



Status of capture data for ^{206}Pb , ^{238}U and ^{241}Am

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EC – JRC – IRMM

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$^{206}\text{Pb} + n$: experimental data



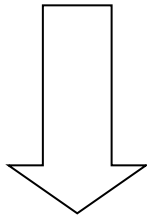
	Facility	(n,tot)	(n, γ)	(n,n)	Energy Range	Exp. data	Comments
Ioffe et al (2000)	BER-II			x	thermal	X	
Koester et al. (1995)	FRM			x	thermal	X	
Blackmon et al. (2002)	NIST		x		thermal	X	
Borella (to be publ.)	BNC		x		thermal	X	
Mizumoto et al. (1979)	ORELA	x	x		1 – 50 keV	0	$g\Gamma_n + K_\gamma$
Horen et al. (1979)	ORELA	x		x	25 – 600 keV	X	$g\Gamma_n + J^\pi$
Horen et al. (1981)	ORELA	x		x	600 – 900 keV	X	$g\Gamma_n + J^\pi$
Borella et al. (2007)	GELINA	x	x		1 – 620 keV	X	$g\Gamma_n + K_\gamma$
Domingo et al. (2007)			x		1 – 450 keV	0	K_γ (WF - without threshold)

All RP obtained by Reich-Moore

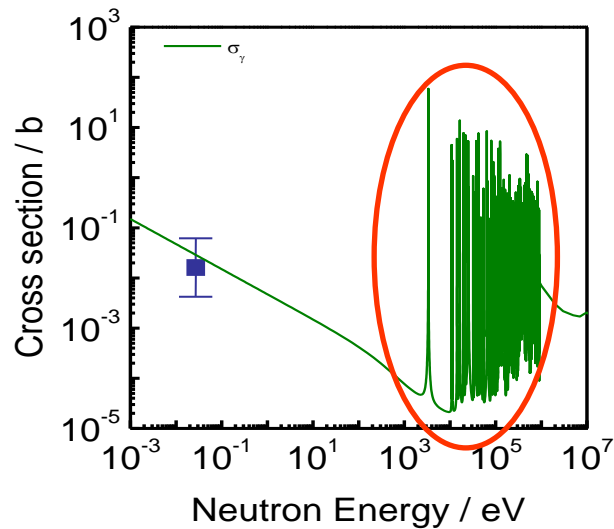
$^{206}\text{Pb} + n : \text{BNC} + \text{GELINA} + \text{ORELA}$



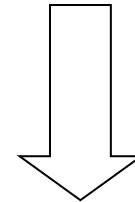
Thermal



BNC



RRR



GELINA + ORELA

- **Budapest Neutron Centre**
 - $\sigma(n_{th}, \gamma)$
- **GELINA**
 - Transmission at 25 m : < 80 keV
 - Capture at 60 m : < 620 keV
- **ORELA**
 - Transmission at 200 m : < 900 keV

Simultaneous analysis: ORELA + GELINA



ORELA Horen et al., PRC 20 (1979) 478 & 24 (1981) 1961)

Transmission at 200 m

- $\Delta t = 5$ ns, NE110-plastic scintillator
- 88.4 % ^{206}Pb (0.0989 at/b)

ℓ assignment

scattering at 39, 55, 90, 126, 150° with NE-110

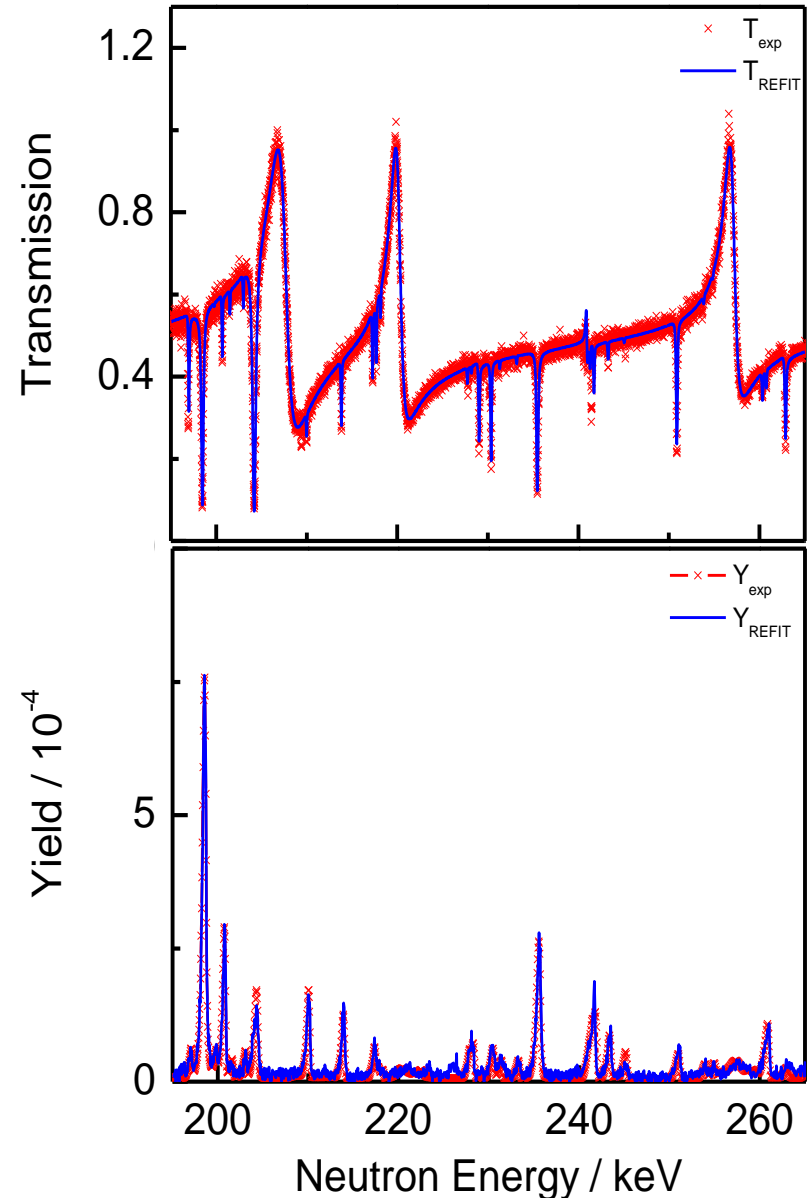
GELINA Borella et al., PRC 76 (2007) 014605

Transmission at 25 m

- $\Delta t = 1$ ns, NE912 Li-glas
- 99.82 % ^{206}Pb (0.016 & 0.030 at/b)

Capture at 60 m

- $\Delta t = 1$ ns, C_6D_6 at 125°
- 99.82 % ^{206}Pb ($3.546 \cdot 10^{-3}$ at/b)



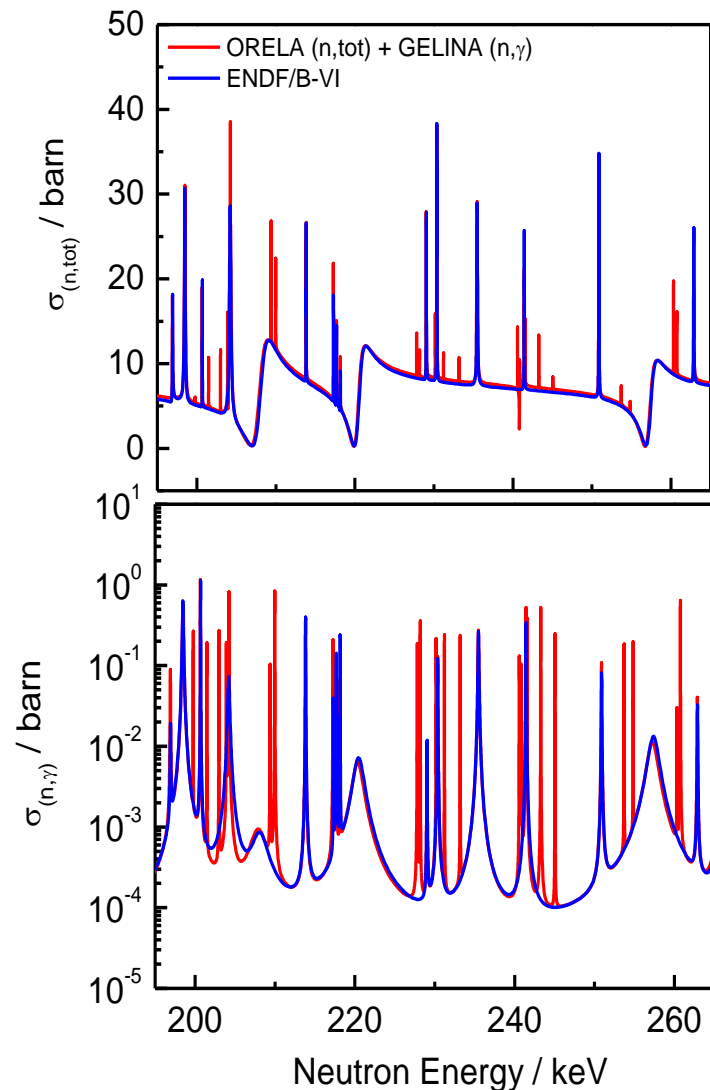
- **396 resonances analysed**

- $(E_R, \Gamma_n, \Gamma_\gamma, J^\pi)$
- $R_{\ell=0} = 9.5$ fm and $R_{\ell=1} = 6.0$ fm

- **Consistency: $\sigma(n,\gamma)$ and $\sigma(n,n)$ at 0.025 eV**

- $\sigma(n_{\text{th}},\gamma) = 28.7$ (0.9) mb
 - from ($\ell=0$ & $E_R > 0$) = 11 mb
 - direct capture = 14 mb (A. Mengoni)
- $b_c = 9.22$ fm (Ioffe et al., EPJA 7 (2000) 197)
- b_c from RP ($E_R > 0$) = 8.9 fm

⇒ **bound state required**



- **New evaluation is possible (peak cross sections < 5 – 10%)**
- **Study of gamma-ray cascades (Borella et al. (GELINA) and Mizumoto et al. (ORELA))**
 - ⇒ **Reich – Moore or Full R-matrix**
 - ⇒ **Interference effects : cross sections in between resonances (?)**

	Facility	(n,tot)	(n, γ)	(n,n)	Energy Range	Exp. data	Comments
Ioffe et al (2000)	BER-II			x	thermal	X	
Koester et al. (1995)	FRM			x	thermal	X	
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Borella (to be publ.)	BNC		x		thermal	X	
Mizumoto et al. (1979)	ORELA	x	x		1 – 50 keV	0	
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- **Resolved resonance region**
 - **Sowerby and Moxon, 1994, NEANDC – 313 U**
 - **Derien et al. ,2005, ORNL/TM – 2005/241**
(reflects status of available experimental data)

- **Unresolved resonance region**
 - + **Overview experimental data base**
 - **Poenitz et al. , (n, γ) , 1977, ANL/NDM – 32**
 - **Poenitz, (n, γ) , 1979, NBS 594 (1979) 368**
 - **Poenitz, (n, γ) , 1982, ANL – 83 – 4, 288**

 - **Smith et al., (n,tot) ANL/NDM – 74**

Evaluation based on HF + WF

- **Fröhner, NSE 103 (1989) 119 & NSE 111 (1992) 404** HF + WF
all data before 1989
- **Maslov et al., Ann. Nucl. En. 29 (2002) 1707** HF + WF
Moxon, de Saussure, Poenitz, Kazakov et al., Quang and Knoll
- **Courcelle et al., NSE 156 (2007) 391** HF + WF
Moxon, de Saussure, Kazakov et al.

**GMA evaluation by Pronyaev as part of standards evaluation (IAEA TECDOC 2007)
quoted uncertainties : 1 – 2%**

$^{238}\text{U}(n,\gamma)$: experimental data base in URR



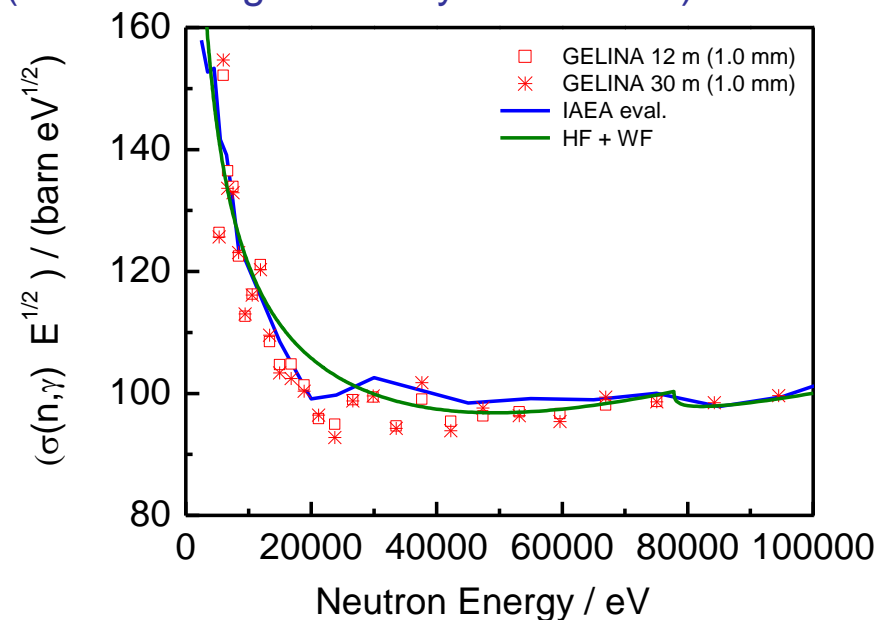
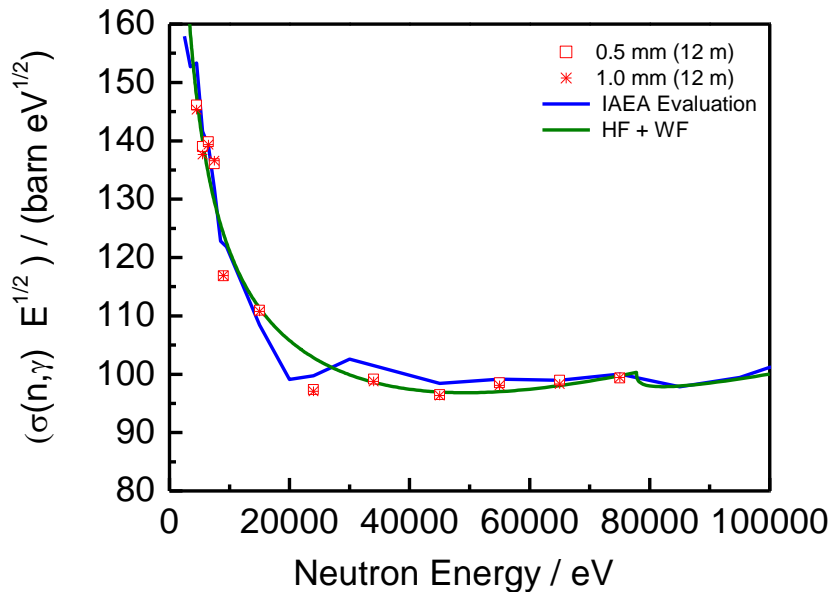
- **Before 1977, see Poenitz et al. ANL/NDM-74**
- **After 1977**
 - **Quang and Knoll** **NAA (filtered beams)**
 - **Macklin et al., ANE 18 (1991) 567** **TA (LS)**
 - **Kazakov et al., 1986** **TA (LS)**
 - **Poenitz et al., NSE 78 (1981) 239** **NAA**
 - **Yamamuro et al., JNST 17 (1980) 582** **TE (C₆D₆)**
 - **Wisshak and Käppeler , NSE 66 (1978) 363** **TE (MR)**
- + a set of self-indication measurements in Fröhner NSE
(used for validation of his evaluation)
- + new measurements at nTOF and GELINA
- **GELINA : same methodology as for $^{197}\text{Au}(n,\gamma)$ has been applied**

GELINA : $^{197}\text{Au}(n,\gamma)$ methodology



Borella et al., NIMA 577 (2007) 626

- Total energy principle: C_6D_6 with weighting functions
- Weighting functions which account for the threshold
- Verify experimentally the effect of WF and threshold
- Correction for γ -ray attenuation in the sample
- Use fixed background filters
- Perform background measurements with additional filters
- Perform additional background measurements with Pb
- Determine neutron flux with a double ionization chamber 2 thin layers of ^{10}B
- Normalization at a saturated resonance (account for gamma-ray attenuation)



$^{238}\text{U}(n,\gamma)$: experimental data base in URR



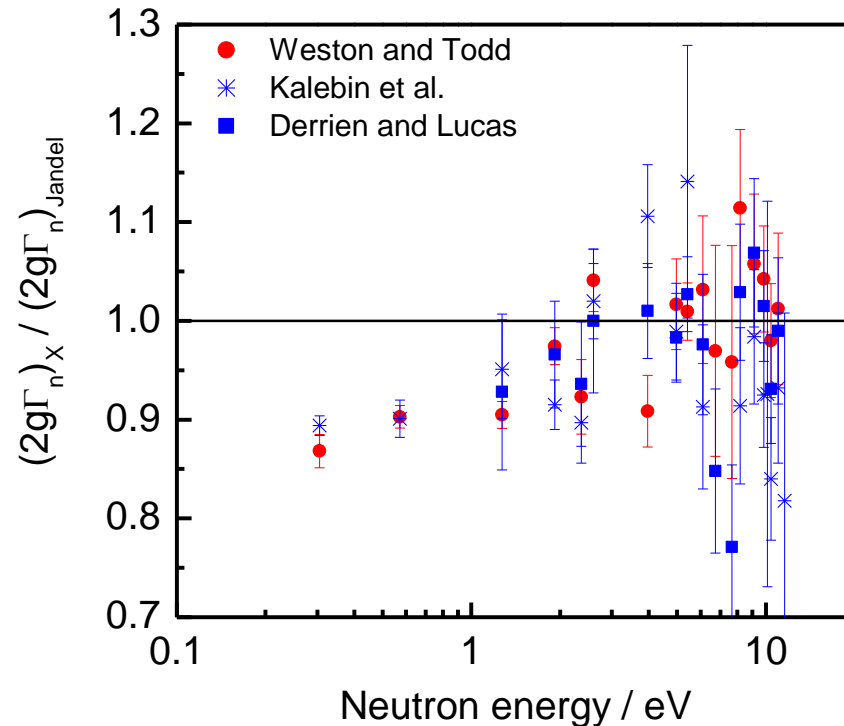
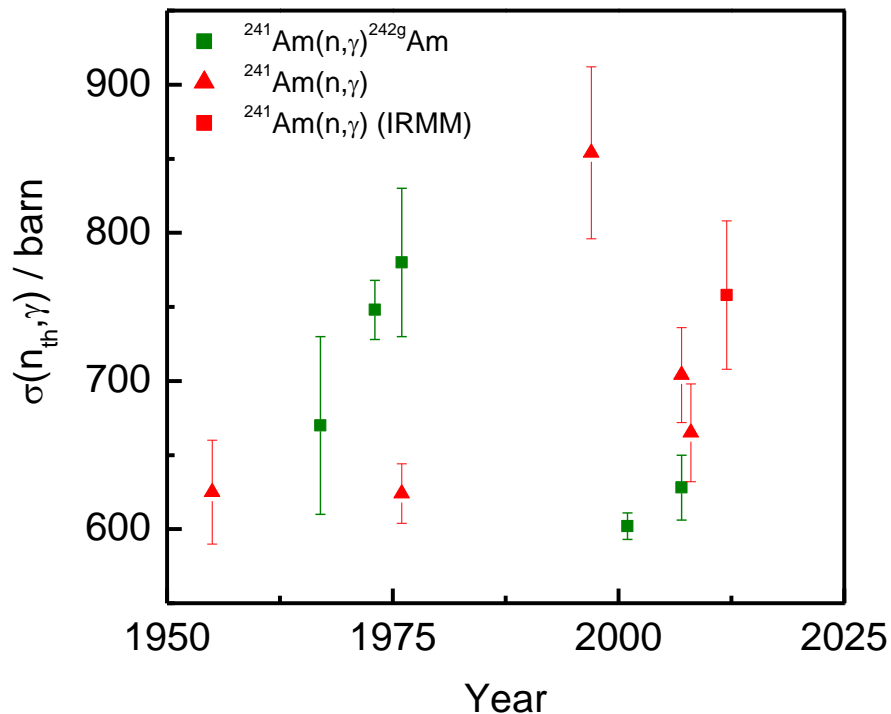
	(n,tot)	(n, γ)	Energy Range	Comments
Kazakov et al., 1986		TA (LS)	4 – 460 keV	Norm. : sat. resonance Flux : combination $^6\text{Li}(n,\alpha)$ & $^{10}\text{B}(n,\alpha,\gamma)$ (thick monitors) All corrections reported
de Saussure NSE 52 (1973) 382 Moxon et al., 1969		TA (LS) TE (MR)	< 100 keV 1 – 100 keV	Norm. + BGR correction based on RRR Norm. : sat. resonance Flux : $^{10}\text{B}(n,\alpha,\gamma)$ same detector as (n, γ)
Quang and Knoll, NSE 110 (1991) 282 Poenitz et al. NSE 78 (1981) 239		NAA NAA	23 & 967 keV 20 – 400 keV	Not used by Courcelle, Not used by Courcelle,
All other data: evaluation Poenitz				Not used by Courcelle, Maslov
<i>Yamamuro et al., JNST 17 (1980) 582</i>		<i>TE (C₆D₆)</i>		<i>Norm : 24 keV Flux : $^{10}\text{B}(n,\alpha,\gamma)$ same detector as (n,γ) Inconsistent data, validation by Frohner Used for validation by Frohner</i>
<i>Macklin et al., ANE 18 (1991) 567 Fujita et al. 1991, (SI)</i>		<i>TA (LS)</i>	<i>1 – 100 keV</i>	
GELINA, nTOF		TE (C₆D₆) TE (C₆D₆)	5 – 80 keV	Same methodology as for $^{197}\text{Au}(n,\gamma)$
Harvey et al., 1988, MITO	X			High accuracy
Tsubone et al., NSE 88 (1984) 579	X			
Poenitz et al., NSE 78 (1981) 333	X			
Knonnov et al., 1974	X			
Cabe et al, 1973	X			
Byoun et al, 1972	X			
Uttley et al.	X			
Inelalastic, Plompen				

$^{241}\text{Am} + n : \text{RRR} + \text{URR}$



	Facility	(n,tot)	(n, γ)	Energy Range	Exp. data	Comments
Bernard & Bouland (2012)	EVAL		x	Thermal		Overview of exp. thermal data
Kalebin et al. (1975)	Russia	x		0.03 – 8 eV	X	Chopper
Belanova et al. (1974)				8 – 150 eV		AmO ₂
Derrien and Lucas (1975)	Saclay	x		0.8 eV – 150 eV	X	TOF
				150 eV – 1 keV		AmO ₂
Gayther and Thomas	Harwell			1.2 eV – 10 eV	?	Booster
						AmO ₂
Weston and Todd (1976)	ORELA	x	TE (C ₆ D ₆) + 3.2 mm Pb	0.025 – 100 eV	X	Norm. : $\sigma(n_{\text{th}},\gamma) = 582 \text{ b}$
						Flux :
						AmO ₂ + S powder
Weston and Todd (1976)	ORELA	x	TE (C ₆ D ₆) + 3.2 mm Pb	0.025 – 100 eV	X	Norm. : $\sigma(n_{\text{th}},\gamma) = 582 \text{ b}$
						Flux :
						AmO ₂ + S powder
Vanpraet et al. (1986)	GELINA		TE (C ₆ D ₆) + 2 mm Pb	0.7 eV – 200 eV + 1 keV – 15 keV	X	Norm : saturated (no correction for γ -att)
						Flux : $^{10}\text{B}(n, \alpha_1\gamma)$
						Metal disc
Jandel et al. (2008)	LANSCE		TA (BaF ₂)	0.025 – 12 eV + 600 - 20 keV	X	Norm. : Au (not sat.) $n_{\text{Au}} ? + \text{RP} ? + \varepsilon_\gamma$ (MC)
						Flux : $^{10}\text{B}(n,\alpha)$, $^{235}\text{U}(n,f) + ^6\text{Li}(n,\alpha)$
						^{241}Am electrodeposition
Wisshak and Kaeppler (1980)	KfK		TE (MR)	10 – 250 keV	X	Norm: absolute
						Flux : $^{197}\text{Au}(n,\gamma)$
						AmO ₂ powder
Lampoudis et al. (2012)	GELINA	x	TE (C ₆ D ₆) + 1 cm Pb	0.025 – 100 eV	X	Flux : $^{10}\text{B}(n,\alpha)$
						(n, γ) norm. on (n,tot)
						AmO ₂ in Y ₂ O ₃ (solgel)
Fraval et al.	nTOF		TE (C ₆ D ₆) + ? Pb	?		Norm. ?
						Flux : ?
						AmO ₂ in Al (solgel)
Cano-Ott et al.	nTOF		TA (BaF ₂) + ? Pb	?		Norm. ?
						Flux : ?
						AmO ₂ in Al (solgel)
Harada et al.	JPARC		TE (Ge)	0.1 – 100 eV		Norm: ?
						Flux : $^{10}\text{B}(n, \alpha_1\gamma)$
						AmO ₂ powder

^{241}Am : thermal + RRR

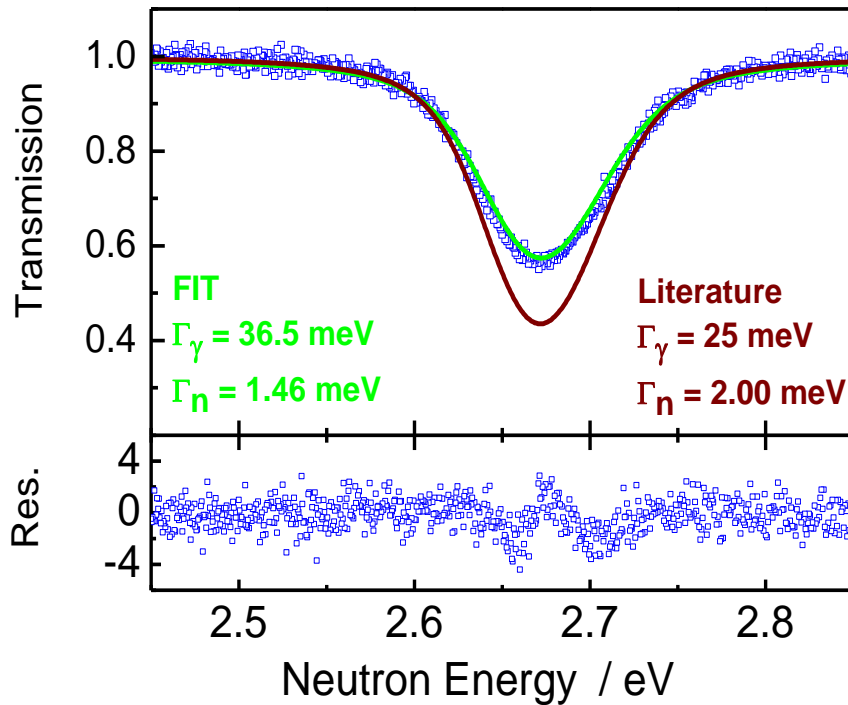


- Jandel et al. : Electroplated
- Weston and Todd : $\text{AmO}_2 + \text{S}$ powder
- Kalebin et al. : AmO_2 powder
- Derrien and Lucas : AmO_2 powder

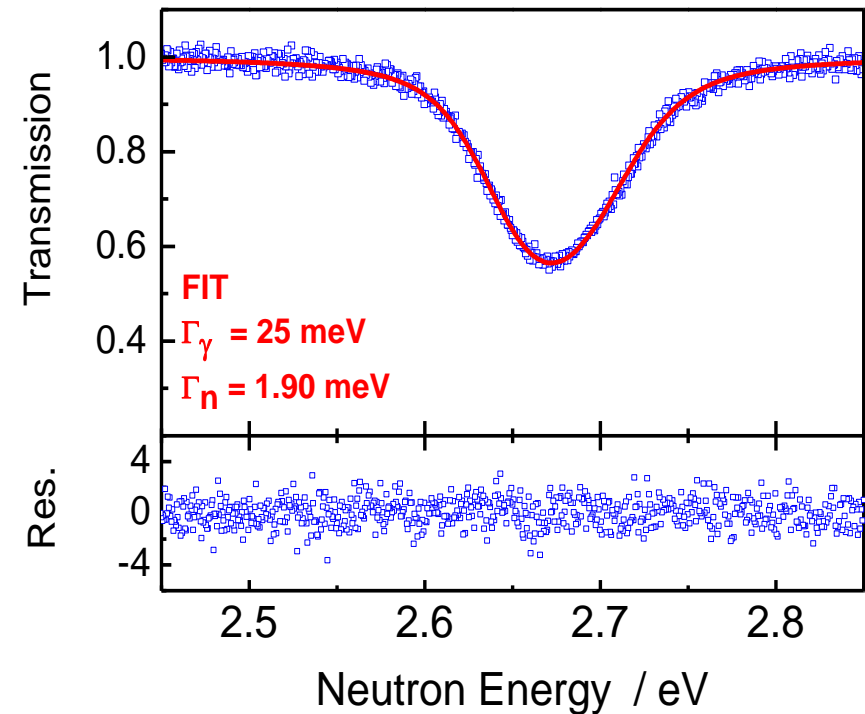
Impact of target properties e.g. $^{242}\text{PuO}_2$



Homogeneous sample



REFIT: accounting for the powder grain size



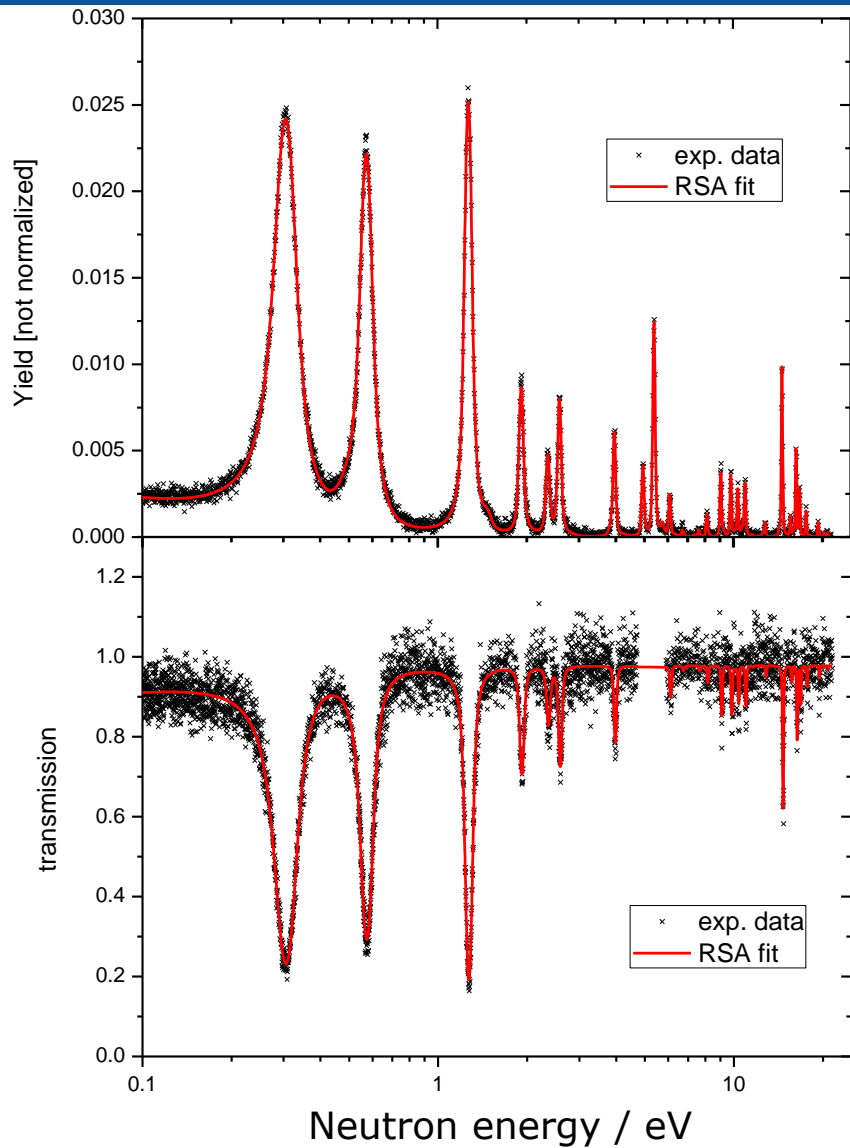
For inhomogeneous target

For $\Gamma_n < \Gamma_\gamma$

Γ_n underestimated

Γ_γ overestimated

^{241}Am : GELINA transmission + capture



GELINA
Transmission + capture
 $\langle \Gamma_\gamma \rangle = 42 \text{ meV}$

$\Gamma_\gamma / \text{meV}$	
LANSCE	Weston and Todd
44.4 ± 0.3	46.9 ± 0.3
43.3 ± 0.5	47.3 ± 0.3
45.3 ± 0.7	49.2 ± 0.3

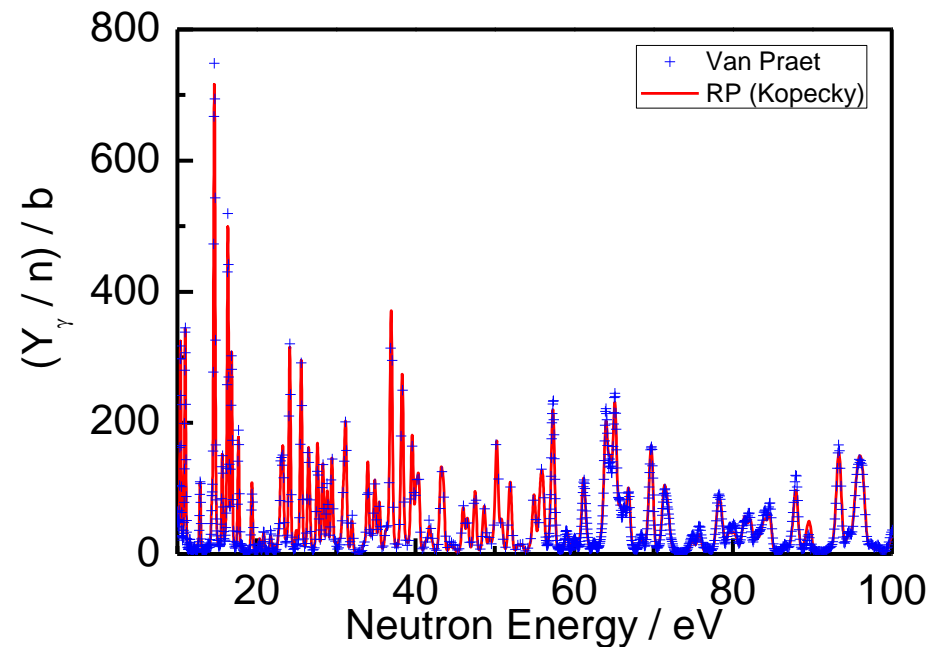
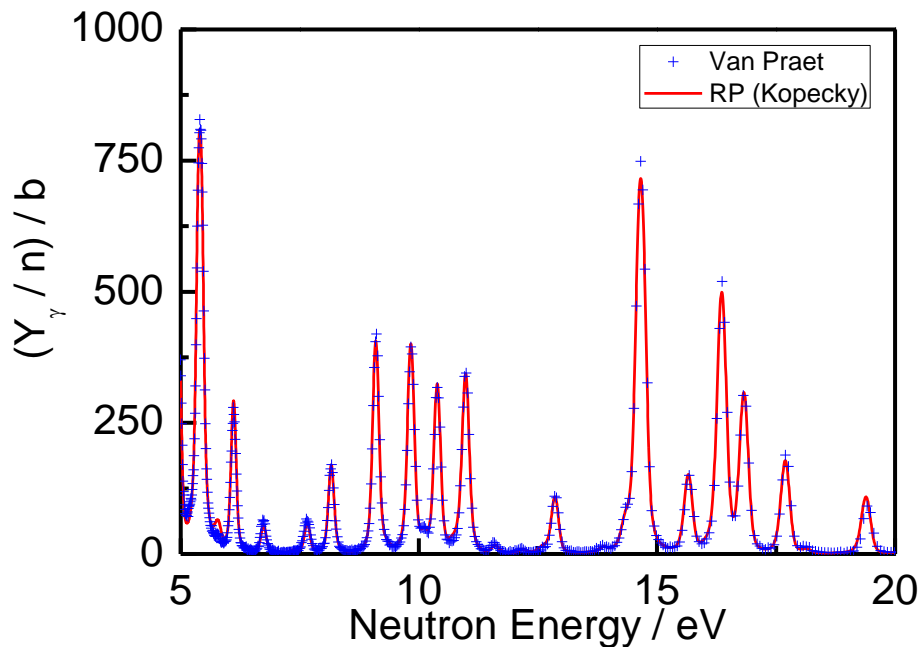
First three resonances

Jandel et al. : Electroplated
 Weston and Todd : $\text{AmO}_2 + \text{S}$ powder

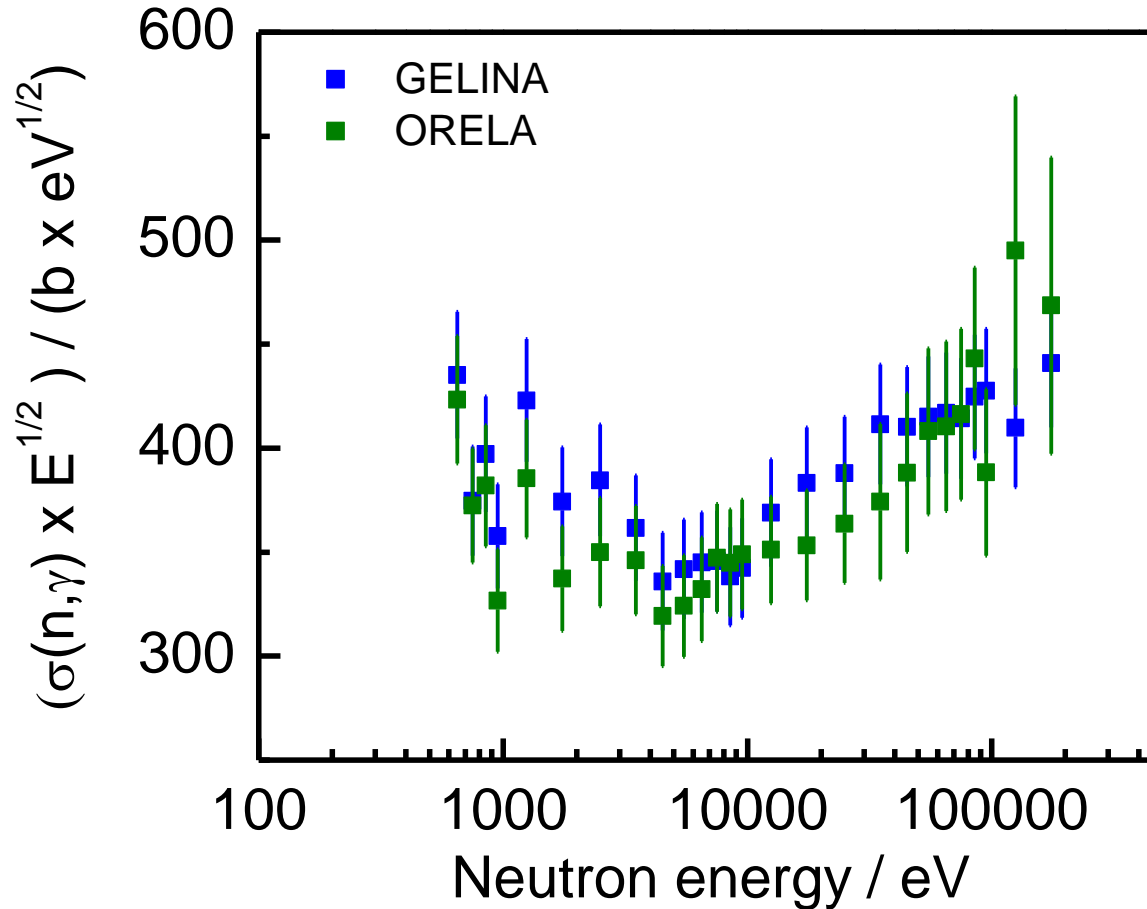
Van Praet et al. (GELINA, metallic sample) :

- normalized at saturated resonance
- no correction for γ - ray attenuation (Borella et al., NIMA 577 (2007) 626)

⇒ Normalization correction by 5% (REFIT)



$^{241}\text{Am}(n,\gamma) : \text{URR}$



+ KfK
Wisshak and Käppeler

Corrections for self-shielding and multiple collision ?

- **Data in RRR + resonance integrals**
 - $\sigma(n_{\text{th}}, \gamma)$: 5 %
 - Accuracy of 5% for $^{241}\text{Am}(n, \gamma) < 200$ eV (peak cross sections)

- **Data in URR: only (n, γ) data available**
 - Optical model calculations required to compensate for lack of total cross section data

- **Isomeric state**
 - RRR ?
 - URR (KfK)