Status of the ^{243}Am neutron capture data

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CIEMAT

I. Status of the capture data data (1/)

Transmission

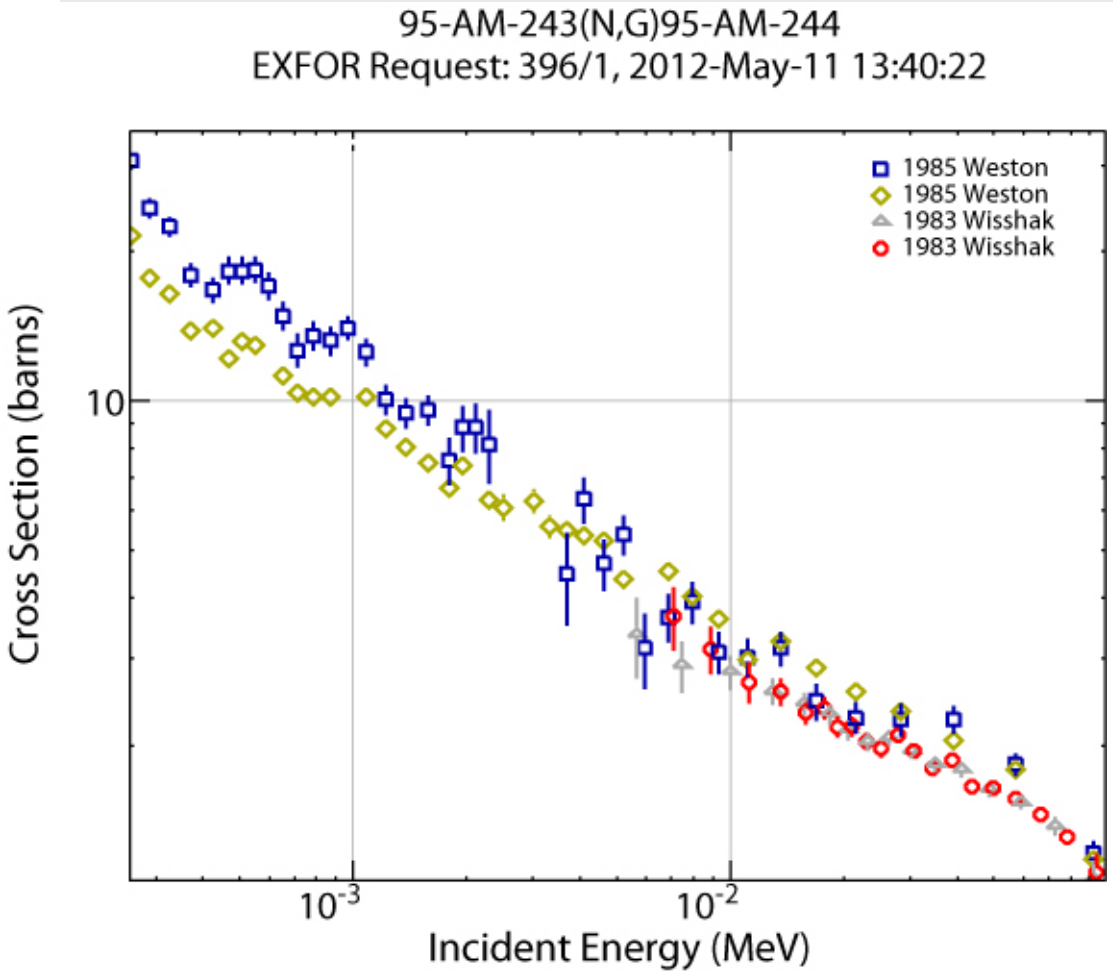
T.S.Bellanova et al.,	1976,	0.35 eV - 35 eV
(ORELA) O.D.Simpson et al.,	1974,	0.5 eV - 1 keV
J.R.Berreth et al.,	1970,	0.008 eV - 25.6 eV
R.E.Cote et al.,	1959,	0.0014 eV - 15.44 eV

Capture

K. Wisshak et al.,	1983,	5 keV – 250 keV
L.W.Weston et al.,	1985,	258 eV – 92.1 keV
M. Jandel et al. (DANCE),	2009,	~90 eV – 220 keV
J. Hori et al. (KURRI),	2009,	0.01 eV – 400 eV
E. Mendoza et al. (n_TOF),	2011,	~5 eV – 2 keV

Fission has been neglected at this stage...

(n,γ) data in EXFOR



No resonance parameters from any of the 2 data sets.

1983 Wisshak et al. (128 mg AmO_2/AmO_3 9ellet, 99.82% pure, in Al). Photproduction LINAC.

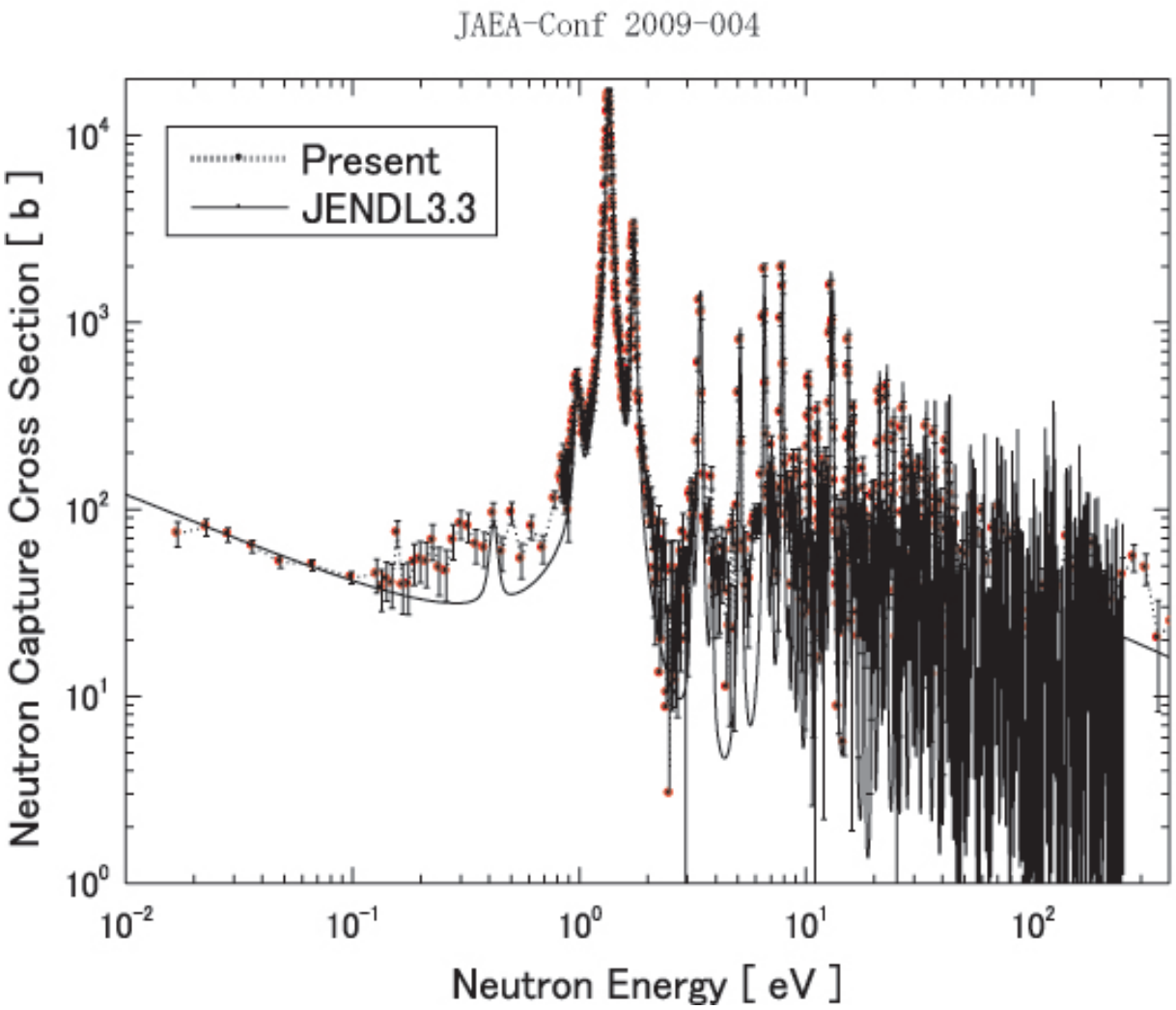
Moxon-Rae for (n,γ)+ liquid scintillator for (n,f): different flight paths and Moxon-Rae converters.
Uncertainty (relative to ^{197}Au) < 5%

1985 Weston et al. (0.2 g of AmO_2 99.99% purity, in stainless steel). VdG Li(p,n) source. C_6F_6 total energy detectors. Two data sets:
1. Low repetition down to thermal E. Normalisation equivalent to 74.8 b at 0.0253 eV.
2. High repetition. Normalised to the thermal data set between 4 – 40 keV.
Unexplained poor agreement between them below 1 keV (up to 30 – 40 % discrepancy)

2.4% (normalisation thermal) + 2% (statistical) + 5% fast (keV) relative to thermal = 6% total

Weston is about 8% above Wisshak.

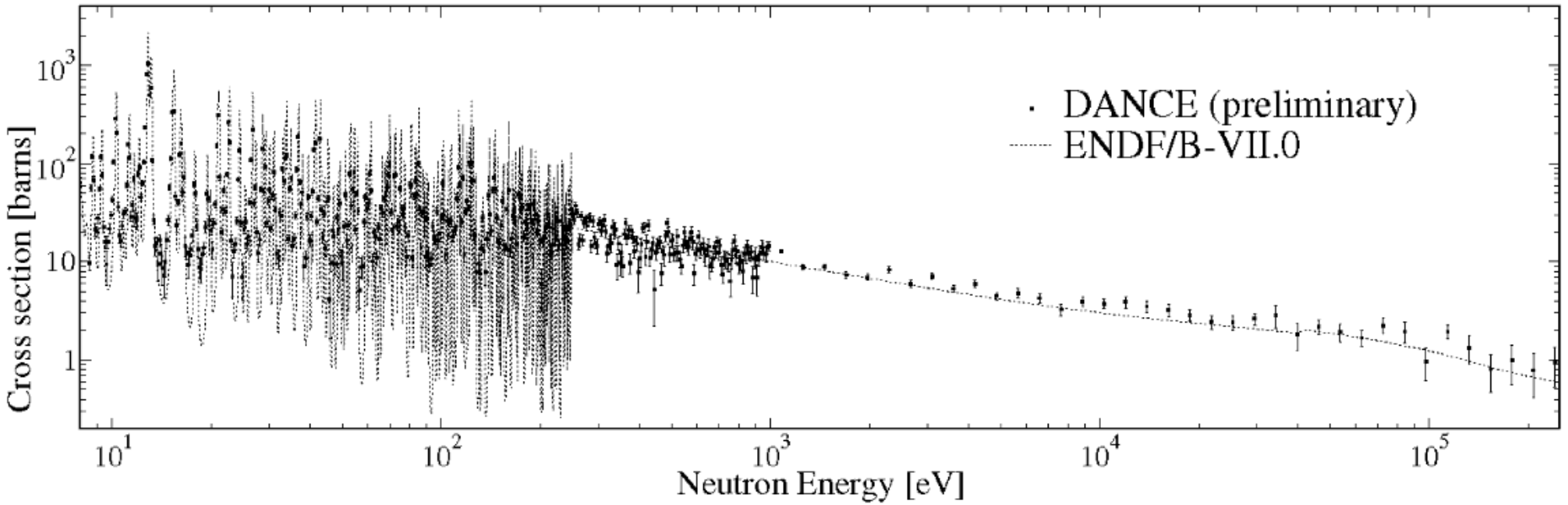
(n,γ) data from KURRI



2009 Hori et al. (128 mg of AmO_2 in Al). Photoproduction LINAC.
High efficiency Ge spectrometer.
0.1 eV – 400 eV
Normalisation equivalent to 74.8 b at 0.0253 eV (JENDL 3.3 value).
Resonance integral I_0: 1969+-111 b

Not yet in EXFOR

(n,γ) data from LANSCE



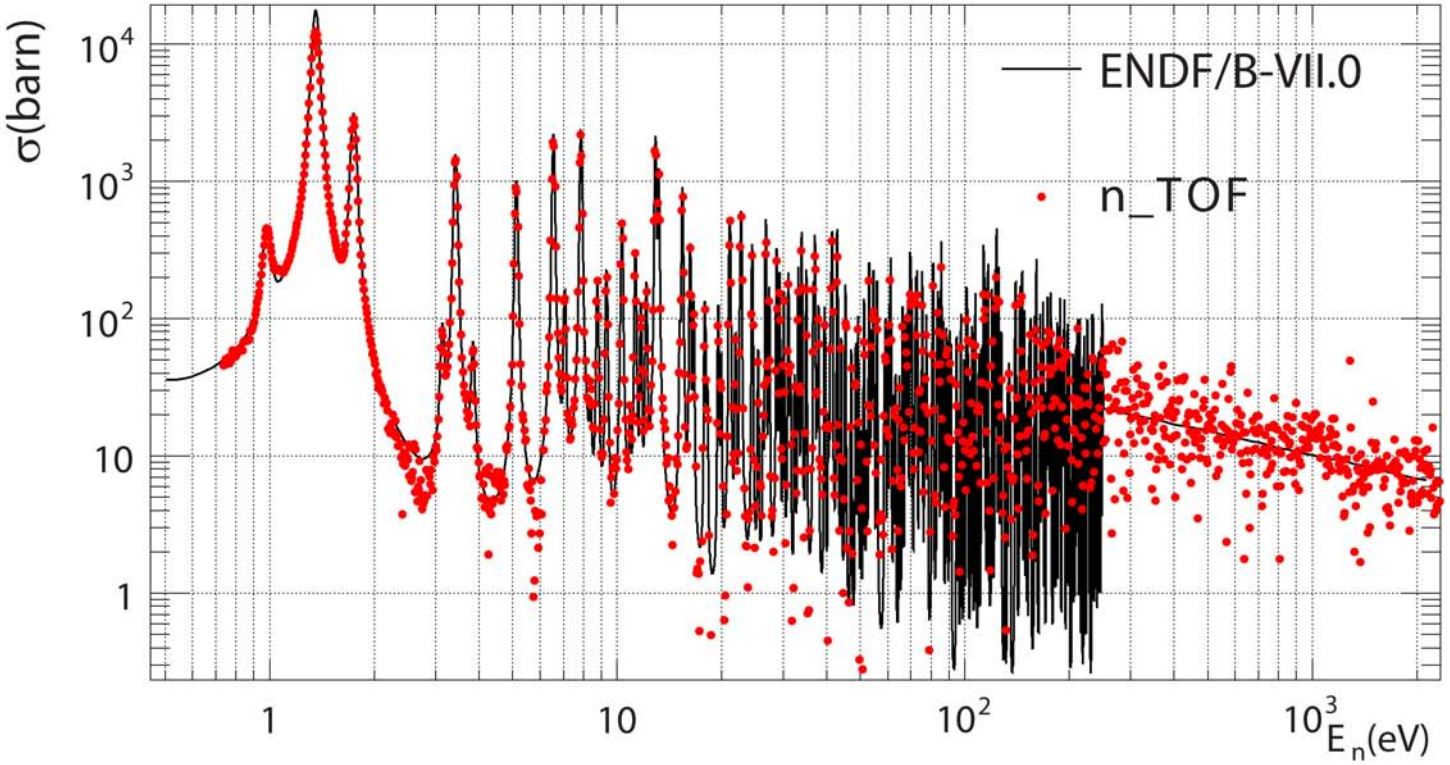
2009 Jandel et al. (267 μg of AmO_2 in Al). Spallation.
Total absorption calorimeter BaF2.
8 eV – 220 keV
Normalisation equivalent to ENDFB/VII.0 in the region between 250 and 400 eV.

Not yet in EXFOR

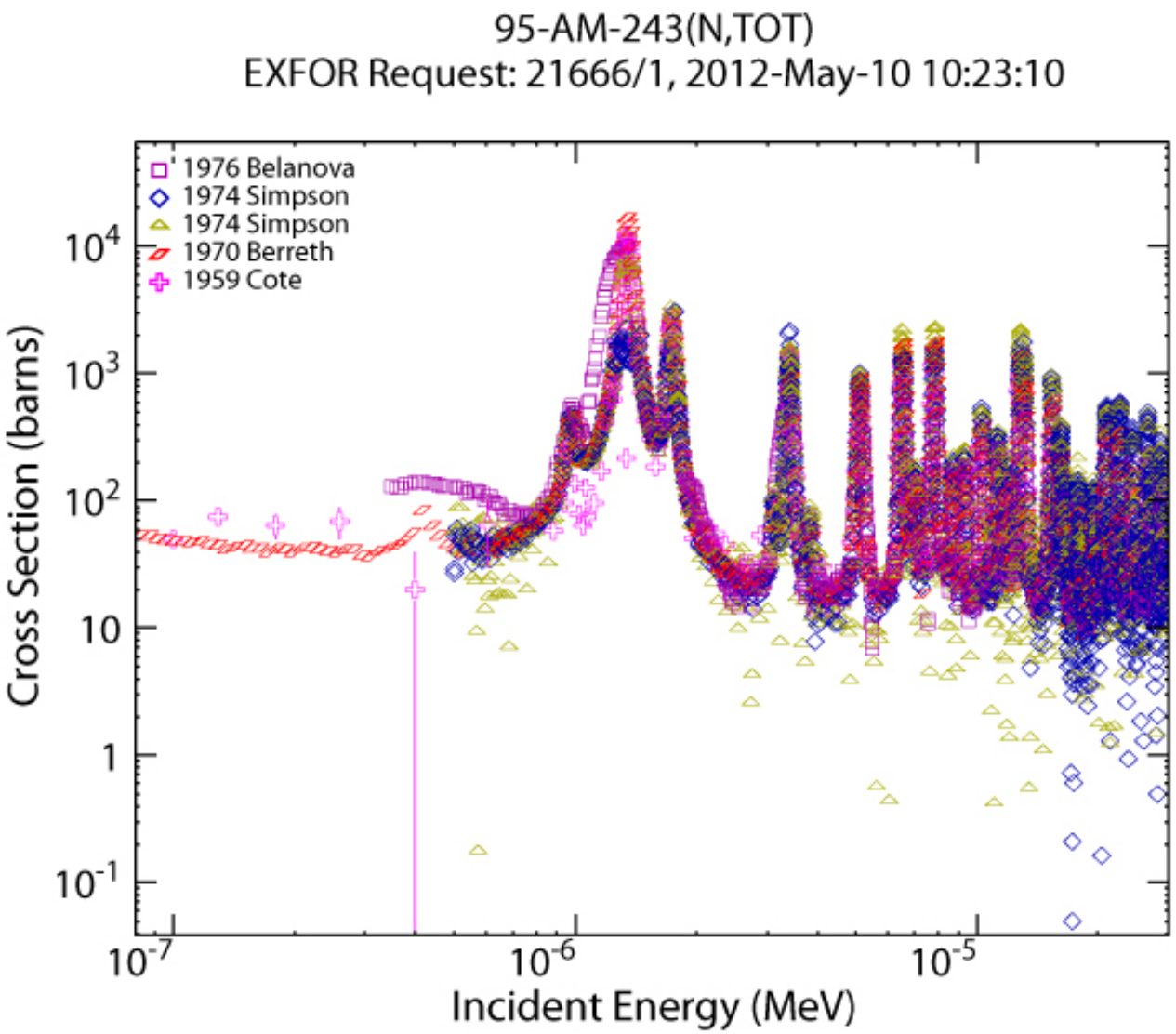
2012 Mendoza et al. (~6 mg of ^{243}Am / 10 mg reported by manufacturer, 99.2% ^{243}Am, 0.77% ^{241}Am, 0.04% ^{240}Pu, encapsulated in Ti). Spallation.
Total absorption calorimeter BaF_2. 185 m long flight path **EXCELLENT resolving power**

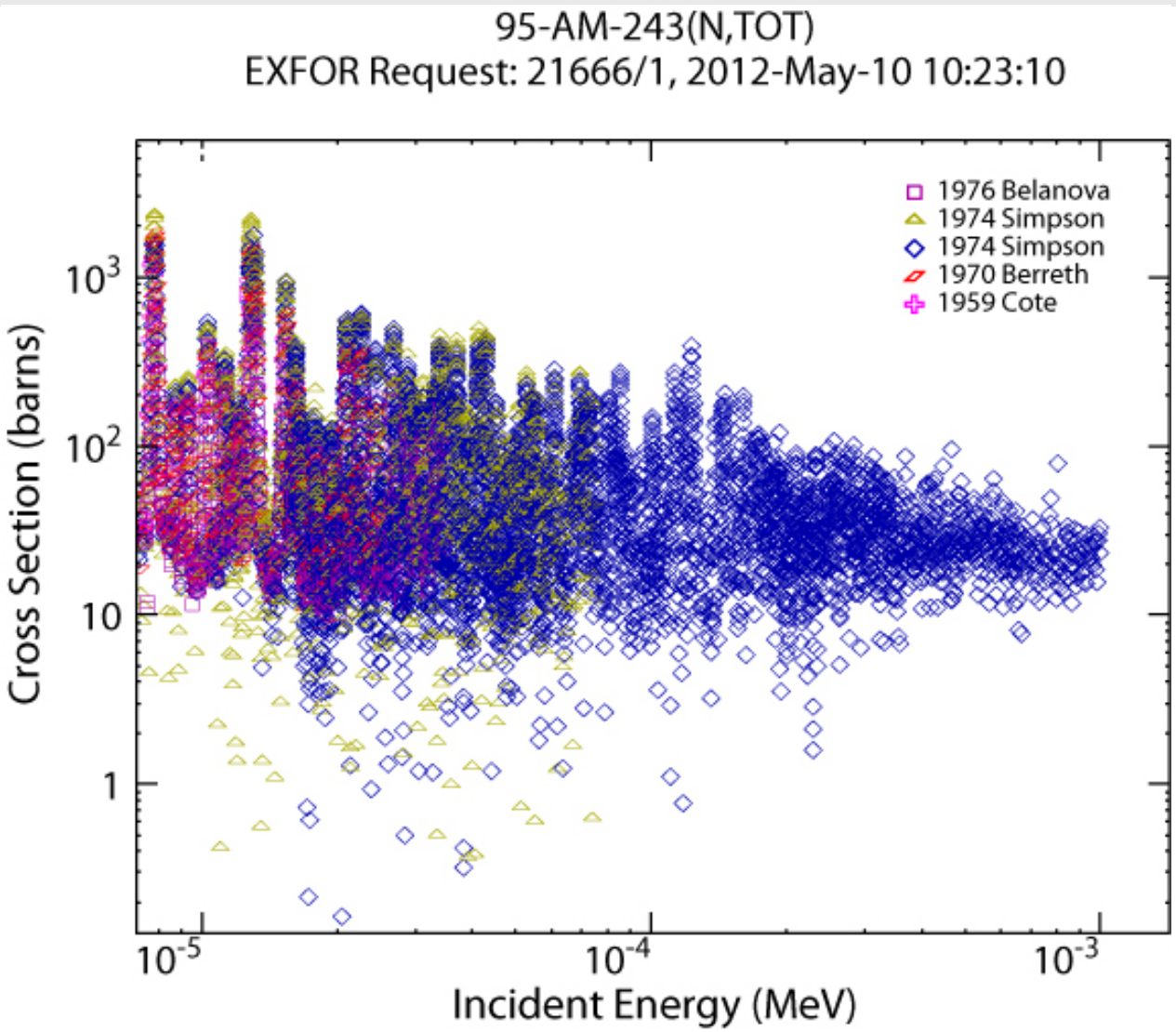
6 eV < En < 2 keV
Target in-homogeneities are very likely: no accurate resonance analysis below 6 eV

Various normalisations applied in the 3 eV – 50 eV range: to transmission data by Simpson et al (thin and thick samples), to ENDFB/VII.1, ENDFB/VII.0, JENDL-4.0, JEFF3.1, RP by Simpson, Berreth...



(n,tot) data in EXFOR




95-AM-243(N,TOT)
EXFOR Request: 21666/1, 2012-May-10 10:23:10
1976 Belanova
1974 Simpson
1974 Simpson
1970 Berreth
1959 Cote
Cross Section (barns)
10^3
10^2
10
1
10^-5
10^-4
10^-3
Incident Energy (MeV)

1974 Simpson et al.

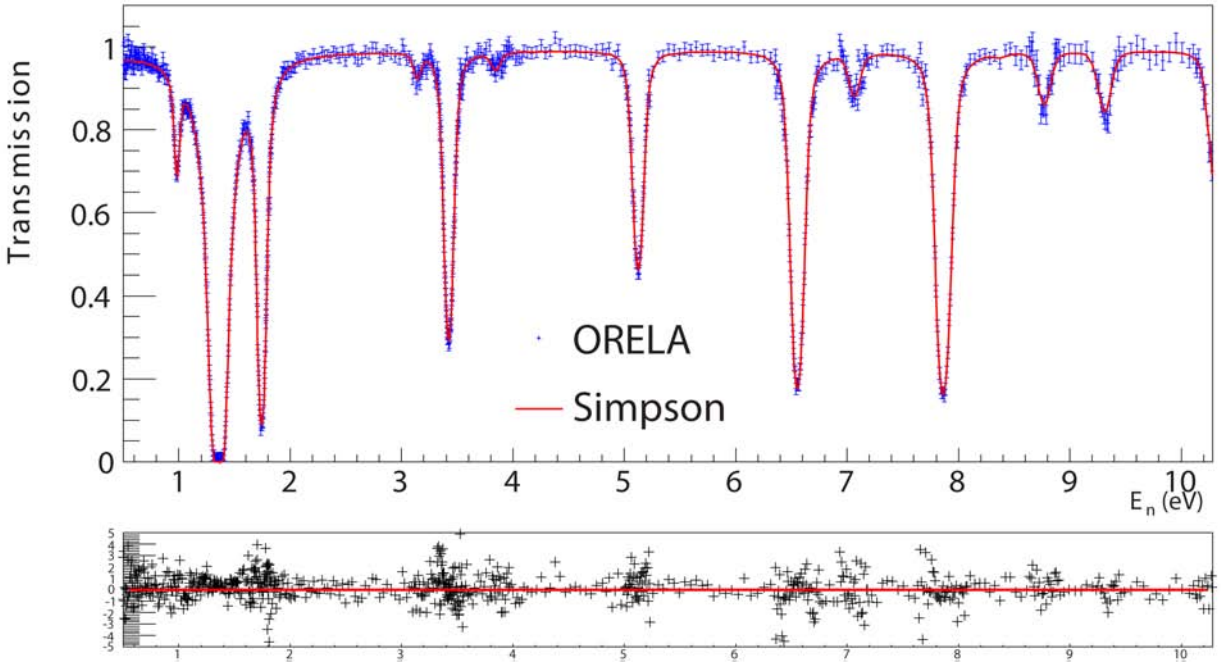
Main source for the resolved resonance region.

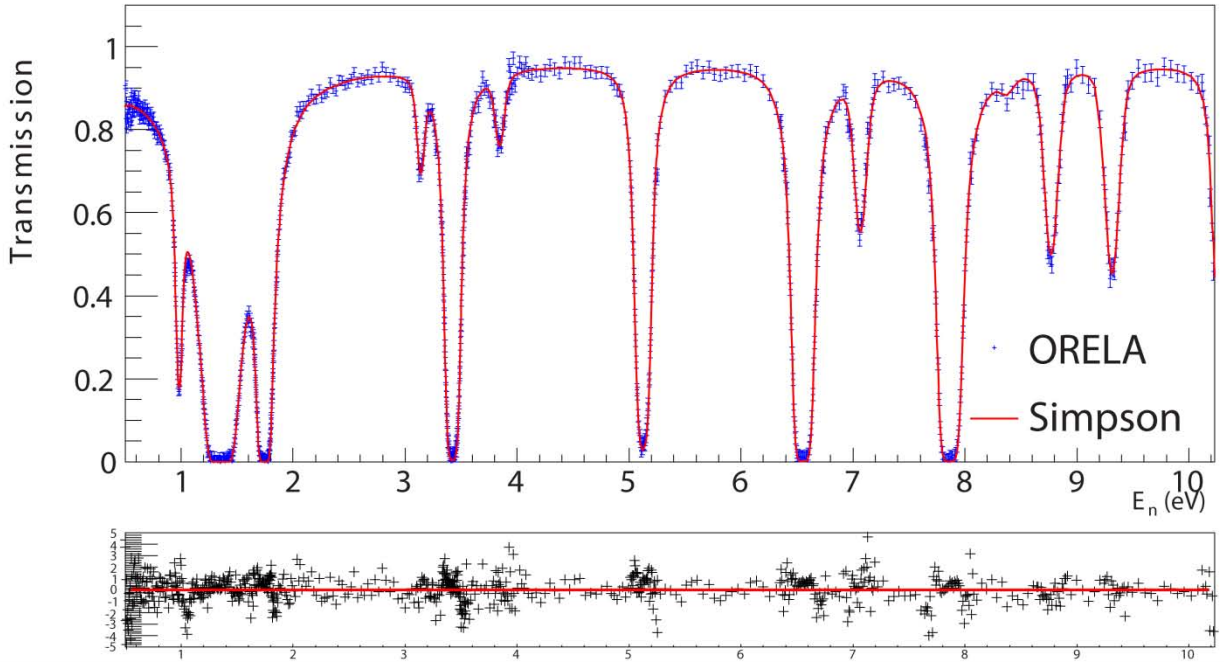
Two AmO_2 samples: 279.3 b/atom and 1288.2 b/atom.

Two sets of resonance parameters:
Shape analysis E_n < 20 eV (compared to the previous measurements of Berreth et al. 1970)
Area analysis 20 eV < E_n < 250 eV

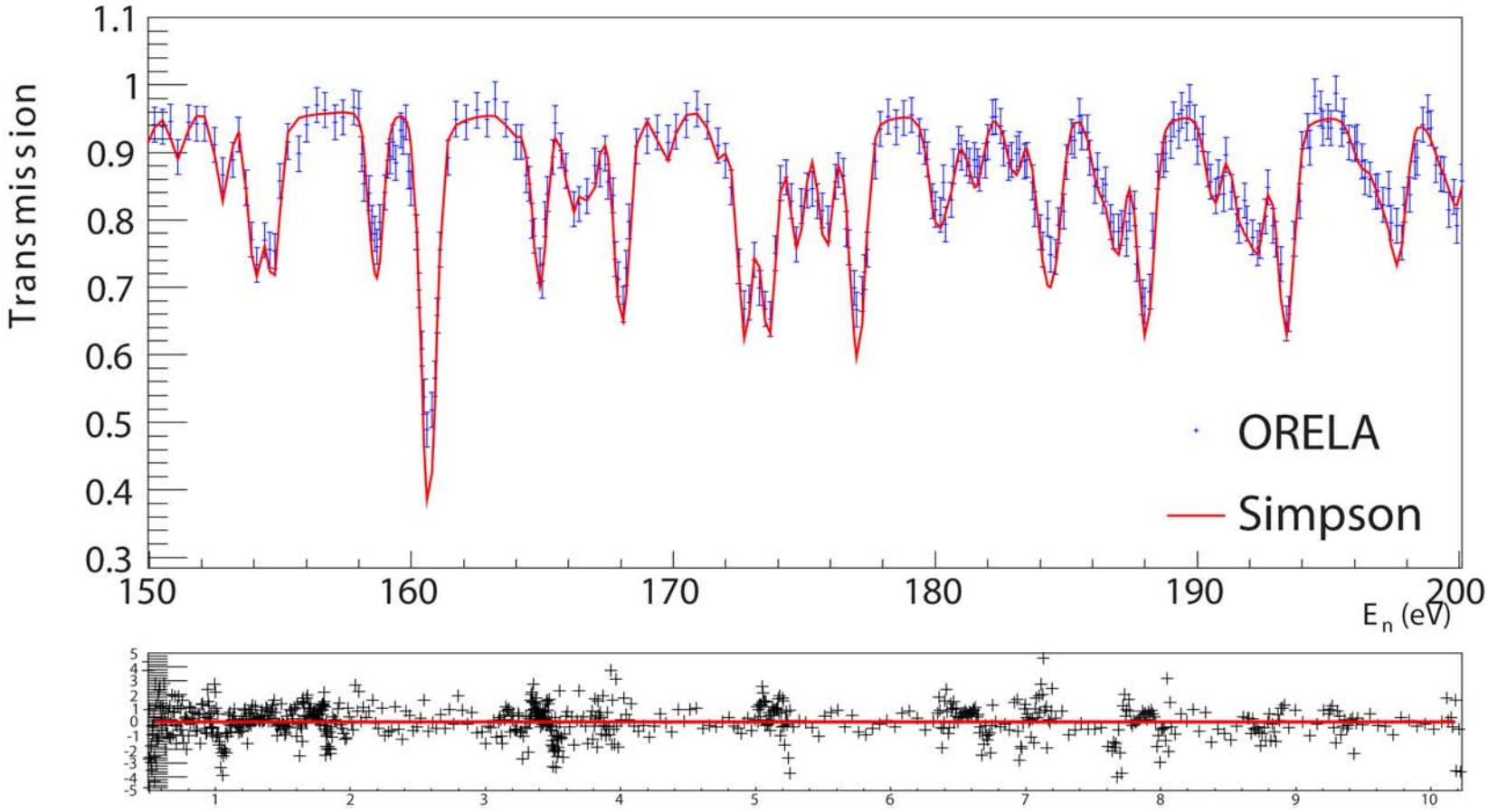
The Nucl. Sci. Eng. 55,273-279 (1974) paper refers to ANCR-1060 Aerojet Nuclear Company (1972) report for details. The reference has not been found!

Two sets of time of flight data exist in EXFOR (thick and thin sample). Poor information on the resolution function (described insufficiently). No information on the uncertainties in the TOF data.





GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD


Transmission
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
150
160
170
180
190
200
E n (eV)
ORELA
Simpson
1
2
3
4
5
6
7
8
9
10

II. Status of the different evaluations

ENDF/B-VII.0 (2006 P.G. Young, P. Talou - LANL)

It is based on the ENDF/B-VI evaluation by L.W. Weston (ORNL)

Thermal value of 74 b based on Mughaghab.

Resolved resonance region (0-250 eV)
219 resonances + 1 bound level based on Simpson et al.

Unresolved resonance region URR (250 eV – 42 keV)
Parameters based on Froehner et al. (ANTW1982) and Weston, Todd (NSE 1985)

ENDF/B-VII.1 (2006 P.G. Young, P. Talou - LANL)

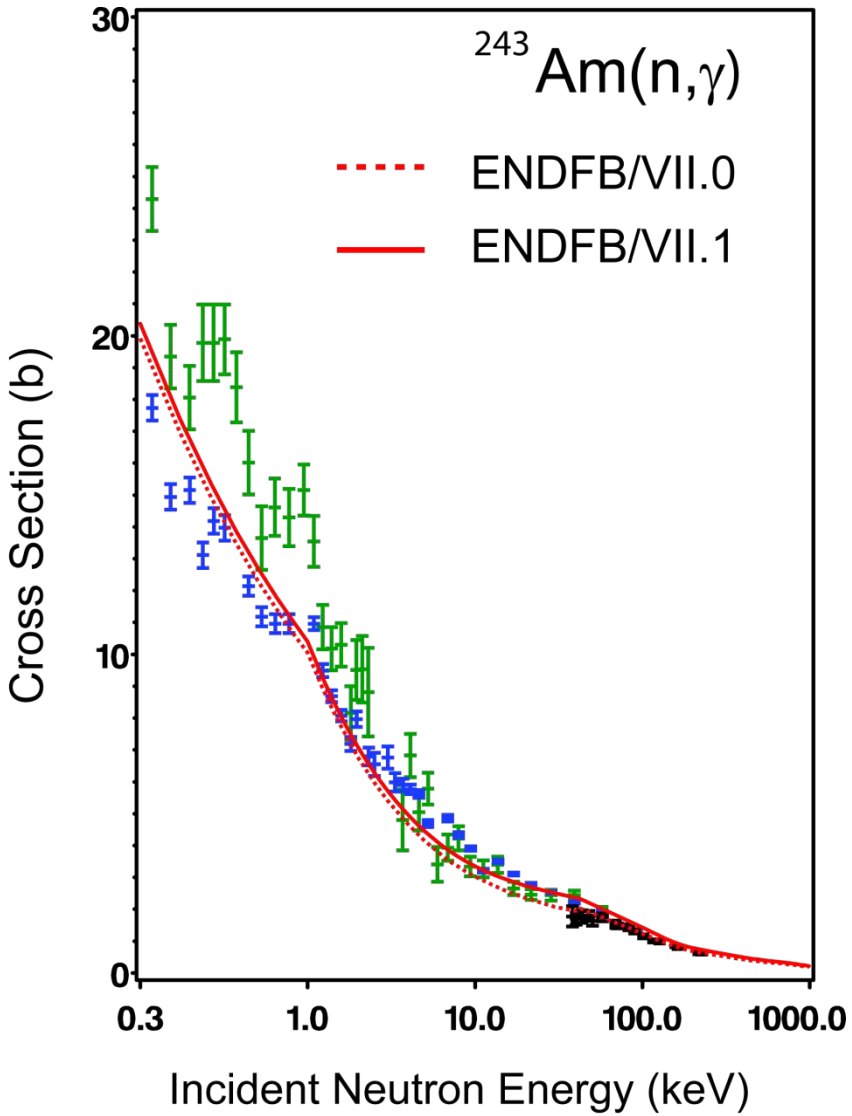
New evaluation in the thermal, resonance and URR, based on the Palmiotti and Hiruta calculations (unpublished), which reveal a 16.6% discrepancy between measured and computed capture reaction rates with ENDFB/VII.0.

Resonance parameters adopted from Mughabghab, slightly different from the ones reported by Simpson.

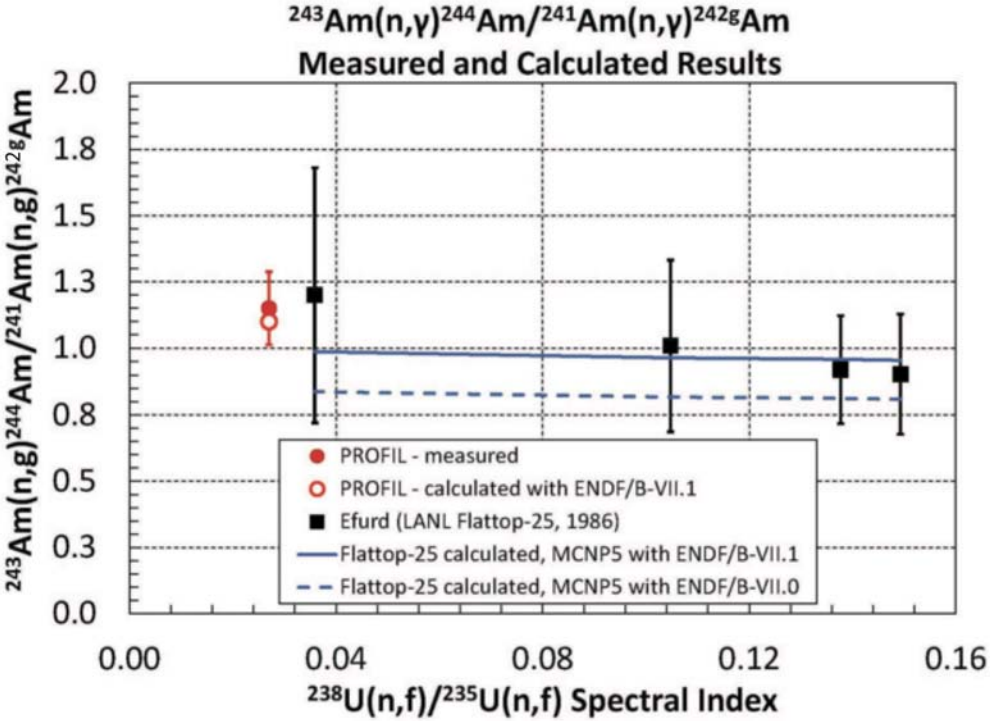
Capture data from Weston and Todd (2 discrepant data sets) were normalised to a σ_{th}**= 74.8 b** thermal cross section. The have been renormalized to a new σ_{th} **= 80.4 ±2.1** from the recent data by Marie et al. (81.8 ±3.6 b), Ohta et al. and the corrected data by Butler et al.

A least squares fit to the renormalized capture data (0.25 keV – 40 keV) was performed to determine s- and p-wave radiative widths.

Radiative widths	s-wave 39.1 ± 0.6 meV
	p-wave 68.8 ± 4.3 meV
Neutron Strength functions	s-wave S=0.98
	p-wave S=2.6
s-wave level spacing	D=0.66 eV



This shows an increase of 15.5% in the energy region between 30 and 40 keV, which "seems" to solve (unpublished) the discrepancy obtained by Palmiotti and Hiruta.



JENDL 3.3 (2002 V.M. Maslov – Minsk, T.Nakagawa – JAERI) [=JEFF3.12]

σ_{th}= 76.71 b from Maslov et al. (from Garvilov and Bak)

Resolved resonance region (0-250 eV)
Resonance parameters obtained from Simpson (transmission) and fission Seeger and Knitter.

Unresolved resonance region URR (250 eV – 42 keV)
Parameters based on Froehner et al. (ANTW1982) and Weston, Todd (NSE 1985)

Radiative widths	s-wave 43.1 meV
Neutron Strength function	s-wave S=0.834
s-wave level spacing	D=0.56 eV

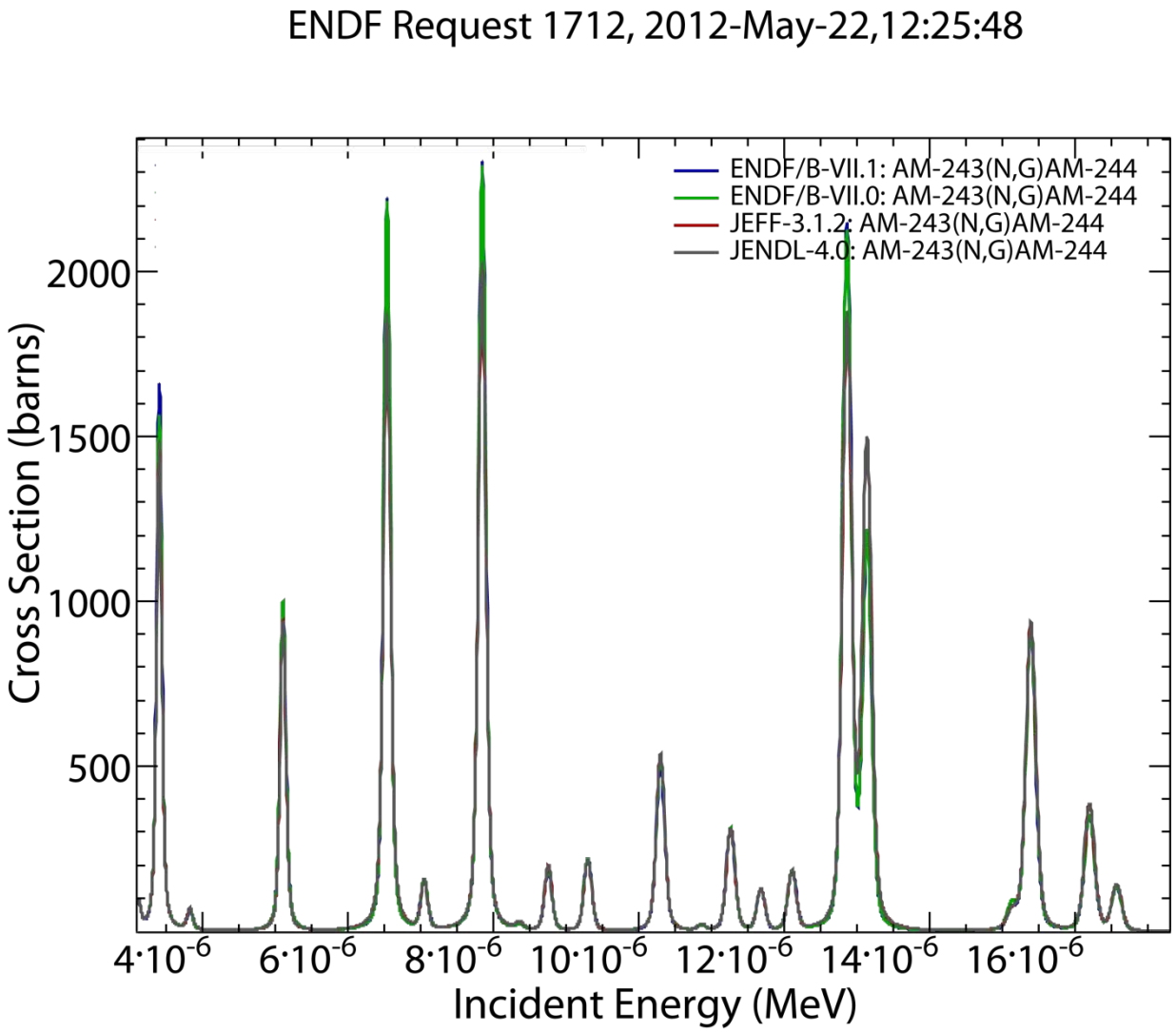
JENDL 4.0 (2010 O. Iwamoto, T. Nakagawa, T. Ohsawa JAERI)

σ_{th}= 79.259 b increased with respect to JENDL3.3 (referring to the measurement by Ohta et al.)

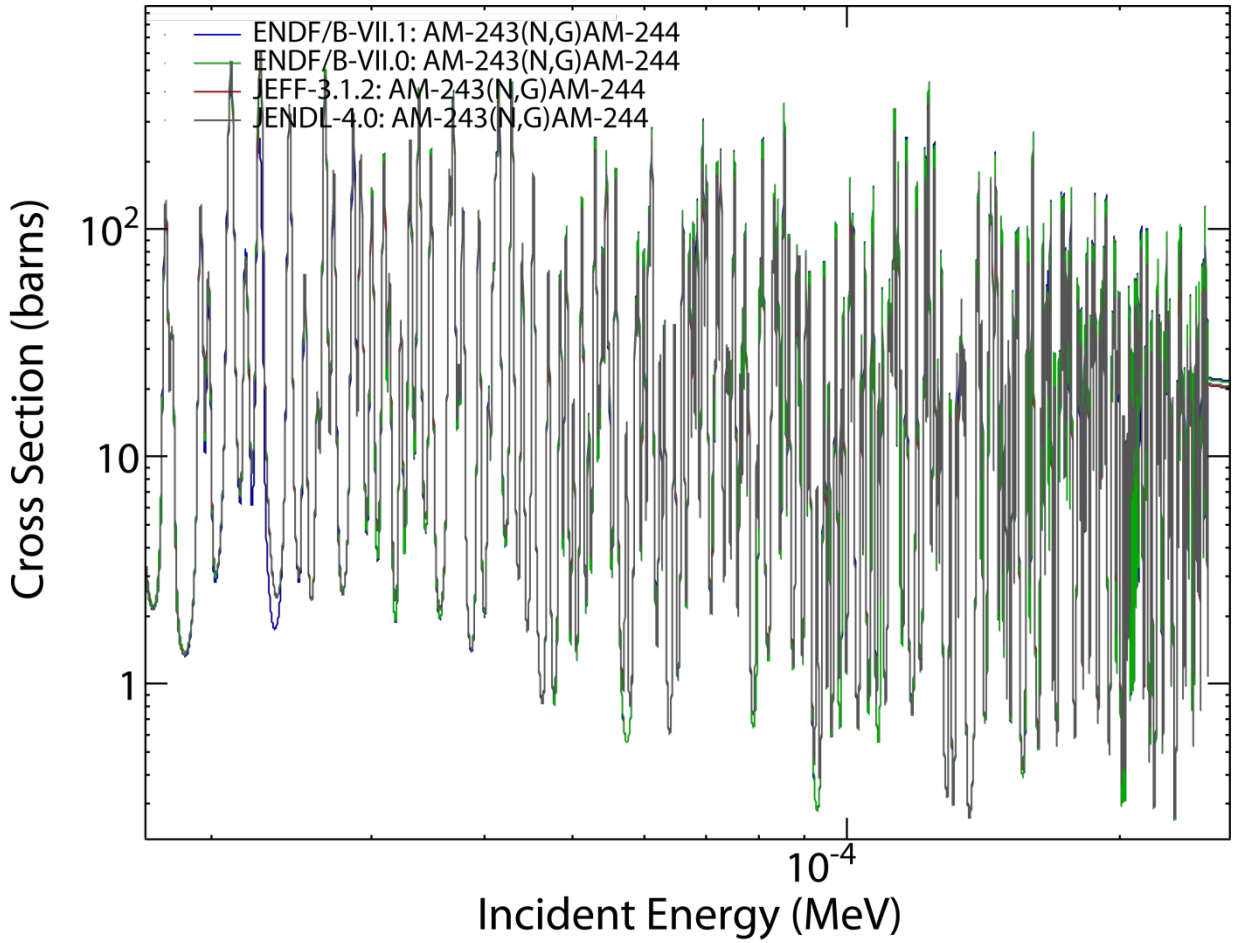
Resolved resonance region (0-250 eV)
Resonance parameters obtained from Simpson (transmission) and fission Seeger and Knitter evaluated by Maslov/Nakagawa). Resonance parameters below 1.744 eV modified for reproducing the resonance integral by Ohta et al (Very large Γ_γ for the 1.35 eV resonance).

Unresolved resonance region URR (250 eV – 40 keV)
Parameters calculated with ASREP code.

Resolved resonance region

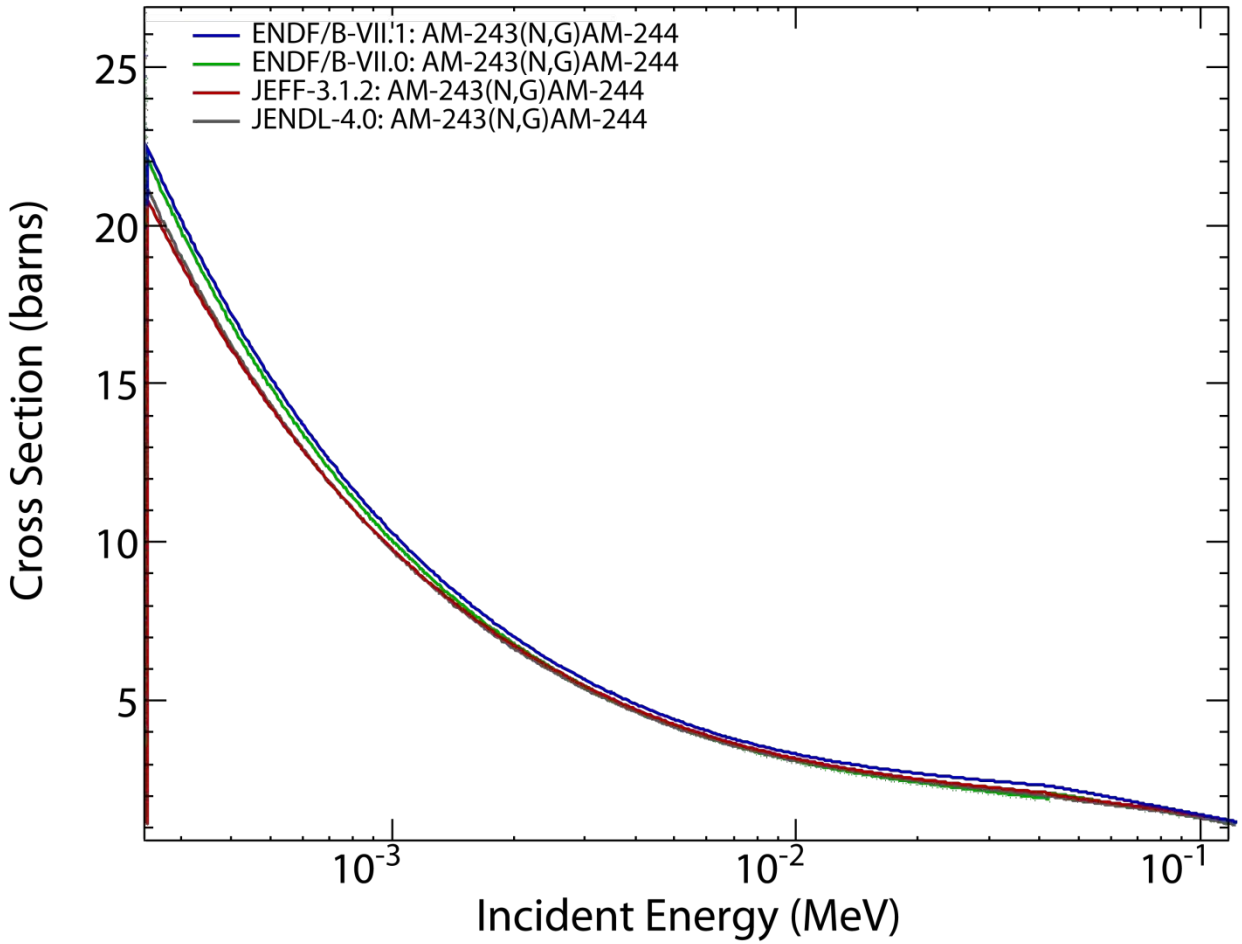


Resolved resonance region

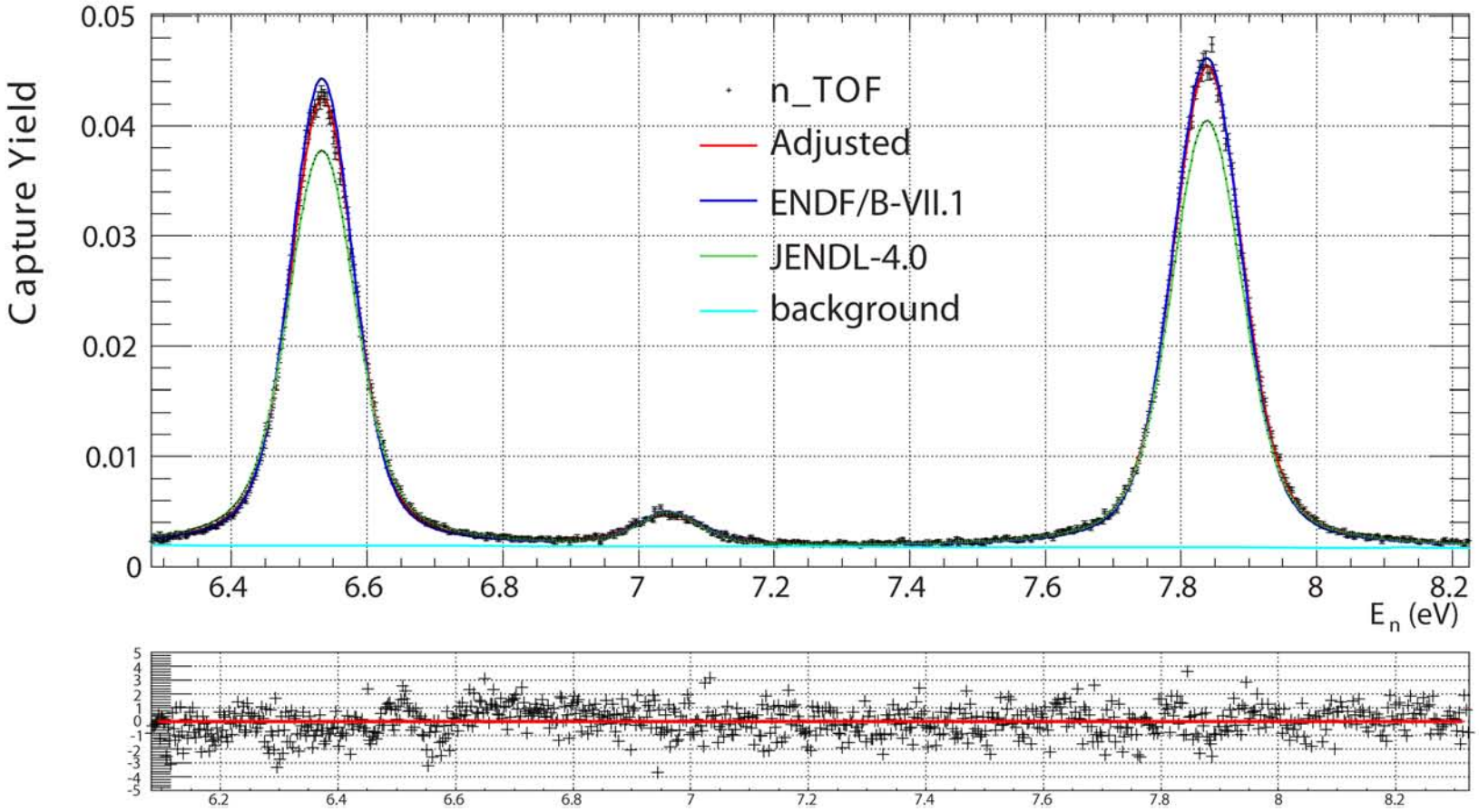


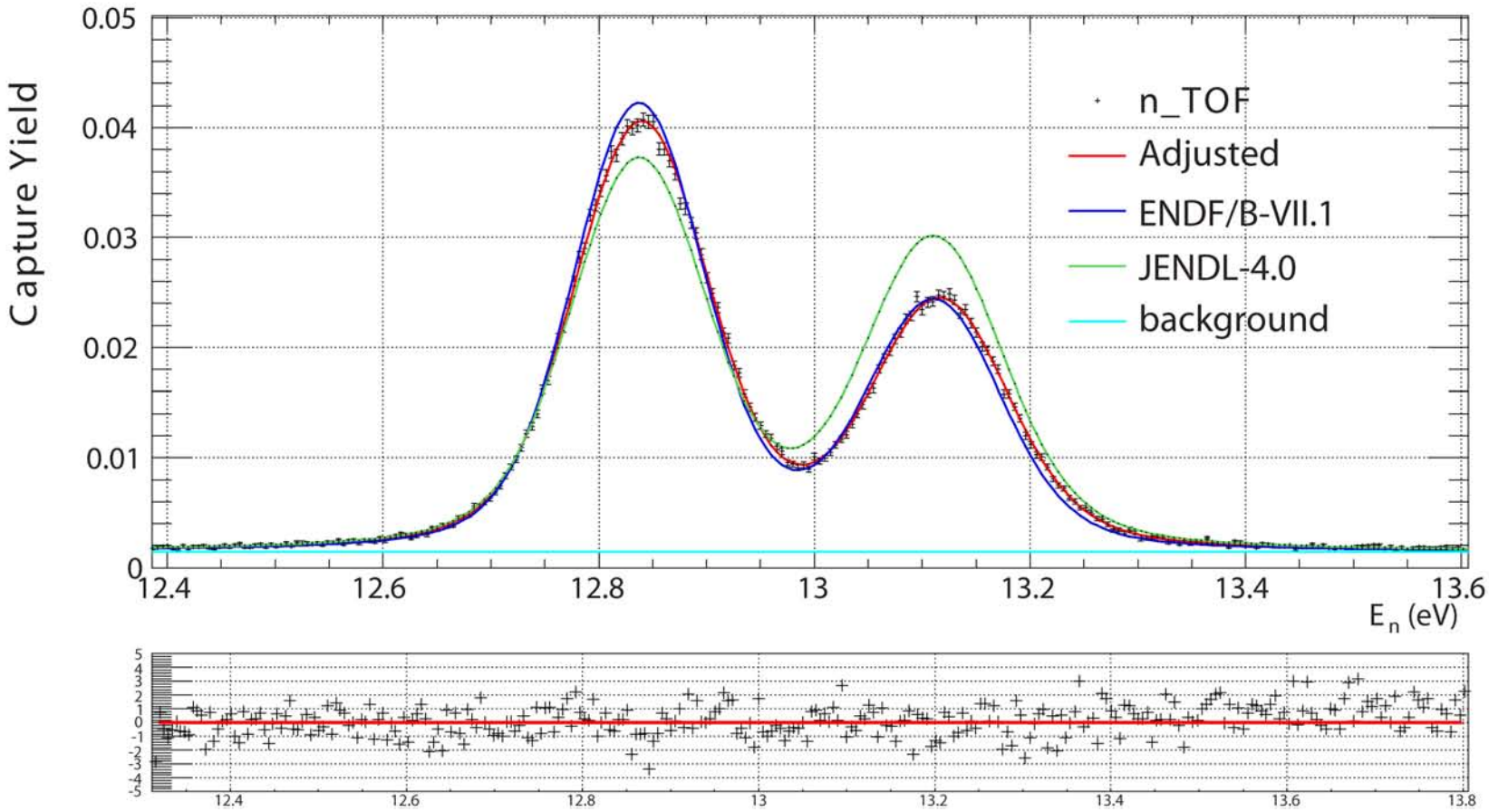
Differences are observed despite the availability of one singe data set (Simpson et al.) – Maslov/Nakagawa, Mughabghab, Simpson

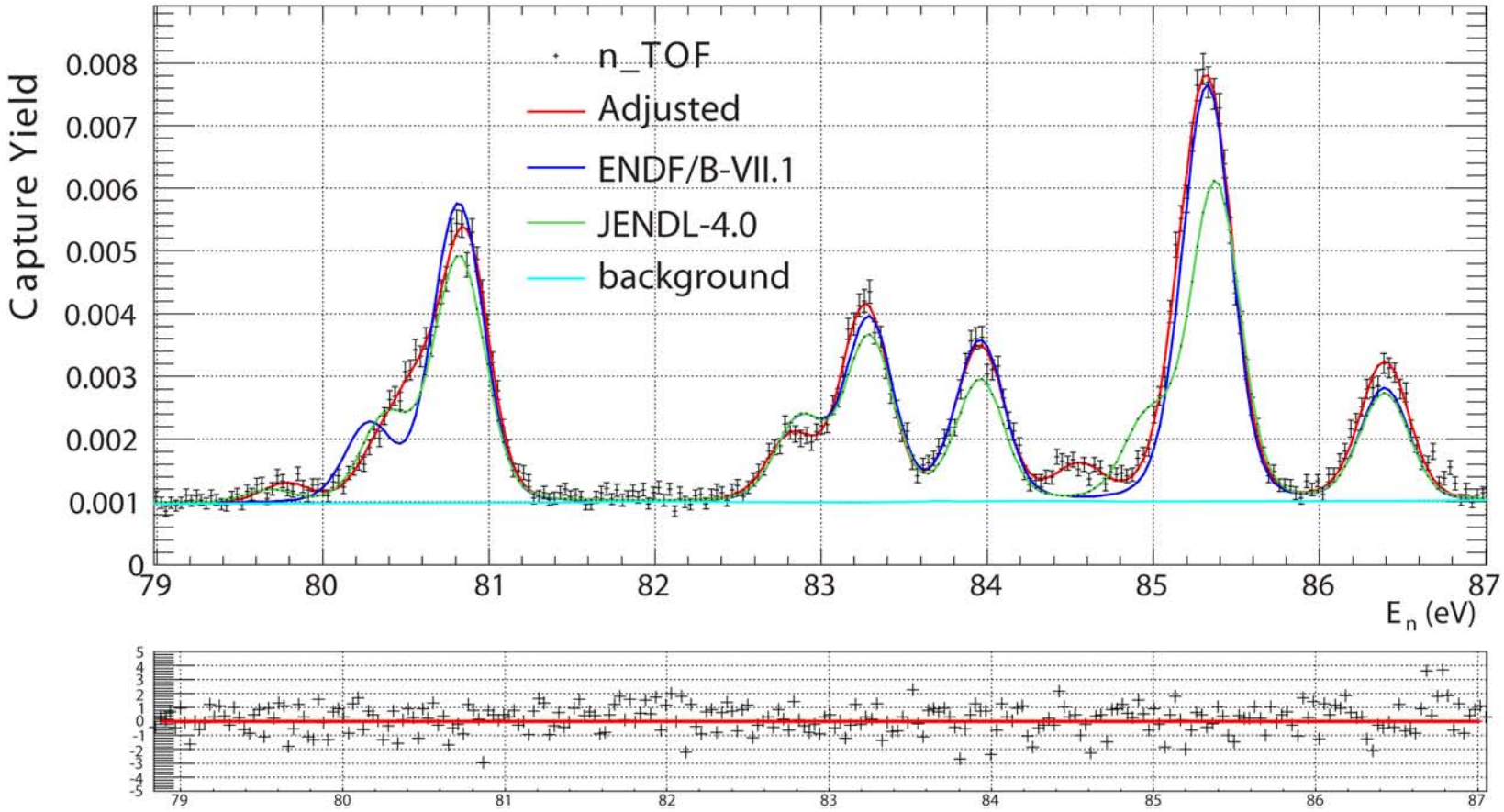
Unresolved resonance region

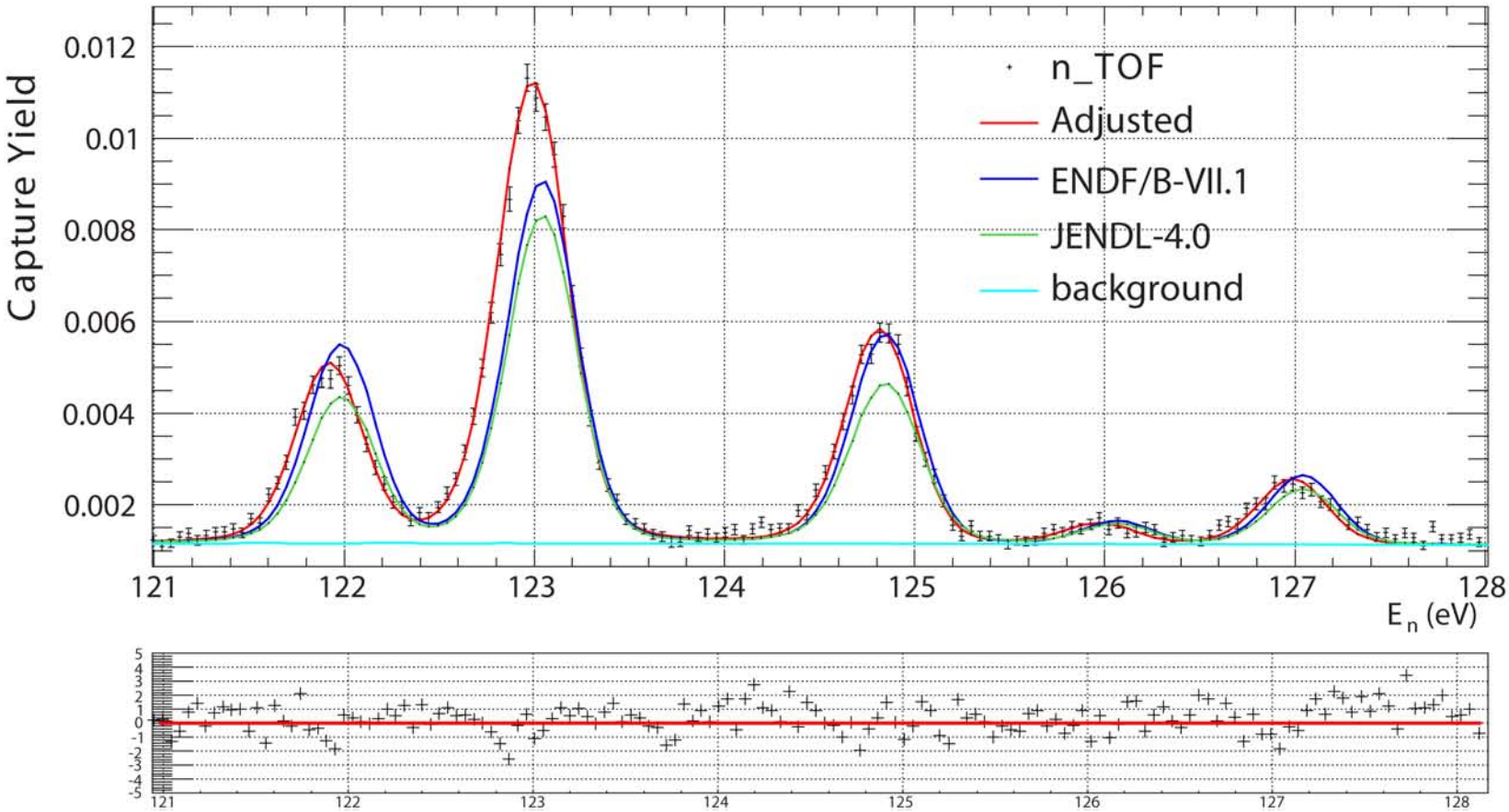


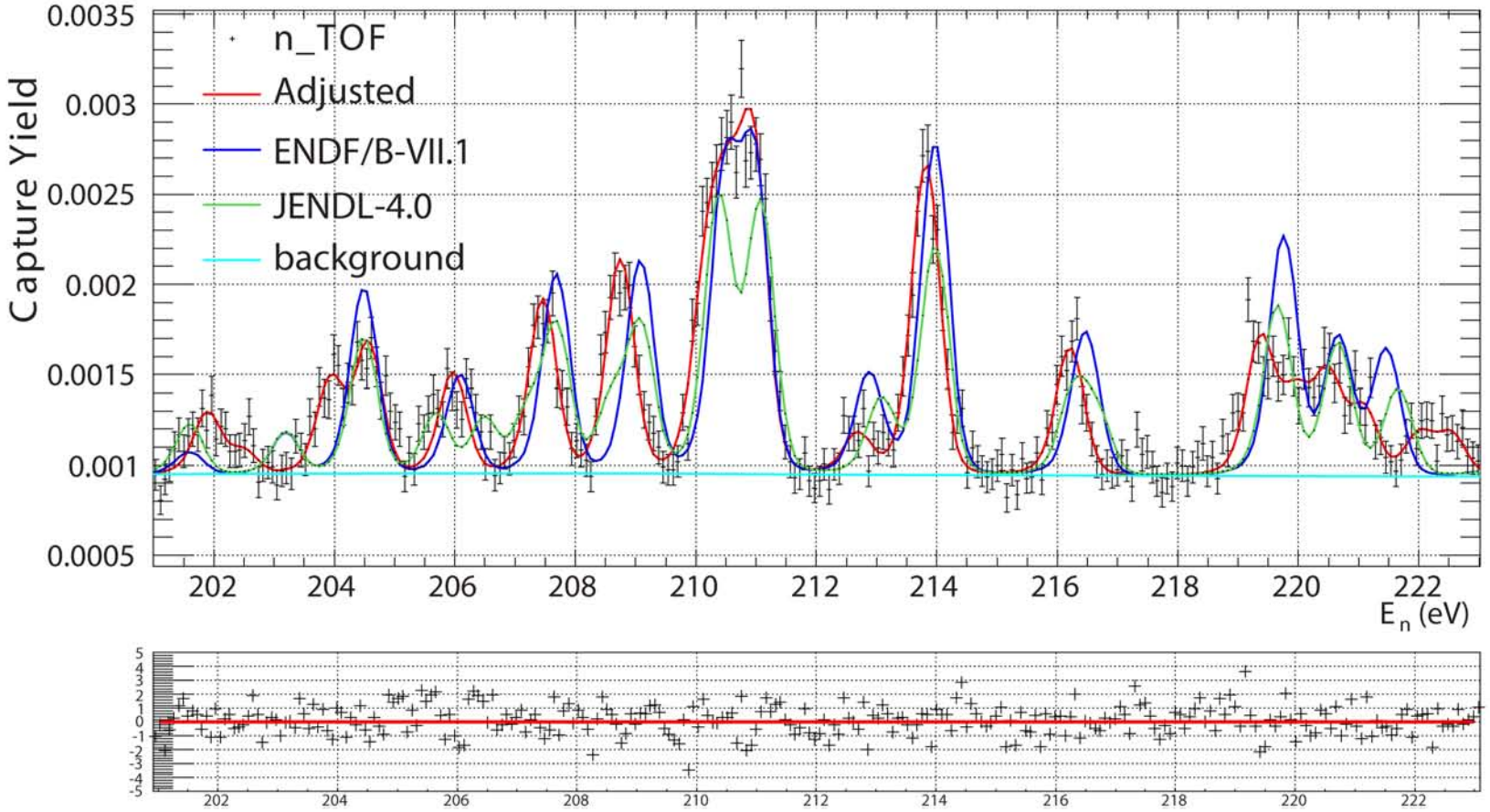
^{243}Am(n,γ) data measured at n_TOF

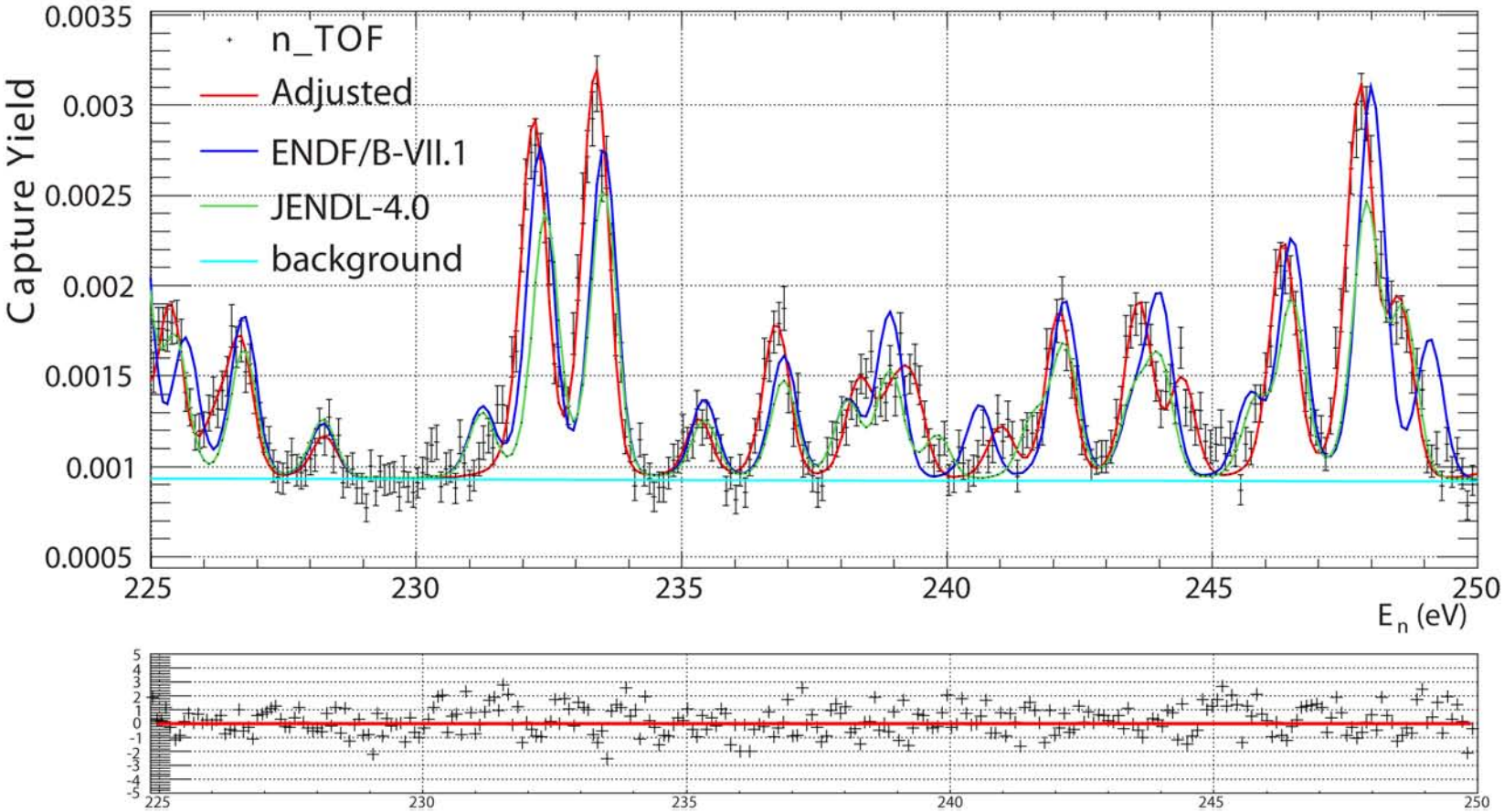


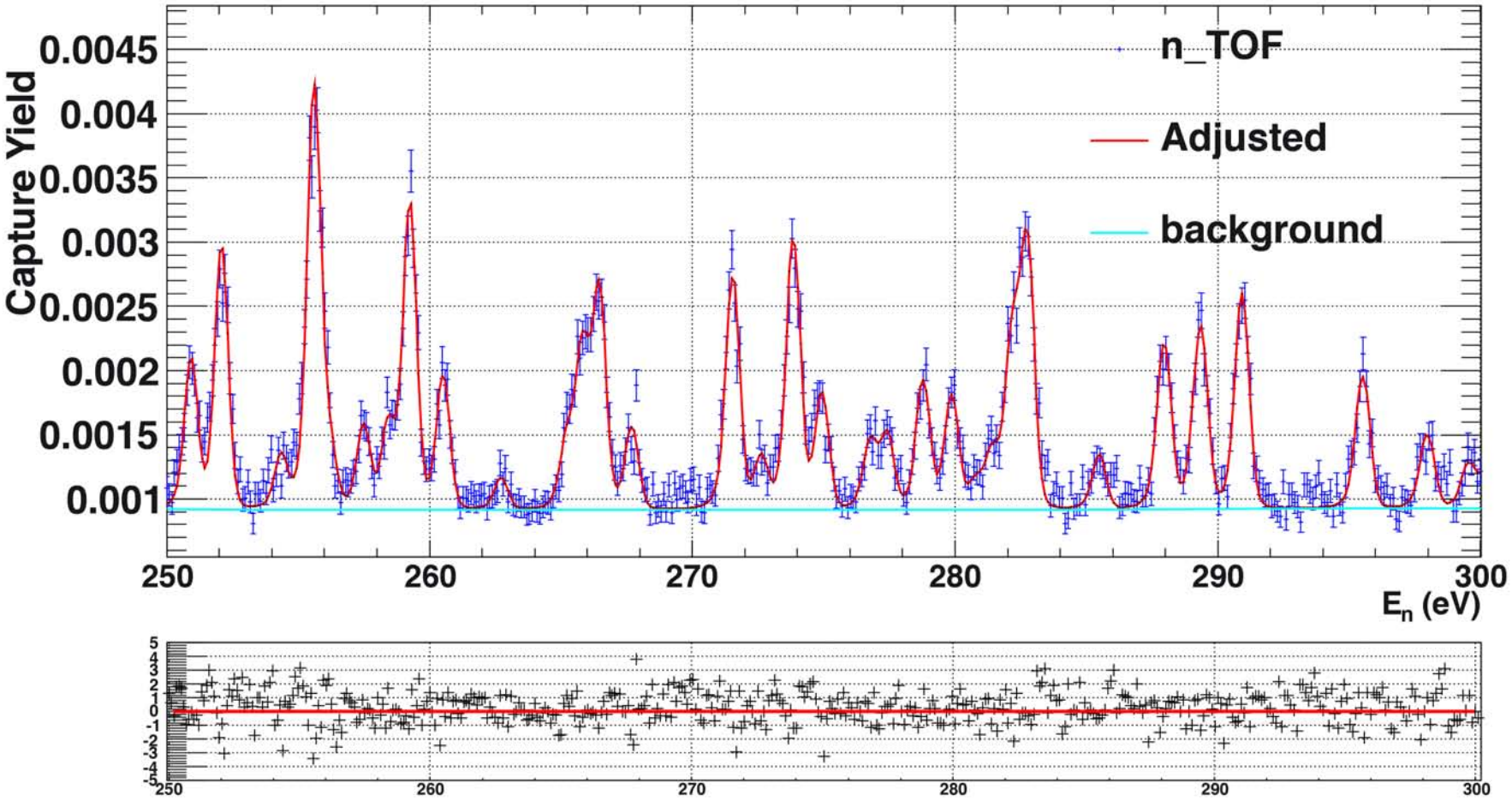

Capture Yield
0.05
0.04
0.03
0.02
0.01
0
12.4
12.6
12.8
13
13.2
13.4
13.6
E n (eV)
n_TOF
Adjusted
ENDF/B-VII.1
JENDL-4.0
background

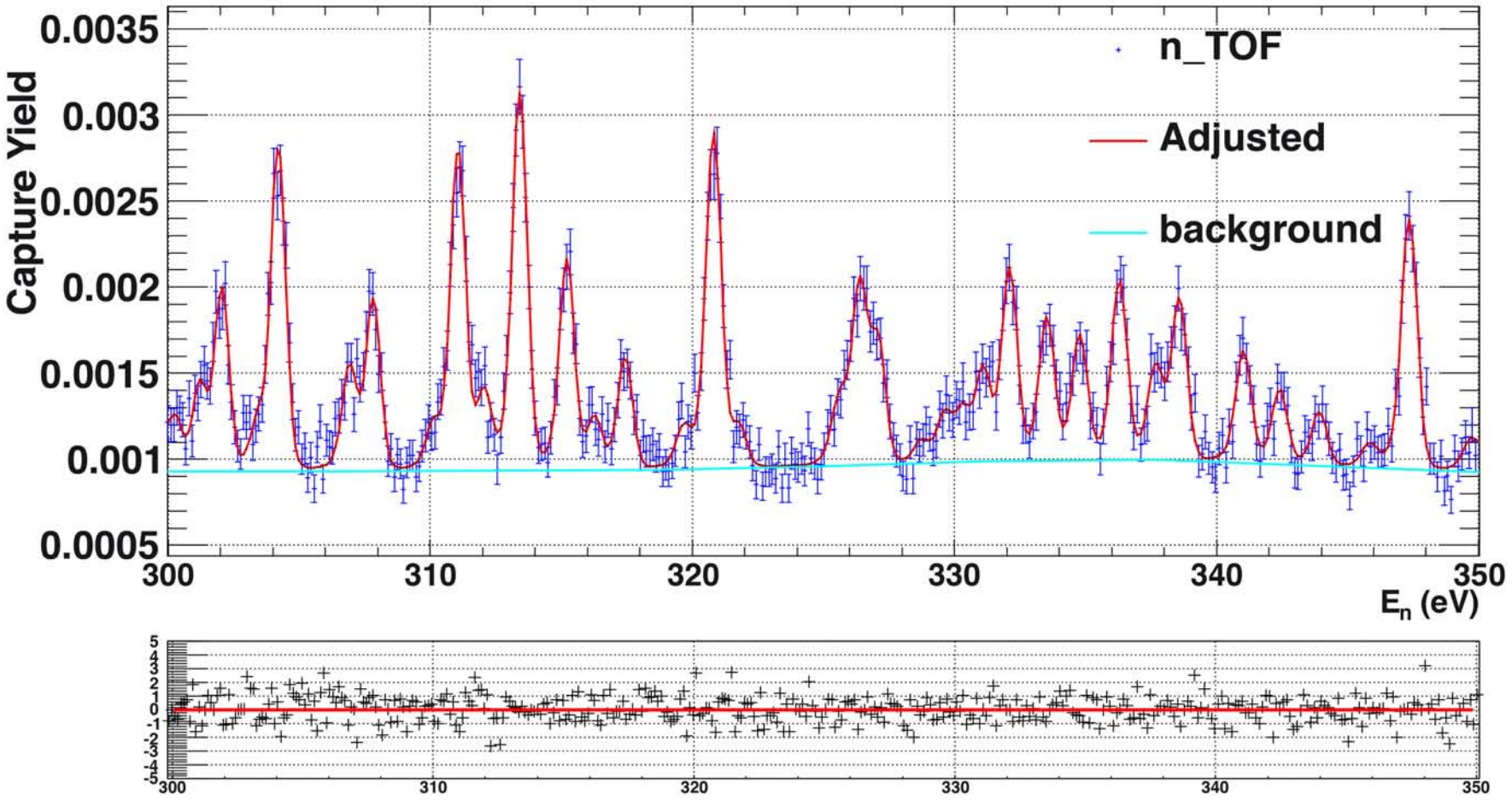

Capture Yield
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
n_TOF
Adjusted
ENDF/B-VII.1
JENDL-4.0
background
79
80
81
82
83
84
85
86
87
E n (eV)
5
4
3
2
1
0
-1
-2
-3
-4
-5

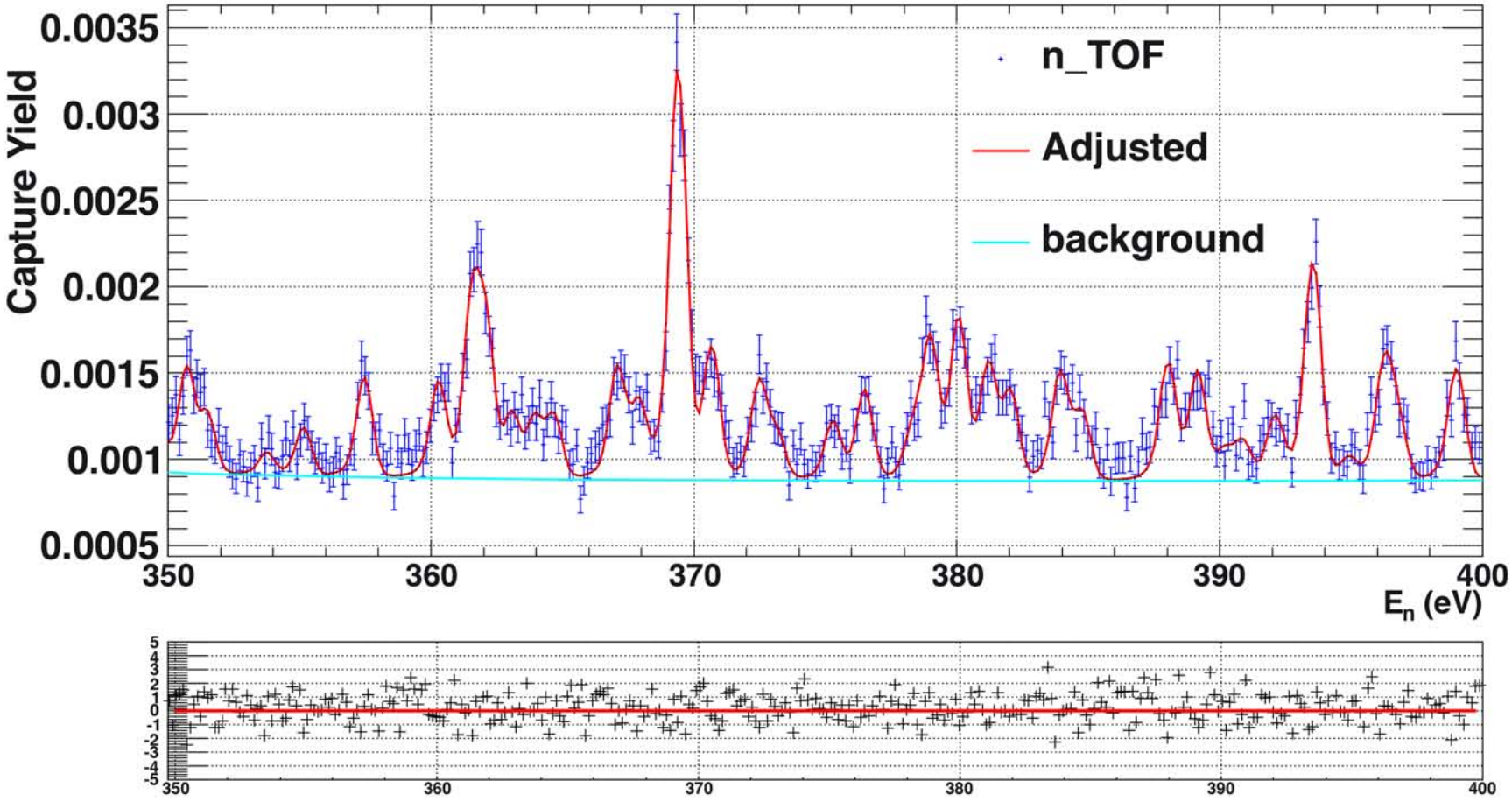

Capture Yield
0.012
0.01
0.008
0.006
0.004
0.002
n_TOF
Adjusted
ENDF/B-VII.1
JENDL-4.0
background
121
122
123
124
125
126
127
128
E n (eV)

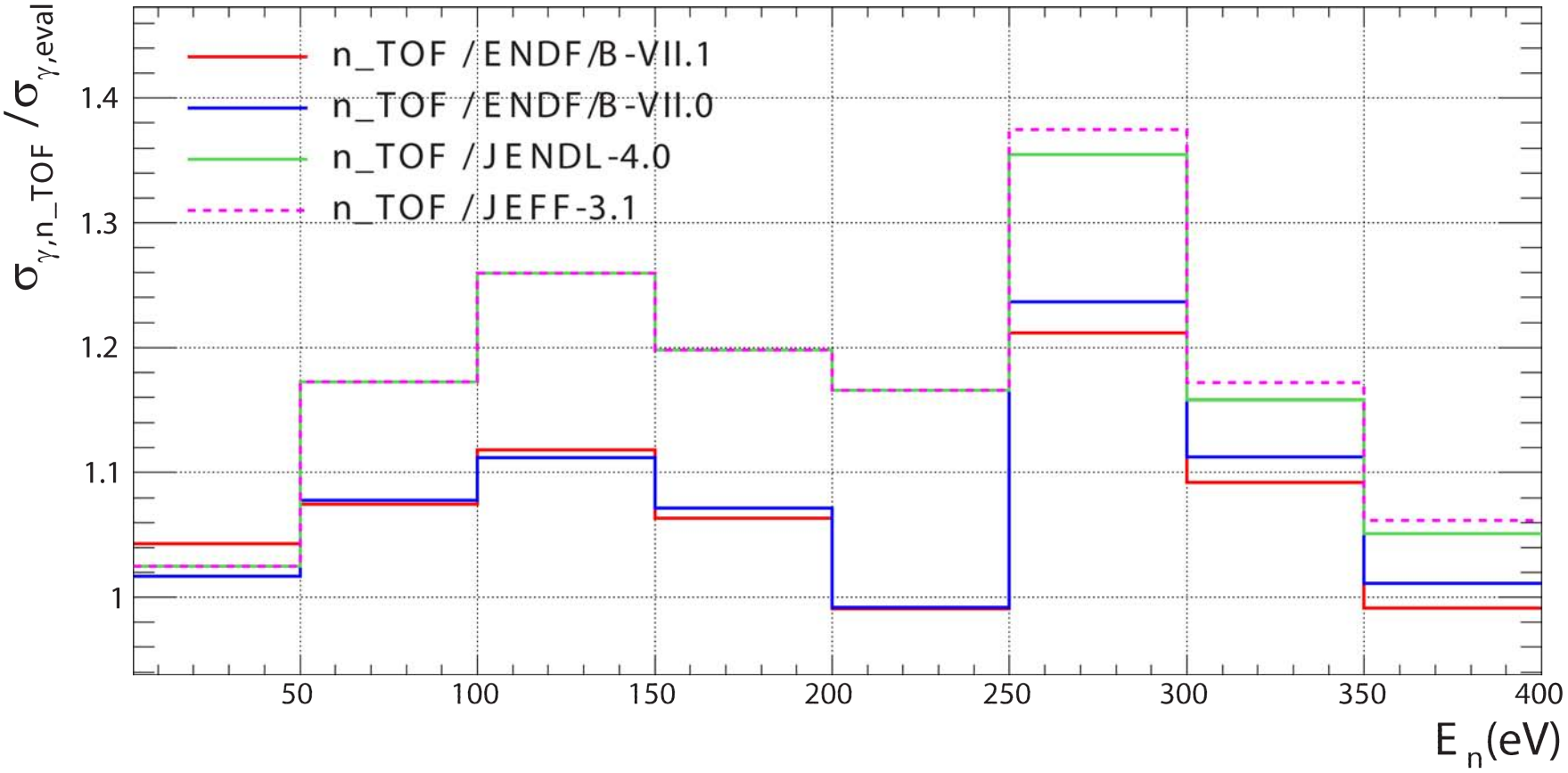

n_TOF
Adjusted
ENDF/B-VII.1
JENDL-4.0
background
Capture Yield
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
202
204
206
208
210
212
214
216
218
220
222
E n (eV)


n_TOF
Adjusted
ENDF/B-VII.1
JENDL-4.0
background
Capture Yield
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
225
230
235
240
245
250
E n (eV)


Capture Yield
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
n_TOF
Adjusted
background
250
260
270
280
290
300
E_n (eV)
5
4
3
2
1
0
-1
-2
-3
-4
-5
250
260
270
280
290
300

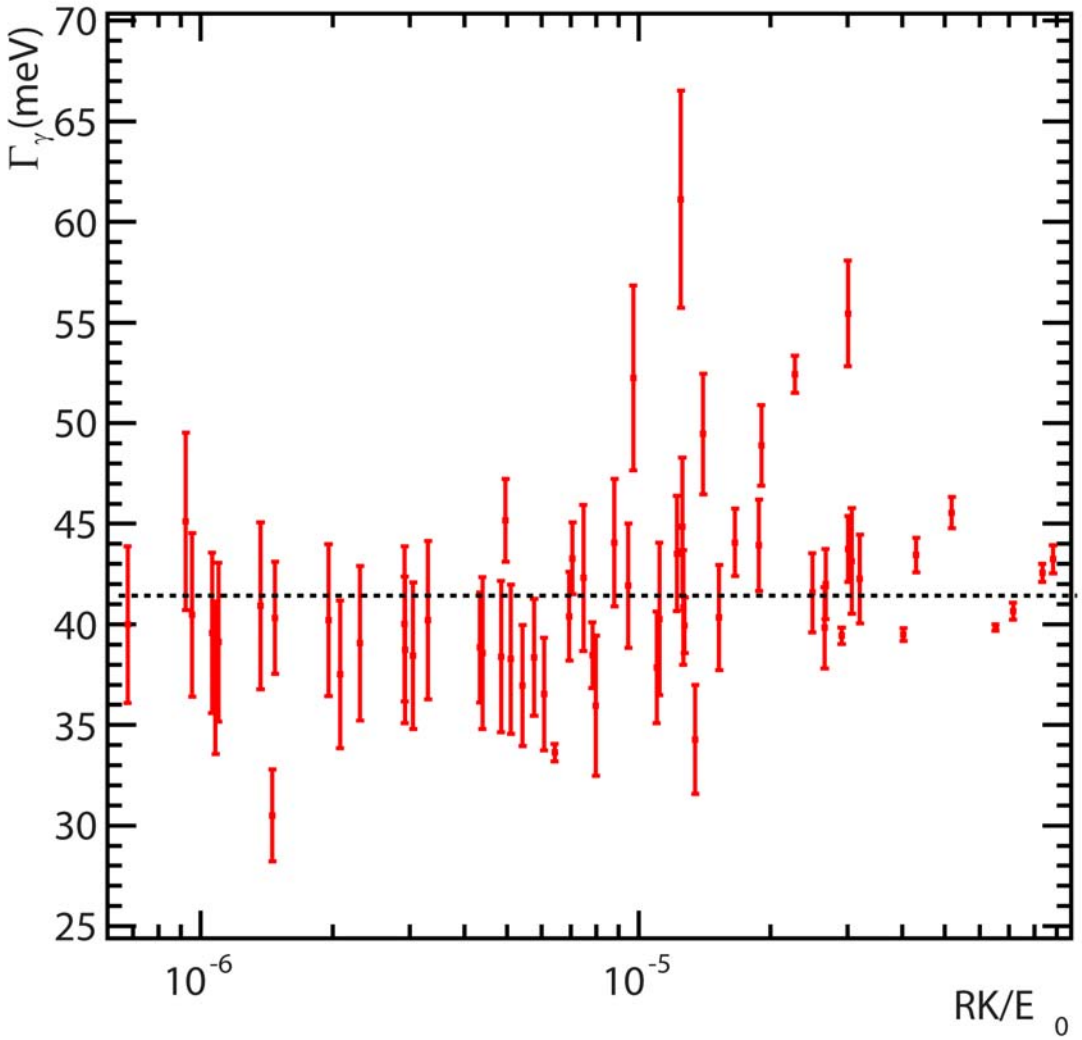

Capture Yield
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
300
310
320
330
340
350
E_n (eV)
n_TOF
Adjusted
background


Capture Yield
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
n_TOF
Adjusted
background
350
360
370
380
390
400
E_n (eV)
5
4
3
2
1
0
-1
-2
-3
-4
-5
350
360
370
380
390
400


n_TOF / ENDF/B-VII.1
n_TOF / ENDF/B-VII.0
n_TOF / JENDL-4.0
n_TOF / JEFF-3.1
σγ,n_TOF /σγ,eval
1.4
1.3
1.2
1.1
1
50
100
150
200
250
300
350
400
En(eV)

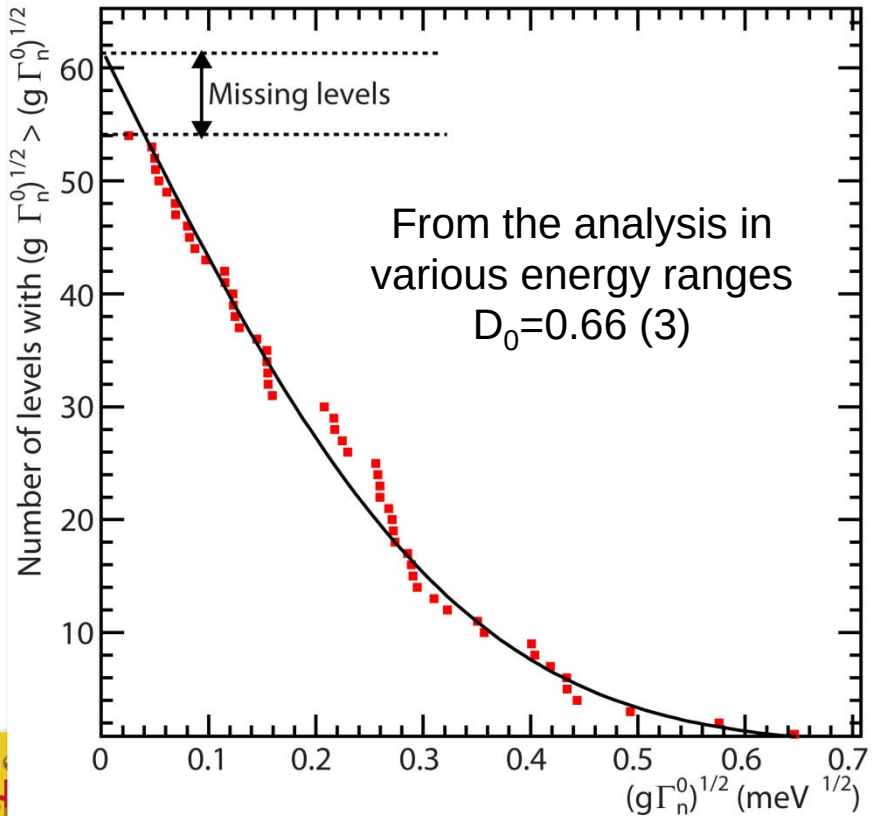
n_TOF data statistical analysis

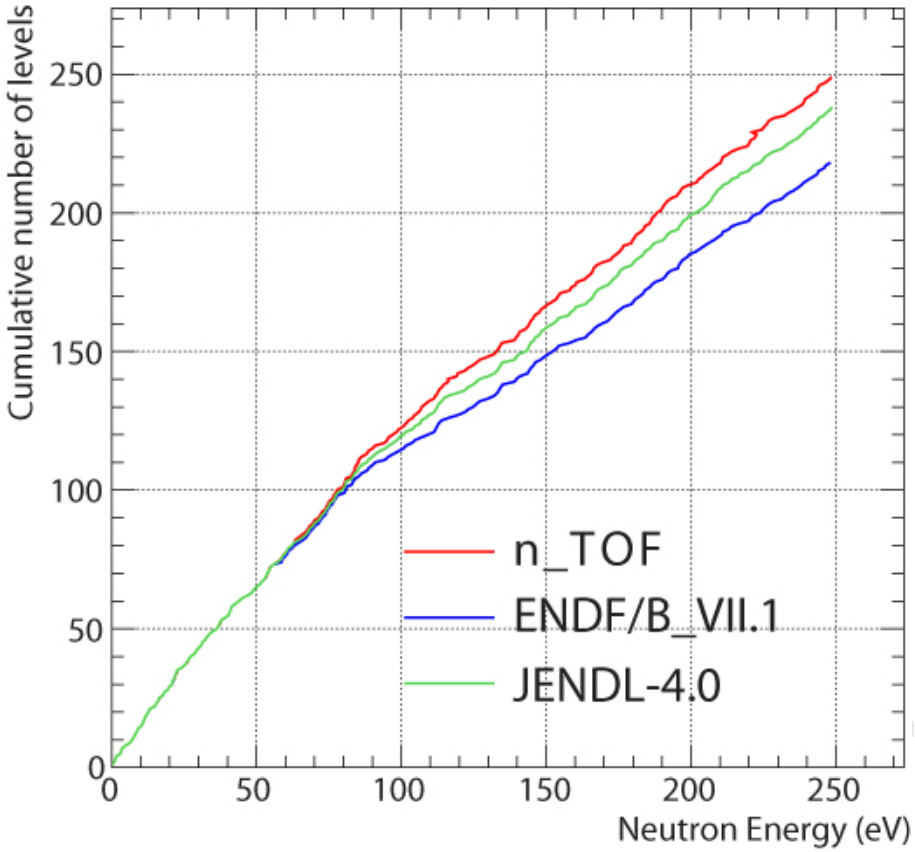
$<\Gamma_\gamma>=41.33(12) \pm 0.4_{T} \pm 0.7_{Doppler} \pm 0.6_{Inhomogeneities}$

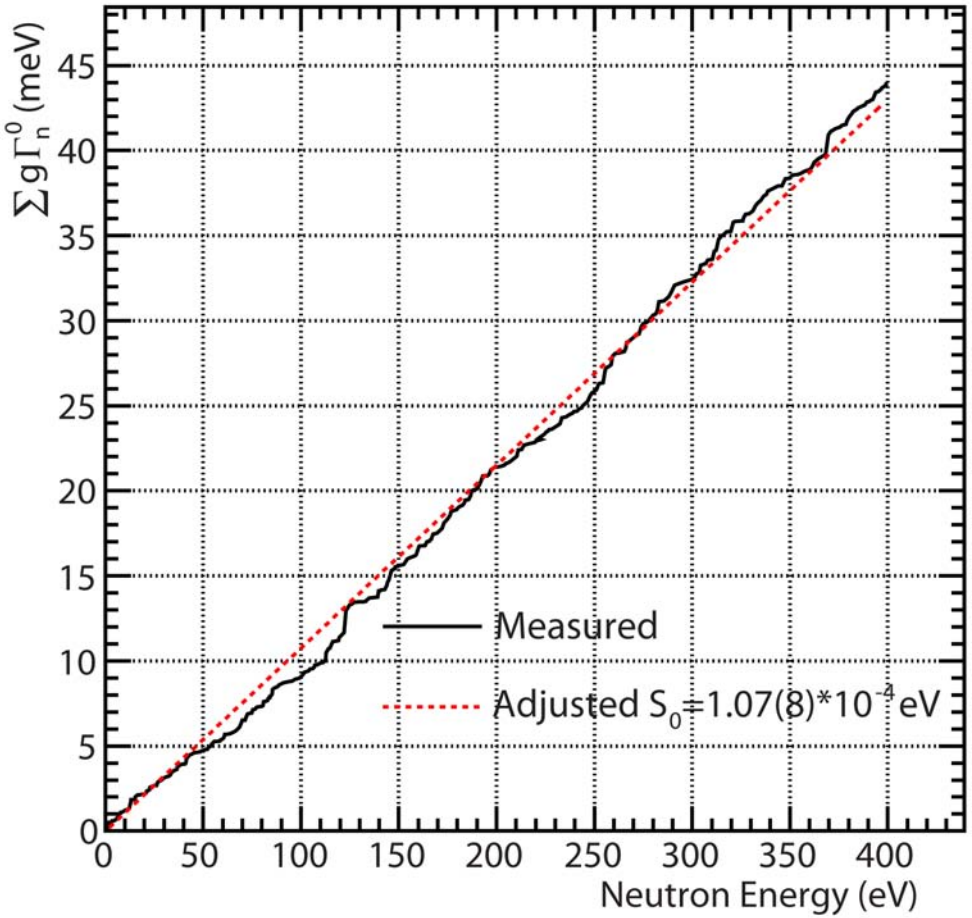


Number of resonances

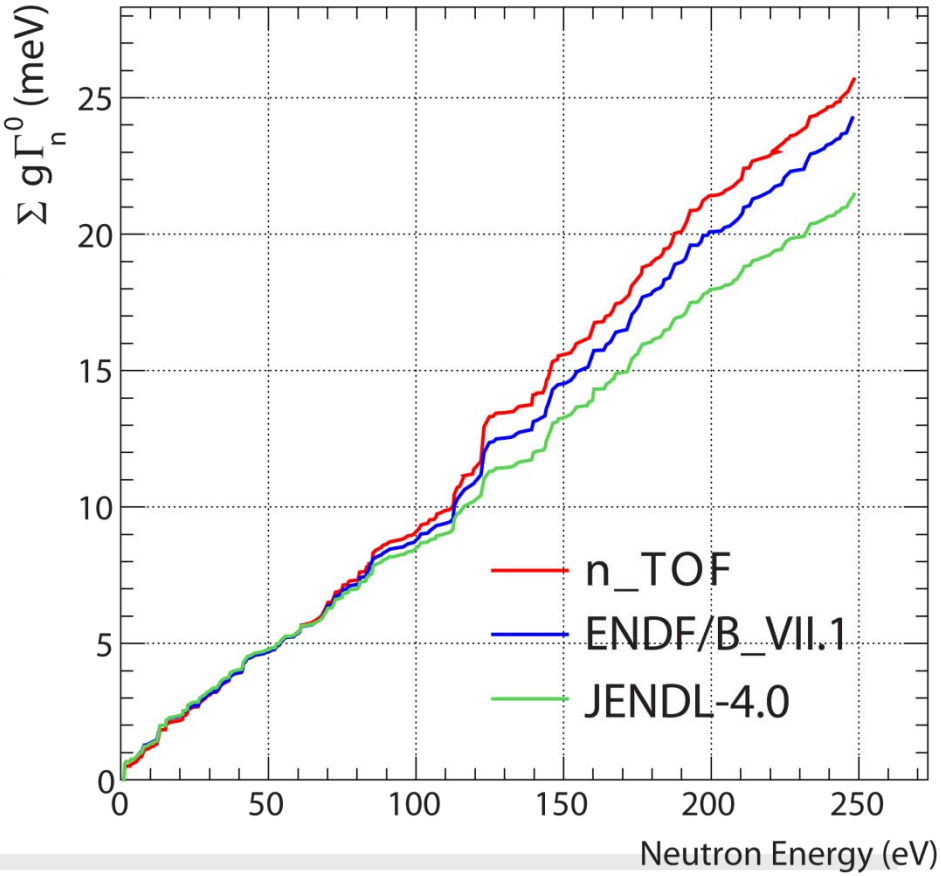
	0 – 250 eV	250 – 400 eV
ENDFB/VII.1 (Mughabghab)	218	-
JENDL-4.0 (Maslov)	238	-
n_TOF	249	104

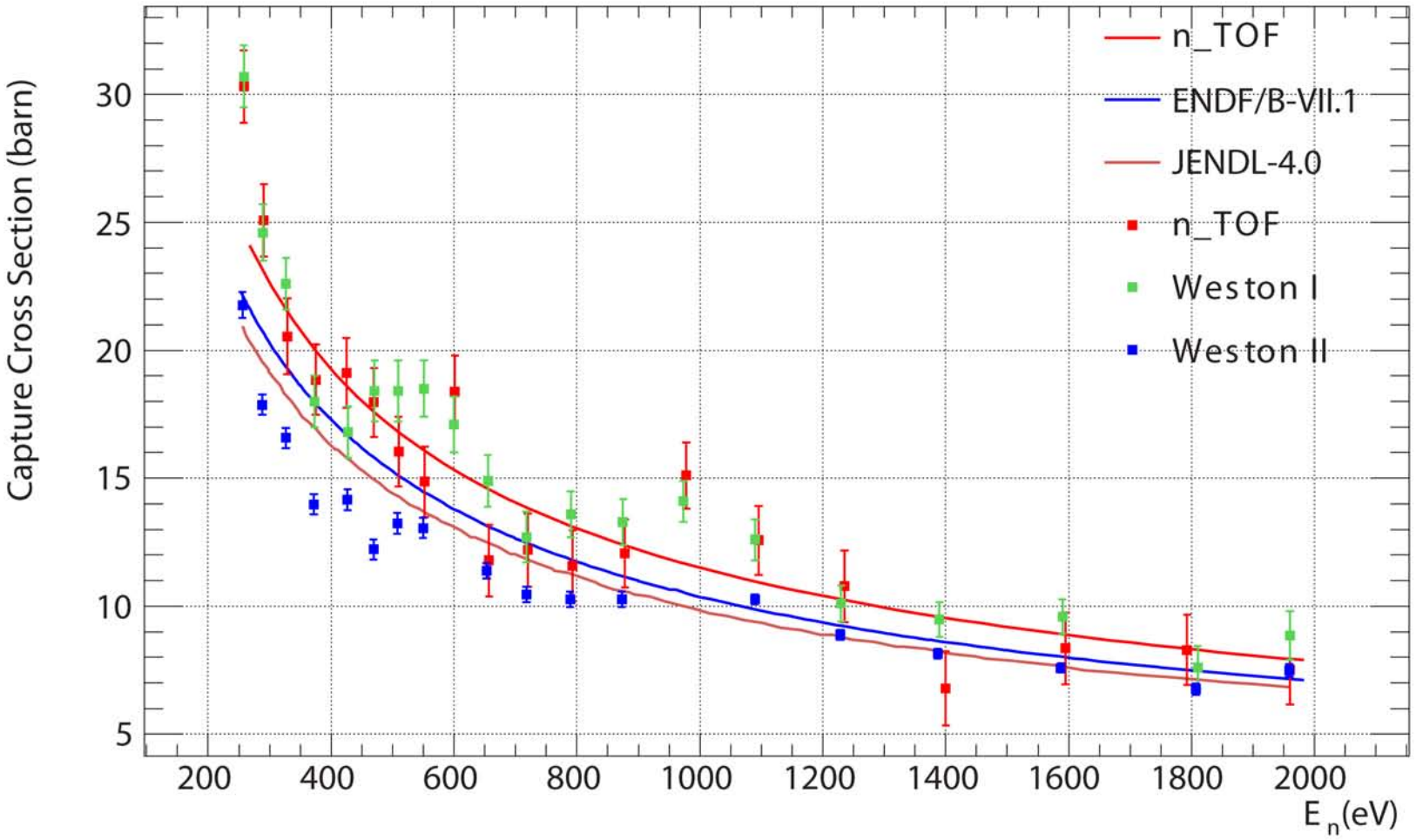






S_0=1.07(8)·10^{-4} eV (0.98 ENDFB/VII.1)




Capture Cross Section (barn)
30
25
20
15
10
5
200
400
600
800
1000
1200
1400
1600
1800
2000
E n (eV)
n_TOF
ENDF/B-VII.1
JENDL-4.0
n_TOF
Weston I
Weston II

Normalisation at thermal energies. Which value?

Reference	σ_0(barn)	I_0(barn)	I_0/σ_0
Hori et al. (2009)	76.6[a]	1970(110)	25.7(1.5)
Marie et al. (2006)	81.8(3.6)		
Ohta et al. (2006)		2250 (250)	28(4)
Y. Hatsukawa et al. (1997)	84.4		
Garvilov et al. (1977)	83(6)	2200(150)	26.5(2.6)
Simpson et al. (1974)		1819(80)[c]	
Eberle et al. (1971)		1930(50)[c]	
Berreth et al. (1970)		1824(80)[c]	
Folger et al. (1968)	78	2250[d]	29
Bak et al (1967)	73(6)	2300(200)	32(4)
Ice et al. (1966)	$66<\sigma_0<84$		
Butler et al (1957)	73.6(1.8)	2290(50)	31(1)
Harvey et al (1954)	140(50)		
Stevens et al. (1954)	115		
Mughabghab (1984)	75.1(1.8)	1820(70)	24.2(1.1)
ENDF/B-VII.1	80.4	2051	25.5
ENDF/B-VII.0	75.1	1820	24.2
JENDL-4.0	79.3	2040	25.7
JEFF-3.1	76.7	1788	23.3

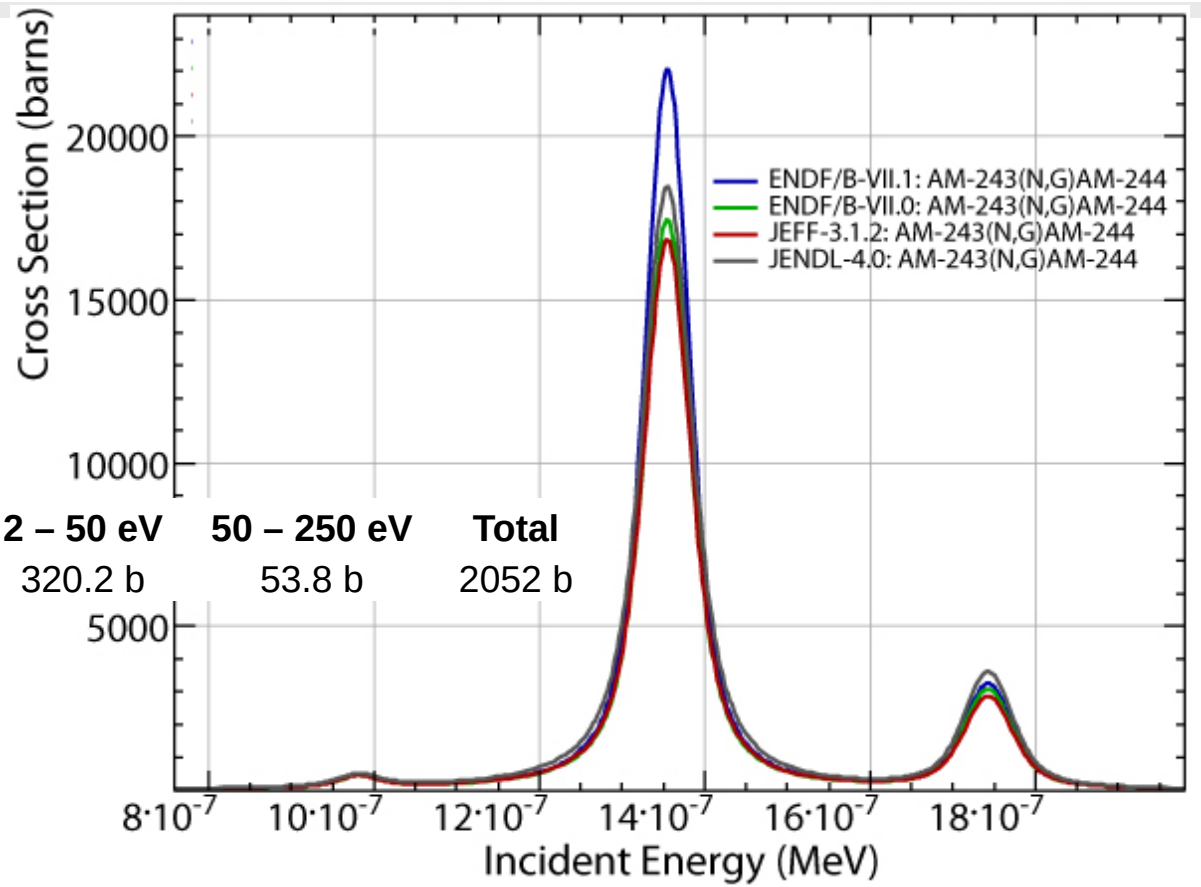
References		σ_0	I_0	$\hat{\sigma}$ (b)
Present result		—	—	174.5±5.3
JENDL-3.3	(2002)[14)]	76.7	1787	150±8
Mughabghab	(1984)[15)]	75.1±1.8	1820±70	150±9
Marie *et al.*	(2006)[16)]	81.8±3.6	(1800)	(156)
			(2250)	(174)

*The effective cross section with the quantity in Westcott's convention $r\sqrt{T/T_0}$=0.037±0.004.

$$\hat{\sigma} = \sigma_0 g G_{\text{th}} + r\sqrt{\frac{T}{T_0}} \cdot \frac{2}{\sqrt{\pi}} (I_0 - 0.45\sigma_0) G_{\text{epi}}.$$

The 1.35 eV resonsance issue (resonance integrals)

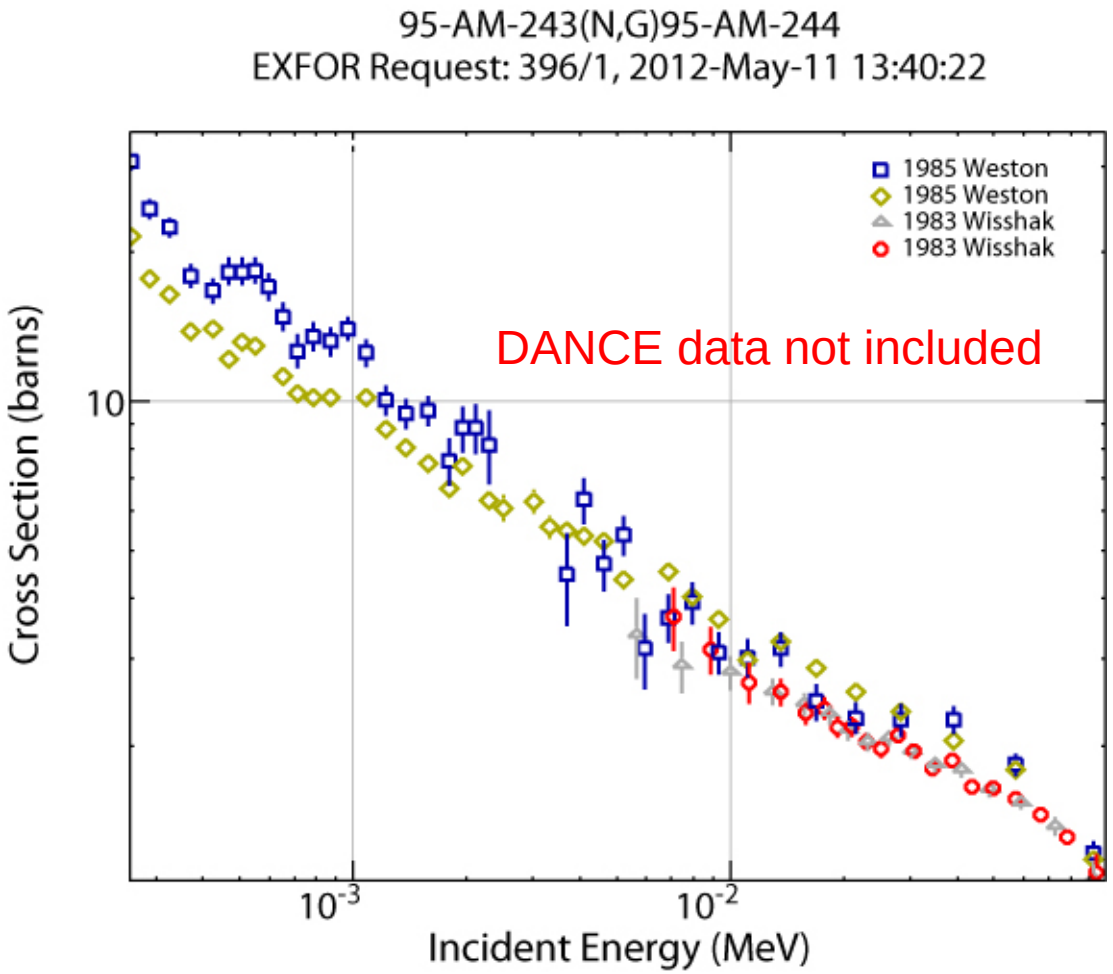
The resonance integral data depend largely on the 1.35 eV resonance parameters, which do vary significantly from library to library.



∫σ/E	0.5 – 1 eV	1 – 2 eV	2 – 50 eV	50 – 250 eV	Total
ENDFB/VII.1	59.2 b	**1576.2 b**	320.2 b	53.8 b	2052 b

	Γ_γ (meV)	Γ_n (meV)	Formalism	Year
ENDFB/VII.1	38.6	1.133	MLBW	2011
ENDFB/VII.0	43.0	1.11	SLBW	2006
JENDL-4	50	1.1	MLBW	2010
JENDL-3.3	45.147	0.9372	MLBW	2002
JEFF3.1.2	45.147	0.9372	MLBW	2012

Improve the data in the URR



Summary and conclusions

The Weston (n,γ) data are normalised to thermal and the two data sets are discrepant in the keV region. Weston data are ~10% above Wisshak data in the region of overlap.

Thermal cross section data are scattered and do not necessarily agree (even the recent measurements) and there is no clear choice about which should be used from the point of view of the data.

Possible clues on the 1.35 eV resonance issue:
Resonance parameters from the DANCE and KURRI data.

New future measurements:
- A new transmission measurement (no uncertainties are available for the Simpson data).
-A new capture measurement with C_6D_6 detectors in the keV region (for example, at n_TOF experimental area 2).