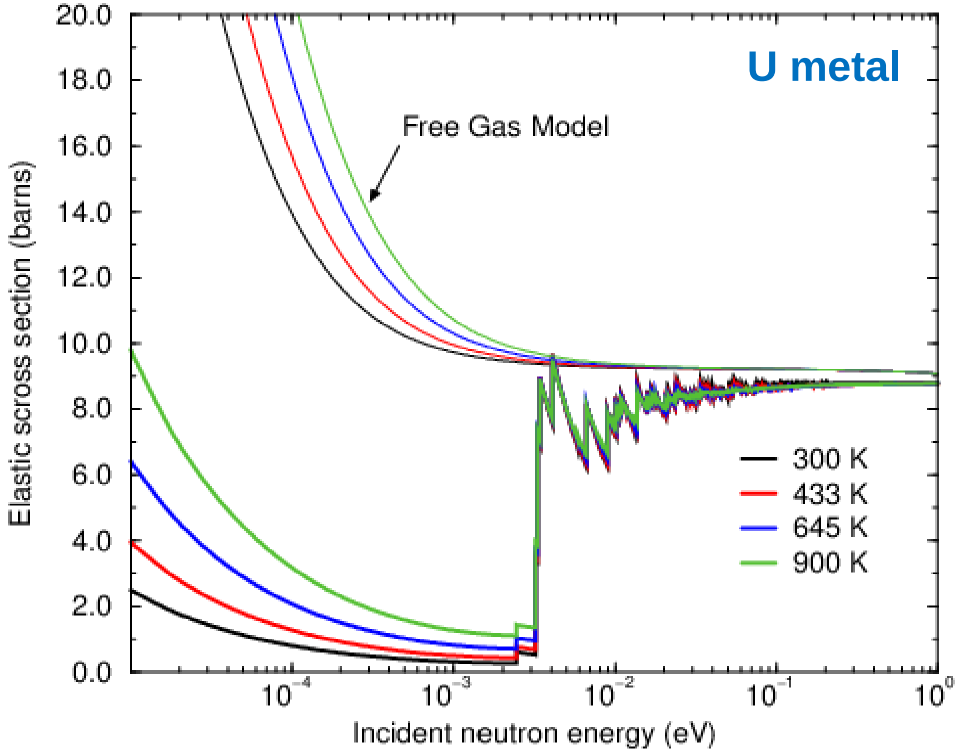
U^{233}	12.5 ± 1.0 b	OLEKSA (1958)
U^{235}	15 ± 2.5 b	FOOTE (1958)
Pu^{239}	10 b	Calculated potential scattering.

However, as HAVENS and MELKONIAN (1958) have observed, these values may be somewhat high at 2200 m/sec. as a result of molecular and crystallic binding effects in the coherent scattering.

Block, NSE 8, 112 (1960) ⇒

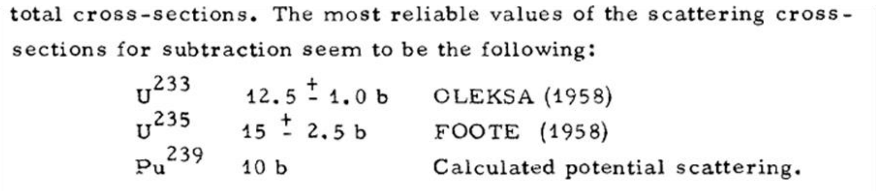


In order to arrive at the "effective" scattering cross section, σ_{sc} in Eq. (2), it is necessary to take into account both the true scattering cross section and the crystal extinction effects. These crystal extinction effects are the result of Bragg scattering in samples where there is a preferred orientation of crystals; this preferred orientation can be brought about in the rolling process. The net result of this effect is generally to lower the measured cross section. In thermal measurements with gold samples it has been noted (*1*) that rolled samples give thermal total cross section values which are ~2 barns lower than those obtained with powdered samples. Since gold has a thermal scattering cross section of ~9 barns, this represents an extinction effect of ~20% of the scattering cross section.



Focus on issues with neutron scattering cross section

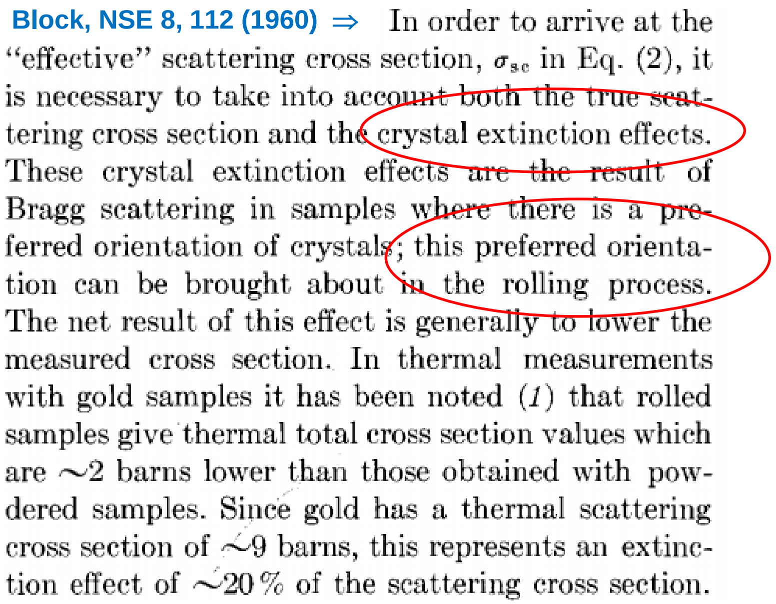
Sjostrand (1960)



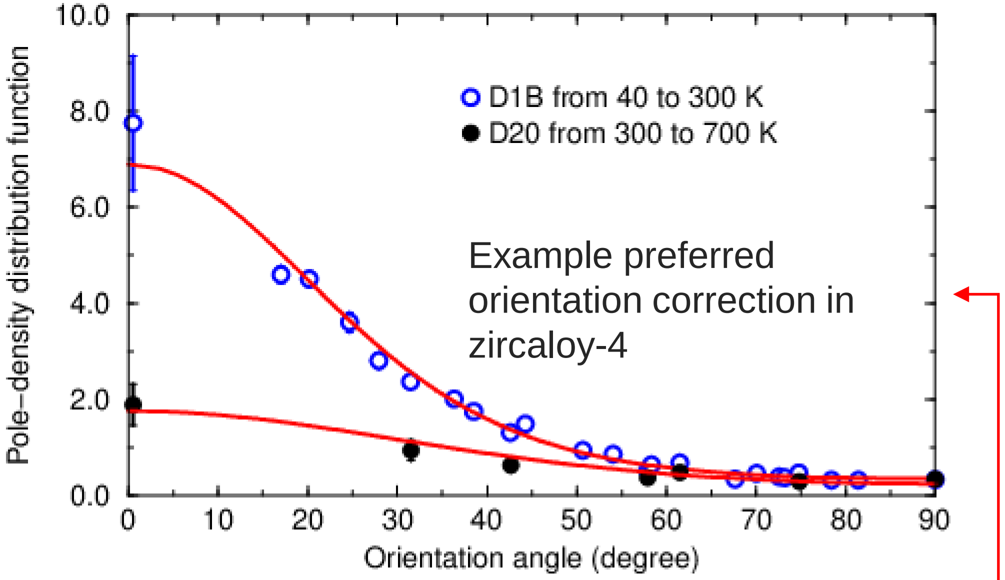
total cross-sections. The most reliable values of the scattering cross-sections for subtraction seem to be the following:

U^{233}	12.5 ± 1.0 b	OLEKSA (1958)
U^{235}	15 ± 2.5 b	FOOTE (1958)
Pu^{239}	10 b	Calculated potential scattering.

Crystal extinction effects due to the structure and dynamics of the molecule in the crystal, taken into account in TNC evaluation



Block, NSE 8, 112 (1960) ⇒ In order to arrive at the "effective" scattering cross section, σ_{sc} in Eq. (2), it is necessary to take into account both the true scattering cross section and the crystal extinction effects. These crystal extinction effects are the result of Bragg scattering in samples where there is a preferred orientation of crystals; this preferred orientation can be brought about in the rolling process. The net result of this effect is generally to lower the measured cross section. In thermal measurements with gold samples it has been noted (*1*) that rolled samples give thermal total cross section values which are ~2 barns lower than those obtained with powdered samples. Since gold has a thermal scattering cross section of ~9 barns, this represents an extinction effect of ~20% of the scattering cross section.



Example preferred orientation correction in zircaloy-4

$$\sigma^{el}_{coh}(E) = \frac{\pi^2\hbar^2}{mNVE}\sum_{hkl}^{E\geq E_{hkl}} d_{hkl}\,|F(\vec{\tau}_{hkl})|^2\,\boxed{\mathcal{P}_{hkl}(\Theta_{hkl})}$$

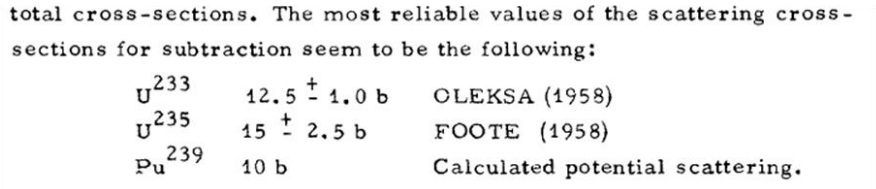
Scattering cross section for rolled metal

$\sigma_{SCR} = N\,\sigma_S$

N (or equivalently σ_S-σ_{SCR}) is a free parameter
Prior σ_S-σ_{SCR} values come from Lemmel (1982)

Focus on issues with neutron scattering cross section

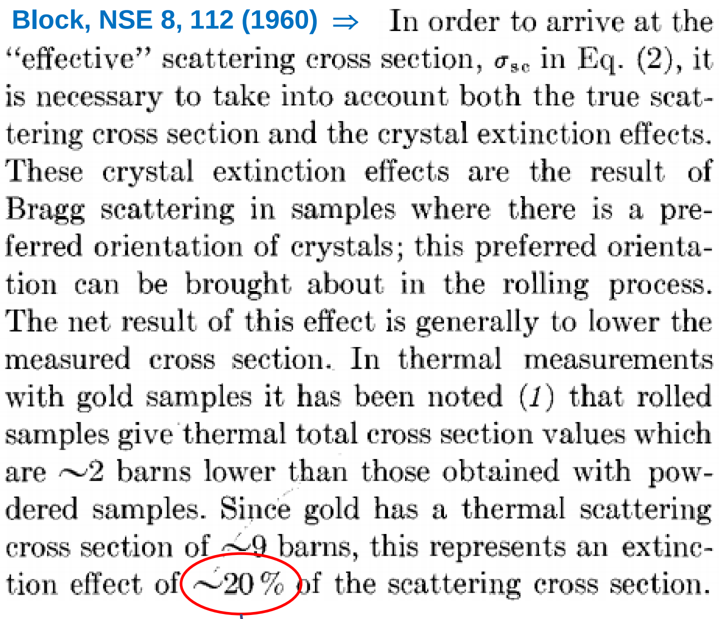
Sjostrand (1960)



total cross-sections. The most reliable values of the scattering cross-sections for subtraction seem to be the following:

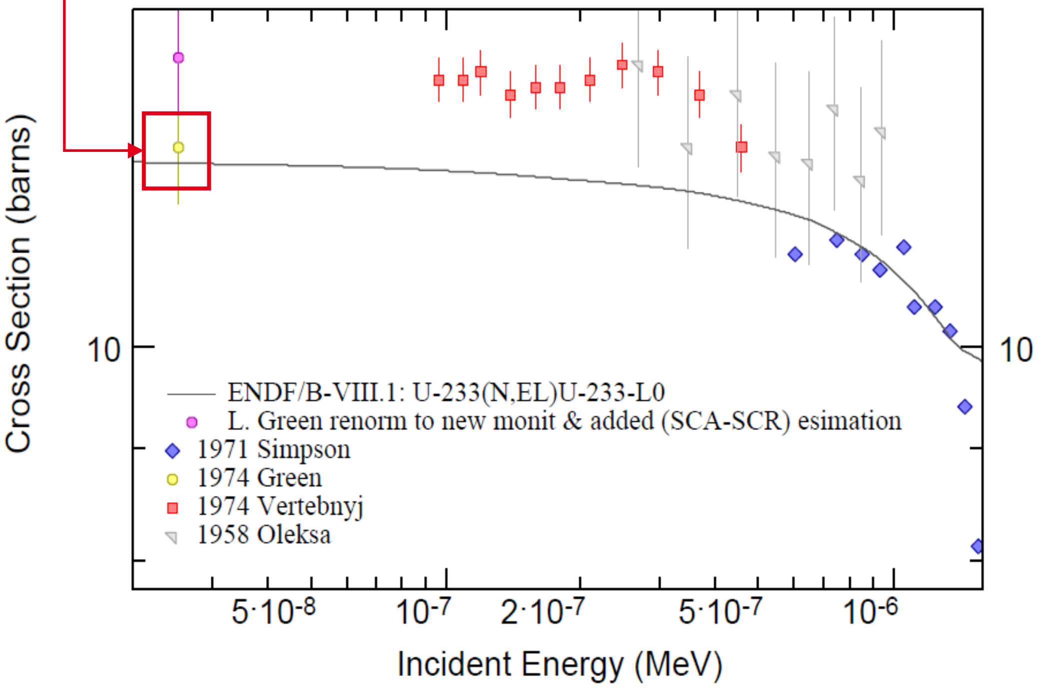
U^{233}	12.5 ± 1.0 b	OLEKSA (1958)
U^{235}	15 ± 2.5 b	FOOTE (1958)
Pu^{239}	10 b	Calculated potential scattering.

Crystal extinction effects due to the structure and dynamics of the molecule in the crystal, taken into account in TNC evaluation



Block, NSE 8, 112 (1960) ⇒ In order to arrive at the "effective" scattering cross section, σ_{sc} in Eq. (2), it is necessary to take into account both the true scattering cross section and the crystal extinction effects. These crystal extinction effects are the result of Bragg scattering in samples where there is a preferred orientation of crystals; this preferred orientation can be brought about in the rolling process. The net result of this effect is generally to lower the measured cross section. In thermal measurements with gold samples it has been noted (*1*) that rolled samples give thermal total cross section values which are ~2 barns lower than those obtained with powdered samples. Since gold has a thermal scattering cross section of ~9 barns, this represents an extinction effect of ~20 % of the scattering cross section.

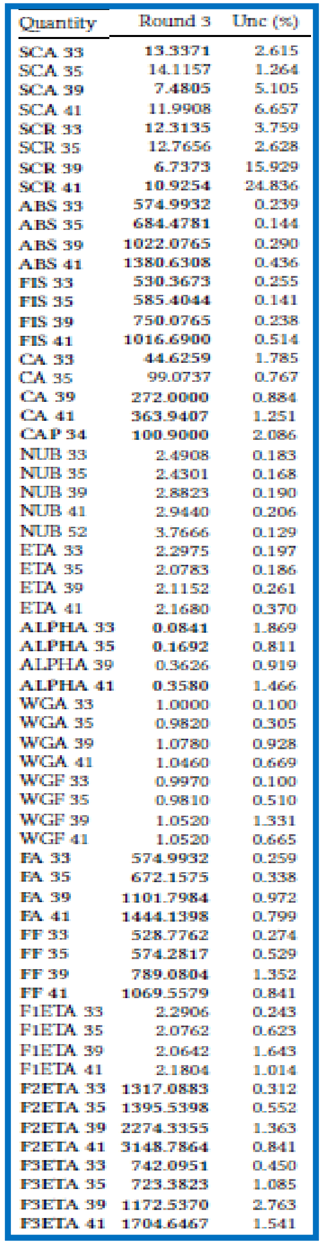
ENDF/B-VIII.1 evaluation of U233(n_{th},n) incorrectly uses values from Green measured with a rolled metal sample (σ_{SCR})



$\sigma_{SCR}=\boldsymbol{N}\,\sigma_s$

σ_{SCR} is 1 or 2 barns lower than σ_s ⇒ impact the capture and/or fission cross sections

gmapy results (round3, 24 June 2026)

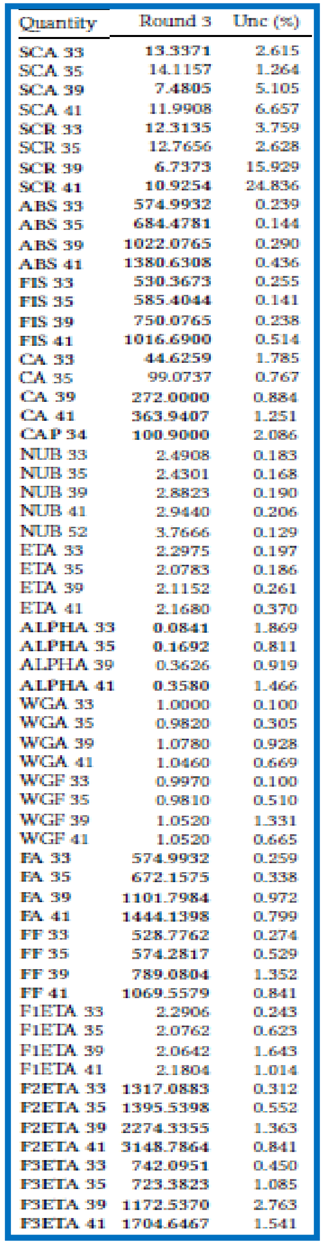


Quantity	Round 3	Unc (%)
SCA 33	13.3371	2.615
SCA 35	14.1157	1.264
SCA 39	7.4805	5.105
SCA 41	11.9908	6.657
SCR 33	12.3135	3.759
SCR 35	12.7656	2.628
SCR 39	6.7373	15.929
SCR 41	10.9254	24.836
ABS 33	574.9932	0.239
ABS 35	684.4781	0.144
ABS 39	1022.0765	0.290
ABS 41	1380.6308	0.436
FIS 33	530.3673	0.255
FIS 35	585.4044	0.141
FIS 39	750.0765	0.238
FIS 41	1016.6900	0.514
CA 33	44.6259	1.785
CA 35	99.0737	0.767
CA 39	272.0000	0.884
CA 41	363.9407	1.251
CAP 34	100.9000	2.086
NUB 33	2.4908	0.183
NUB 35	2.4301	0.168
NUB 39	2.8823	0.190
NUB 41	2.9440	0.206
NUB 52	3.7666	0.129
ETA 33	2.2975	0.197
ETA 35	2.0783	0.186
ETA 39	2.1152	0.261
ETA 41	2.1680	0.370
ALPHA 33	0.0841	1.869
ALPHA 35	0.1692	0.811
ALPHA 39	0.3626	0.919
ALPHA 41	0.3580	1.466
WGA 33	1.0000	0.100
WGA 35	0.9820	0.305
WGA 39	1.0780	0.928
WGA 41	1.0460	0.669
WGF 33	0.9970	0.100
WGF 35	0.9810	0.510
WGF 39	1.0520	1.331
WGF 41	1.0520	0.665
FA 33	574.9932	0.259
FA 35	672.1575	0.338
FA 39	1101.7984	0.972
FA 41	1444.1398	0.799
FF 33	528.7762	0.274
FF 35	574.2817	0.529
FF 39	789.0804	1.352
FF 41	1069.5579	0.841
F1ETA 33	2.2906	0.243
F1ETA 35	2.0762	0.623
F1ETA 39	2.0642	1.643
F1ETA 41	2.1804	1.014
F2ETA 33	1317.0883	0.312
F2ETA 35	1395.5398	0.552
F2ETA 39	2274.3355	1.363
F2ETA 41	3148.7864	0.841
F3ETA 33	742.0951	0.450
F3ETA 35	723.3823	1.085
F3ETA 39	1172.5370	2.763
F3ETA 41	1704.6467	1.541

⇒ 30 free parameters and 72 derived quantities

- Elastic cross section for rolled metallic sample (SCR)
- Total, Capture, fission, elastic cross sections
- Total neutron multiplicities
- α, η, K1 values

gmapy results (round3, 24 June 2026)



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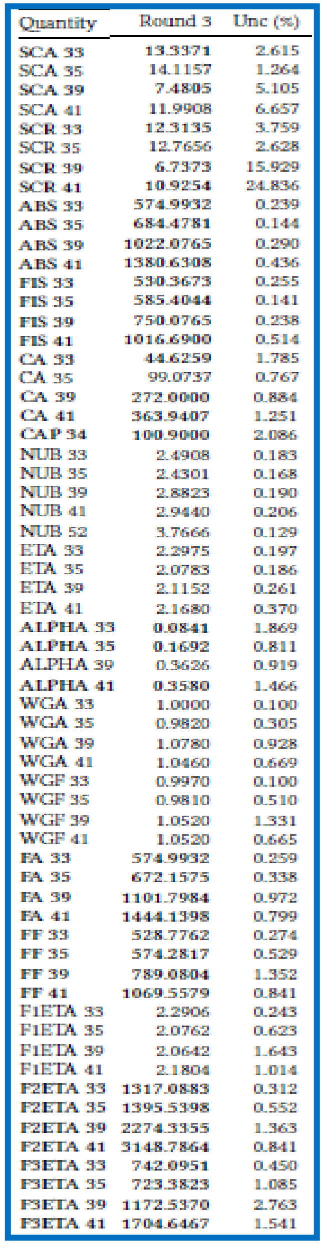
	U233	U235	Pu239	Pu241	Cf252
σ_{tot}	587.7(22) 590.2(14) 590(2) 588.3(13)	697.6(36) 700.4(11) 699.8(20) 698.6(10)	1027.7(48) 1028.6(13) 1029(5) 1029.6(30)	1394.3(169) 1393.6(13) 1399(2) 1392.6(60)	
σ_n	12.3(7) 12.3(5) 12.3(7) 13.3(2)	14.1(7) 14.2(5) 14.1(2) 14.1(2)	8(1) 7.8(10) 8(1) 7.5(4)	12,0(25) 11.9(15) 11,9(25) 12.0(6)	
σ_f	530.4(22) 532.6(7) 533(2) 530.4(14)	585.0(35) 586.4(24) 586.2(3) 585.4(8)	749.1(34) 750.6(19) 751(2) 750.1(18)	1018.0(133) 1018.2(25) 1024(2) 1016.7(52)	
σ_γ	44.9(10) 45.4(17) 45(1) 44.6(8)	98.6(12) 99.8(27) 99(5) 99.1(8)	270.6(29) 270.2(25) 270(3) 272.0(24)	364.3(63) 363.6(32) 363(7) 363.9(46)	
ν_{tot}	2.491(5) 2.487(3) 2.491(5)	2.430(5) 2.425(10) 2.430(5)	2.882(6) 2.873(5) 2.882(5)	2.944(6) 2.940(13) 2.944(6)	3.766(5) 3.767(5)
K1	742.1(50) 742.1(33)	721.0(58) 723.4(78) 723.4(78)	1181.6(103) 1172.5(324) 1172.5(324)	1688.7(328) 1704.7(263)	

From CONRAD using Axton data
From HR TOF data using EXFOR
Expected target values
gmapy results

No suspicious results !!!

gmapy results (round3, 24 June 2026) vs Evaluated Libraries



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	U233	U235	Pu239	Pu241	
σ_{tot}	593.0 589.7 590.3 588.3(13)	700.2 699.6 699.7 698.6(10)	1025.5 1029.5 1032.0 1029.6(30)	1386.4 1399.5 1399.5 1392.6(60)	
σ_n	11.7 12.1 12.2 13.3(2)	14.1 14.1 14.1 14.1(2)	8.1 8.1 9.9 7.5(4)	11.3 12.0 11,8 12.0(6)	
σ_f	537.8 533.5 533.0 530.4(14)	586.7 586.1 586.1 585.4(8)	747.3 751.1 750.7 750.1(18)	1012.2 1023.7 1023.7 1016.7(52)	
σ_γ	43.5 44.1 45.2 44.6(8)	99.4 99.4 99.4 99.1(8)	270.1 270.4 271.4 272.0(24)	363.0 363.8 364.0 363.9(46)	
ν_{tot}	2.4845 2.4869 2.4993 2.491(5)	2.4288 2.4298 2.4367 2.430(5)	2.8742 2.8614 2.8726 2.882(5)	2.9466 2.9453 2.9410 2.944(6)	

JENDL-5
ENDF/B-VIII.1
JEFF-4
gmapy results

Some deviations, but generally good agreement !!!

Conclusions

❑ Full revision of the TNC data base

- Axton report taken as starting point
- Maxwellian data discarded as done for STD2017
- Total and fission cross section data revised based on consistent fits in the energy range I1=[20-60 meV]
- Some (n,tot) data discarded due to large spread within I1
- All available scattering cross section data used with addition of new datasets for U233, U235 and Pu239
- Prior extinction corrections σ_{s}-σ_{SCR} taken from Lemmel (1982) as reported by Axton
- Westcott factors replaced by those of ENDF/B-VIII.1 (SAMMY, ORNL)

❑ Development of a new evaluation tool called gmapy

- New TNC values provided by gmapy are consistent with past works and confirmed the slight overestimation of the U235 and Pu239 fission cross sections in STD2017
- K1 integral parameters (characterizing the criticality of thermal systems) calculated using Westcott factors from ENDF/B-VIII.1 and new TNC are in excellent agreement with recommended values

Derived K1(^{235}U)= **723(7)** b vs. recommended by Hardy and Williams **722.7(39)** b
Derived K1(^{239}Pu)= **1172(32)** b vs. recommended by Noguere (CERES program) **1170(6)** b

CONSISTENT MIC-MAC data but large uncertainties !!