Update of the Thermal Neutron Constant database

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Some actions to be done before the TNC release

- Include TNC in gmapy (done during Georg Schnabel 's visit to CEA Cadarache in 2025)
- Remove TNC data from GMA database (1 points)
- Combine I1/σ_f and I3/I1 ratios determines by Ignacio Duran with GMA results to get I1 and I3
- Use some scattering data reported by Sjostrand (1960) not included in the Axton report
- Add new TNC data and change some data reported by Axton
- Update ν_{tot}(Cf252) uncertainties (dedicated meetings organised by Denis Neudecker in 2025)
- Update Half-live values of U233, U234, Pu239 and Pu241

$T_{1/2}$(U233) = (1.592 ± 0.002).10^5 y	(ENSDF
$T_{1/2}$(U234) = (2.455 ± 0.006).10^5 y	(LNHB = ENSDF)
$T_{1/2}$(Pu239) = (2.4100 ± 0.0011).10^4 y	(LNHB)
$T_{1/2}$(Pu241) = 14.33 ± 0.04 y	(LNHB)

⇒ TNC evaluation should be considered as an independent work and not included in a fitting procedure that combines the full GMA database

Issues with GMA database

Id GMA database	Reference	Comments
		Add Walner fast data at 25 keV and 426 keV, U238 and U235 ratios to Gold ?
359, 170, 1015		No statistical unc in the 3rd columun (see GMA format)
1030		Statistical uncertainty of 145%
602	Meadows (1983)	Delete thermal point in GMA data base
631	Zhuravlev (1977)	Delete thermal point in GMA data base
8029, 8028	Tovesson (2010)	1 data point, deleted in GMA
8027	Calviani (2009)	1 data point, deleted in GMA (extrapolation from 33 to 40 meV)
8026	Adamchuk (1988)	1 data point, deleted in GMA, added in TNC database
1918	Arif (1987)	1 data point, deleted in GMA, added in TNC database
1915,1921	Reed (2004)	1 data point, deleted in GMA because shape data
8099, 8098, 8097	Lounsbury (1970)	Deleted in GMA, added in TNC data base
910 to 934		Id number for TNC values in GMA database
907		Dummy data set from thermal to high energy range U235(n,f)
908		Dummy data set from thermal to high energy range Pu239(n,f)

→ Remove TNC from GMA database

Issues with I3(U235) in the GMA database

Shape data found in the GMA data base covering the thermal and I3 energy ranges

Id GMA database	Reference	I3	Comments
244	Lemley (1971)		
271	Czirr (1977)	x	Contains I3
272	Czirr (1977)		wo I3, different values than 271, verified by Roberto Capote
405	Poenitz (1970)		
425	Linenberger (1944)		
288	Barry (1966)		
325	Johnsrud (1959)		
515	Zhuravlev (1977)		
630	Zhuravlev (1977)		
550	Bergman (1980)		
551	Bergman (1980)		
552	Bergman (1979)		
635	Lehto (1970)		
730	ORNL/RPI (1966)	x	Contains I3 Correspond to Bowman (1966) 4 sets in EXFOR Only 1 value in GMA (and TNC database) Used by Ignacio Duran (estimated difference -0.5%)
732	Bowman (1963)	x	Contains I3
731	Deruytter (1971)	x	Contains I3 Used by Ignacio Duran (estimated difference -1.9%)
676	Gwin (1976)		
681	Gwin (1971)		Different data sets Verified by Roberto Capote
682	Gwin (1971)		
710	Gwin (1984)	x	Contains I3 Different data sets, 2 samples, 2 TOF Verified by Roberto Capote Used by Ignacio Duran (estimated difference +0.2%)
711	Gwin (1984)	x	
712	Gwin (1984)	x	
713	Gwin (1984)	x	
714	Gwin (1984)	x	
541	Wagemans (1979)	x	Contains I3, relative to boron Ignacio Duran used Wagemens (1984), with boron ?
542	Wagemans (1979)	x	Contains I3, relative to Li6 Ignacio Duran used Wagemens (1984), with Li6 ?
546	Wagemans (1984)	x	Contains I3
547	Wagemans (1980)		

Id GMA database	Reference	I3	Comments
	Wagemans (1988)	x	Contains I3 Used by Ignacio Duran but not in GMA Same as 546 (Wagemans, 1984) ?
532	Weston (1984)	x	Contains I3
403	Weston (1993)		
536	Weston (1983)		
	Adamchuk (1955)	x	Contains I3 Used by Ignacio Duran but not in GMA Do not use anymore !
	Amaducci (2019)	x	Contains I3 Used by Ignacio Duran but not in GMA Add in GMA ?
	Melkonian (1958)	x	Contains I3 Used by Ignacio Duran but not in GMA Do not use anymore !
	Mihailescu (1972)	x	Contains I3 Used by Ignacio Duran but not in GMA Do not use anymore !
	Schrack (1988)	x	Contains I3 Used by Ignacio Duran but not in GMA Use in CONRAD for RRR analysis but statistic is not good Do not used ?

Consistency between I3/I1 determined by Ignacio Duran and GMA database ?

Issues with « old » TNC data 1944-1960

Some data reported by Sjostrand in 1960 (close to the TNC-17 value) are not included in the Axton report

① Add scattering cross section not used by Axton

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.

② No time to review and decide for σ_a σ_γ σ_f σ_{tot} and ν_{tot} reported by Sjostrand

Reference	U^{233}	U^{235}	Pu^{239}
MAY (1944)		687 ± 15 695 ± 20	
ANDERSON et al. (1944)			1057
PALEVSKY & MUETHER (1954)	585 ± 10		
PALEVSKY et al. (1954)		685 ± 5	
EGELSTAFF (1954) (Revised)		709 ± 15	
ZIMMERMAN & PALEVSI Y (1955)			1020 ± 10
PATTENDEN (1956)	595 ± 15		1005 ± 30
NIKITIN et al. (1956)	570 ± 20	695 ± 20	1030 ± 30
KUKAVADSE et al. (1956)	618 ± 30		
GREEN et al. (1957)	578 ± 17		
SCHWARTZ (1958)		683 ± 6 681 ± 6	
BOLLINGER et al. (1958)			988 ± 10

Absorption cross section used by Axton

Absorption cross section not used by Axton

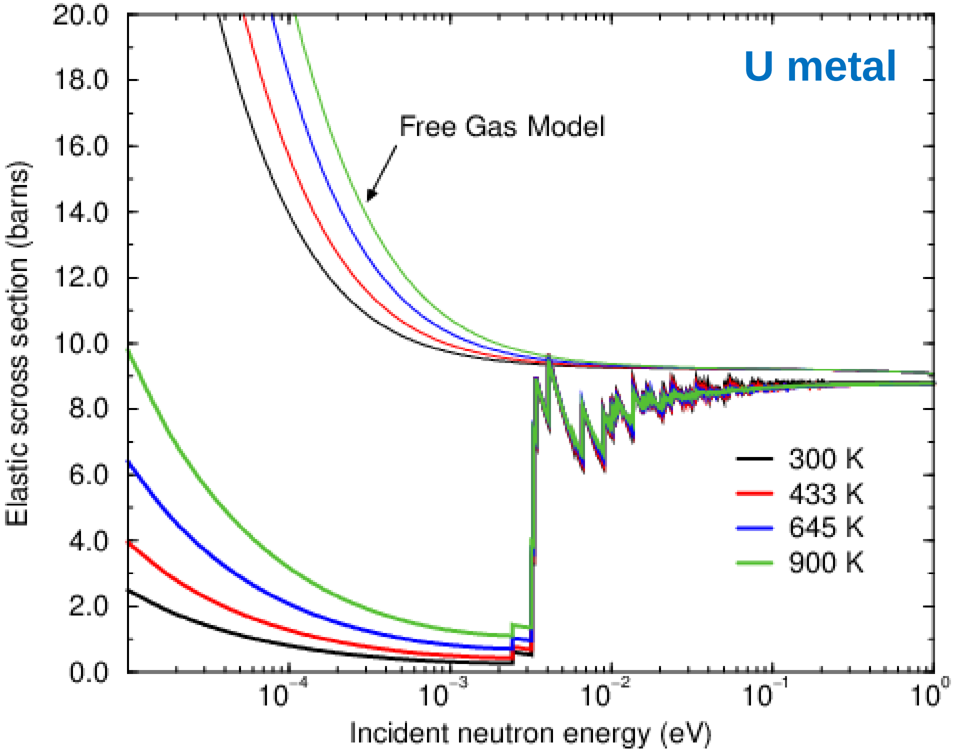
Not easy to understand the data selection of Axton

Issues with neutron scattering cross section

"Crystal extinction effects" due to the structure and dynamics of the molecule in the crystal

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.

« Crystal extinction effects taken into account in the TNC evaluation



It was decided to remove all total cross sections not measured with a metallic sample. Crystal lattice effect of oxide are taken into account via SCA parameter

⇒ Remove all datasets ABS(iso)+SCA(iso) and all quantities with SCA(iso).

Some recommended modifications

Id Axton-TNC database	Id GMA database	Reference	Comments
70		Saplakoglu (1961)	• Change to 694.2(0.7%)
93		Lemmel (1982)	• Data connected to crystal extinction
95		Lemmel (1982)	• Deleted from TNC because large uncertainties
152 to 164		Cabel (1968)	• Deleted because T=116°C
54 to 61		Divadeenam (1984)	• Deleted because Westcoff factor (mac data not used)
76		Safford (1961)	• Pu239 data deleted as this is extrapolation
65		Nikitin (1955)	• Change ABS(35)+SCA(35) in ABS(35)+SCR(35) • Change to 710(2.8%)
73		Nikitin (1955)	• Change ABS(39)+SCA(39) in ABS(39)+SCR(39)
78		Nikitin (1955)	• Change to 580 barn
85		Simpson (1961)	• Change ABS(41)+SCA(41) in ABS(41)+SCR(41)
86		Craig (1964)	• Change ABS(41)+SCA(41) in ABS(41)+SCR(41) • Change to 1383(3.0%)
79		Patenden (1956)	• Change to 590 barn
	8026	Adamchuk (1988)	• Add Adamchuk data in TNC (1 data set) • Remove in GMA data base
	1918	Arif (1987)	• Add Arif data in TNC (1 data set) • Remove in GMA data base
	8099	Lounsbury (1970)	• Values verified by Roberto Capote
	8098	Lounsbury (1970)	• Added in TNC, Removed from GMA
	8097	Lounsbury (1974)	• Lounsbury (1974) originally from 1970.
		Walner (2014)	• Add Walner $^{235}U(n_{th},\gamma)$ values (2 data sets) • See PRL 112, 192501 (2014)
			• Remove all total cross section ABS(iso)+SCA(iso) • Remove SCA(iso) values • Remove all quantities with SCA(iso)

Add scattering data:

- SCR(33) OLEKSA 1958 - Phys Rev.109,1645(1958)- 12.5 (4%)
- SCR(33) Green 1974- 12.30 (5.6%)
- SCR(33) VERTEBNIY 1974- 13.2 (2.2%)
- SCR(33) BLOCK 1960- 11(18%)
- SCR(35) BLOCK 1960- 13(15%)
- SCR(35) CEULEMANS 1970- 14.3 (3.5%)
- SCR(35) FOOTE 1958- 15.0 (6.0%)
- SCR(39) Safford 1961 11(30%)

Please also add/chance the following data:

- ABS(33) + SCR(33) Pshenichnyj 1978- 587.9 (0.5%)
- ABS(33) + SCR(33) Harvey 1979- 590 (0.8%)
- ABS(33) + SCR(33) Moore 1979- 587 (1.0%)
- ABS(33) + SCR(33) Block 1960- 587 (0.5%) **Id=84**
- ABS(33) + SCR(33) Safford 1960- 587 (0.85%) check **Id=83**
- ABS(33) + SCR(33) Pattenden 1956- 590 (2.5%) **Id=79**

- ABS(35) + SCR(35) Spencer 1987 690 (0.8%)
- ABS(35) + SCR(35) Leonard 1954- 702 (1.0%)
- ABS(35) + SCR(35) Safford 1959- 698.3 (0.3%) **Id=68**
- ABS(35) + SCR(35) Simpson 1960- 690 (1.4%) **Id=66**
- ABS(35) + SCR(35) Antonov 1986- 695 (2.4%)
- ABS(35) + SCR(35) Guerasimov 1962 687 (1.2%)
- ABS(35) + SCR(35) Saplakoglu 1961- 694.2 (0.7%) **Id=70**
- ABS(35) + SCR(35) PALEVSKY 1954- 700 (0.7%) **Id=64**

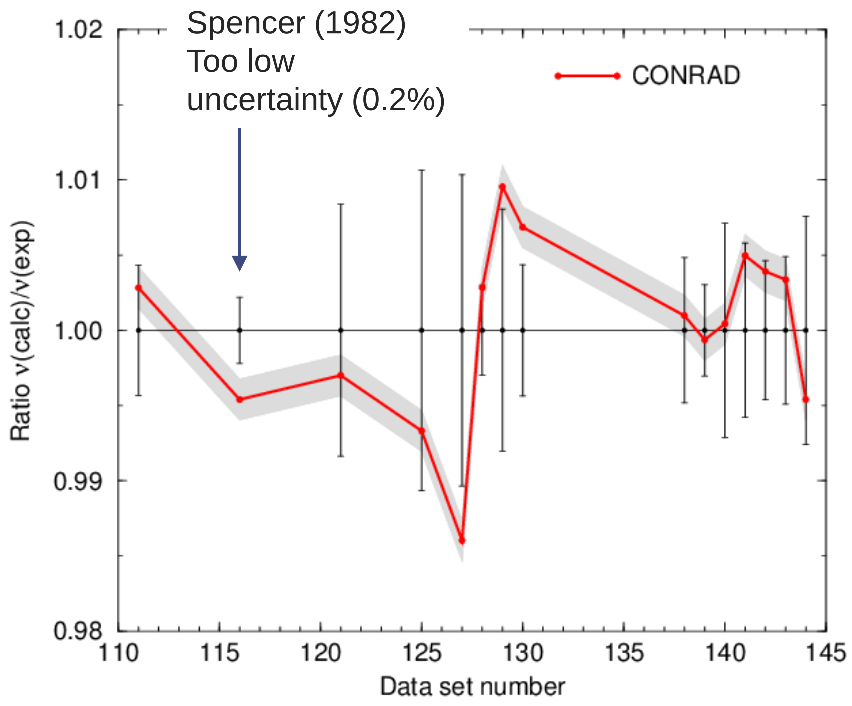
- ABS(39) + SCR(39) Anderson 1945- 1045 (2.4%)
- ABS(39) + SCR(39) Havens 1954- 1067 (1.9%)
- ABS(39) + SCR(39) Palevsky 1955- 1034 (1%) update
- ABS(39) + SCR(39) Leonard 1956- 1055 (1.3%)
- ABS(39) + SCR(39) Bollinger 1958- 1030 (1.0%) update **Id=74**
- ABS(39) + SCR(39) Stoughton & Halperin 1959- 1030(3.9%)
- ABS(39) + SCR(39) Spencer 1987- 1025 (0.6%)

Review υ_t(Cf252)

⇒ 15 experimental values are reported in the Axton's report with uncertainties ranging from 0,2% to 1,1%

GLS and weighted mean value are in good agreement

Analysis		Results
Mean value	weighted	**3,765±0,004 (0,11%)**
	unweighted	3,765
	standard deviation	±0,02 (**0.5%**)
CONRAD (2017)	GLS	**3,765±0,004 (0,11%)**
	GLS+AGS	3,766±0,005 (0,13%)
	GLS+Marg	**3,766±0,007 (0,18%)**
Axton (1986)		**3,764±0,005 (0,13%)**



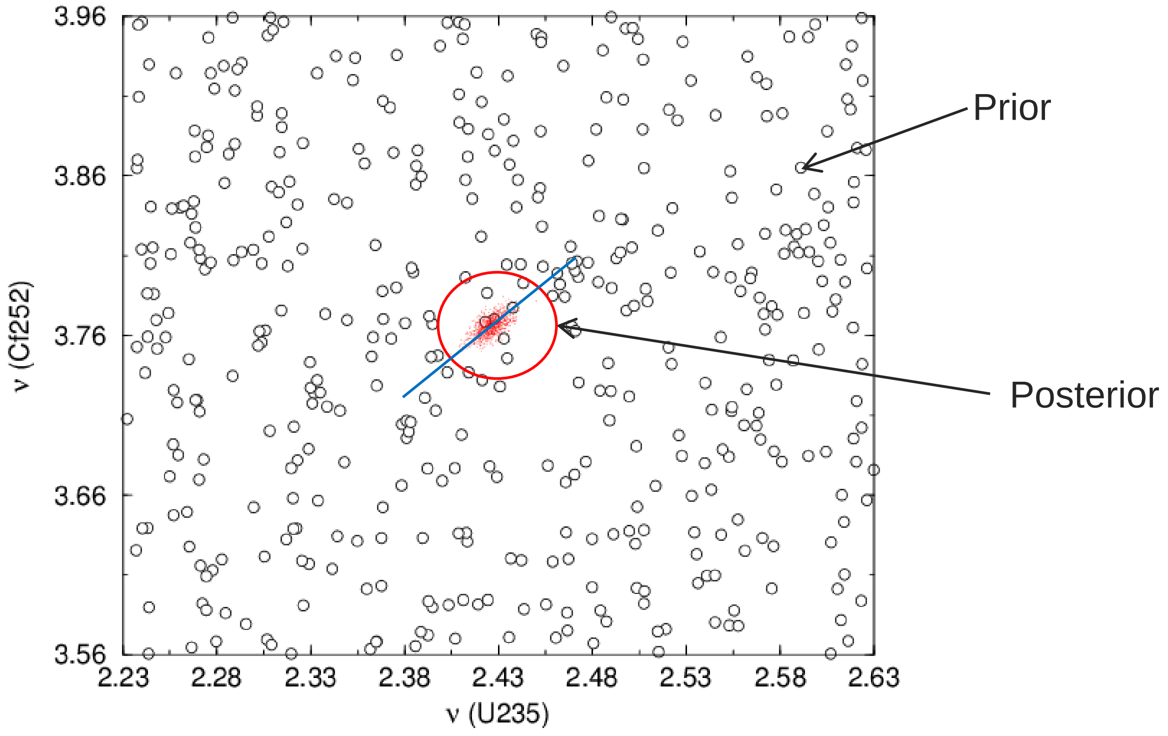
Final υ_t(Cf252) uncertainty is underestimated regardless of the adjustment strategy

⇒ increase uncertainty to **±0.4%** (STD 2018)

Review υ_t(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

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



Neutron multiplicities are strongly correlated, therefore an uncertainty of ±0.4% on υ_t(Cf252) will implies uncertainties on υ_t(U235) close to ±0.5% ⇒ too high uncertainty for U235 which is <u>not confirmed by extensive integral validation studies.</u>

Meetings organized by Denise Neudecker in 2025 to revisit the uncertainties of the 15 experimental values used in the fitting procedure ⇒ 5 measurements (scintillator) were reviewed

Review υ_t(Cf252)

3 main sources of correlated uncertainties in the Axton report

	Boldeman (1977)	Spencer (1982)	Hopkins (1963)	Asplund (1963)	Zhang (1981)
Total uncertainty	0,431 use 0,5xx ?	0,221 use 0,3xx ?	0,838	1,066	0,49 seems Ok
Correlated unc.	0,139 use 0,2xx ?	0,121 use 0,2xx ?	0,161 use 0,3 ?	0,204 use 0,4 ?	0,149 use 0,2xx ?
Uncorrelated unc.	0,408 use 0,48x ?	0,185 use 0,30x ?	0,821 use 1.xxx ?	1,046 use 1,216	0,467 use 0.5xx ?
F: Mn-Bath (NPL)					
G: Mn-Bath 1+sig(S)/sig(Mn)					
L : Cf252 PFNS	0,056 Ok ?	0,019 use 0,08 ?	0,03 use 0,12	0,077 use 0,220	0,077 seems Ok
M: Detector slope (other authors)		0,007	0,018	0,003	0,010
O: Detector slope (Gwin)		0,022			
P: Detector slope (Hopkins)			0,058		
Q: Detector slope (Asplund)				0,010	
Y: Cf252 delayed neutrons	0,106 x 2	0,106 x 2	0,106 x2	0,106 x 2	0,106 x 2
Z: Cf252 delayed gammas	0,07 use 0.1 ?	0,051 not well known	0,1 use 0,2	0,201	0,07 Ok ?
B: Spiegel/Bozorgmanesh unc.					
C: Common unc. (Boldeman)	0,010				
E: B uncertainty					
F: Smith/Aleksandrov unc.					
G: Eta/nubar (Smith)					
Y: NRU Westcott r unc.					
Impurities cor. (use 0.1 !)	unknow		0,1	0,100	
Neutron leakage (use 0.x ?)				0,6 too high	

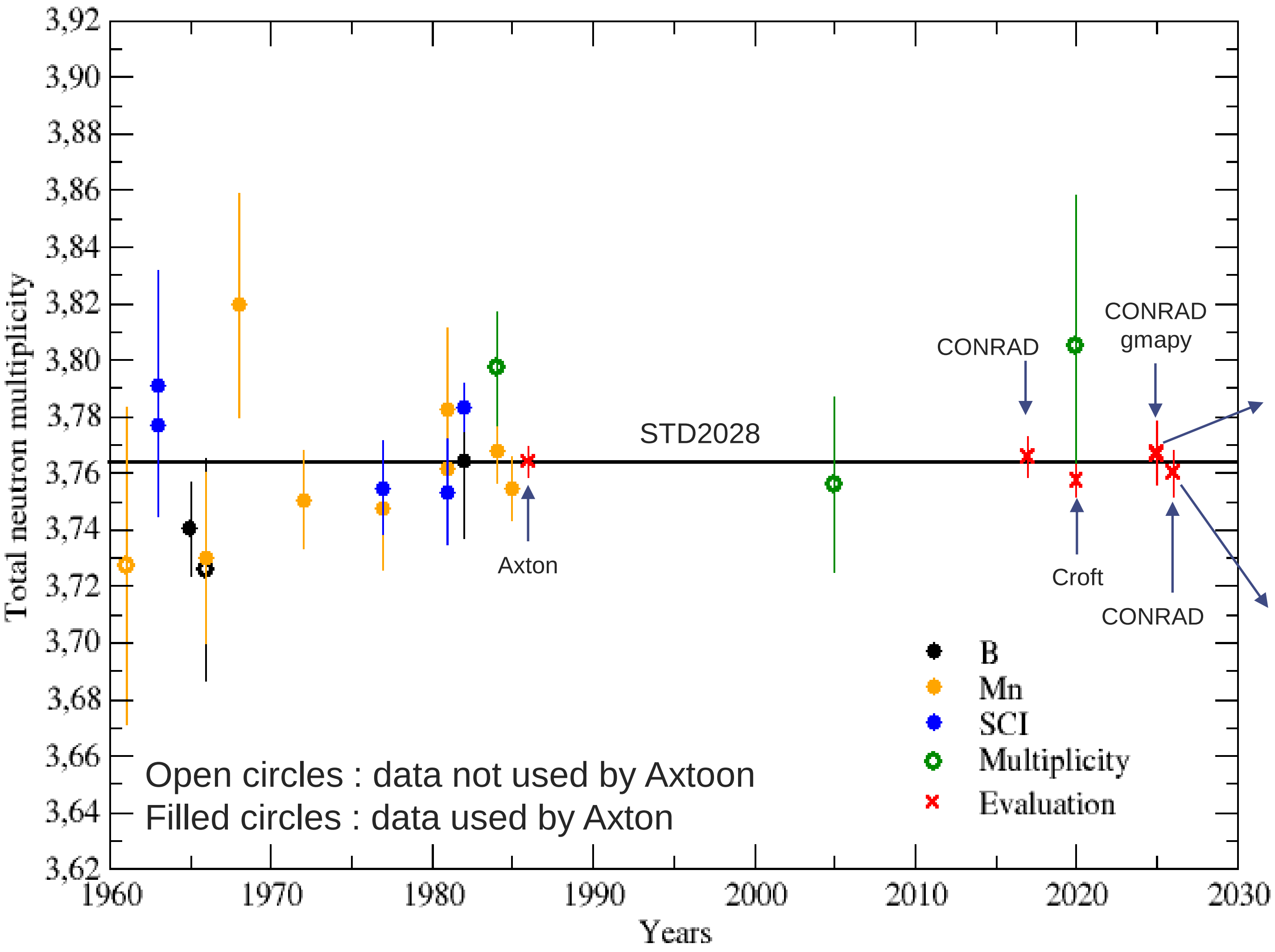
New sources of correlated uncertainties proposed by Denis Neudecker

Review υ_t(Cf252)

List of uncorrelated source of uncertainties ⇒ **impose a minimum value of ±0.4% or ± 0.5% ?**

	Boldeman (1977)	Spencer (1982)	Hopkins (1963)	Asplund (1963)	Zhang (1981)
Total uncertainty	0,431 use 0,5xx ?	0,221 use 0,3xx ?	0,838	1,066	0,49 seems Ok
Correlated unc.	0,139 use 0,2xx ?	0,121 use 0,2xx ?	0,161 use 0,3 ?	0,204 use 0,4 ?	0,149 use 0,2xx ?
Uncorrelated unc.	0,408 use 0,48x ?	0,185 use 0,30x ?	0,821 use 1.xxx ?	1,046 use 1,216	0,467 use 0.5xx ?
Measurement type	prompt nubar	prompt nubar	**prompt nubar !!!!**	prompt nubar	prompt nubar
Gd concentration	0.4% negligible unc.	0.22% negligible unc.			
→ Irradiation Time	40 mic-s quite short	80 mic-s nearly Ok	64 mic-s nearly Ok	30 mic-s short	30 mic-s short
Time veto	585 ns long enought			160 ns	
T(p,n) and T(d,n) neutron source	no impact				
Statistical unc.	0,240	0,170	0,53	0,15 use 0,4	0,150
Energy calibration	0,170	0,020		0,750	
French effect	0,100	0,050	0,1	0,300	0,200
Hole through sintillator	0,200			0,300	
Bkg in proton recoil detector	0,10 - 0,30			0,200	
Variation neutron capture detector	0,10 too low ?			0,200	
Detector response		0,130			
Dead time	0,1 too low ?	0,050	0,6 is huge	0,300	
Off center location		0,050			
False fission		0,080			0,0 ?
Multiple scattering		0,200			0,100
Detector efficiency		0,150	86%	0,200	0,388
Sample uncertainty		negligible			
Anthracene crystal				Pb anisotropie !	
Pulse pile up					0,100
Angular distribution					0,260 large ?
Crystal end effect					0,008
Scattering by Carbon					0,080

Review υ_t(Cf252)



2025 ⇒ **±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 ⇒ **±0.2%** by updating correlated and uncorrelated sources of uncertainties

Conclusions

- Final verification of the proposed modifications (GMA and TNC database)
- Verification TNC results provided by gmapy with CONRAD
- Extract I1 and I3 from Ignacio Duran ratios using TNC/GMA results
- Continue υ_t(Cf252) review work
- Provide H1(n,g) will be usefull
- Provide delayed neutron multiplicities from CRP to deduce prompt neutron multiplicities