European Commission

Evaluation of neutron induced reaction cross sections for ^{197}Au in the resonance region

NEMEA-7/CIELO
International Collaboration on Nuclear Data
A workshop of the Collaborative International Evaluated Library Organization
5-8 November 2013, Geel, Belgium

Bjorn Becker

http://irmm.jrc.ec.europa.eu

Joint Research Centre

Cross section of neutron induced reactions on ^{197}Au

Standard cross section ^{197}Au(n,γ)

- Thermal (0.0253 eV)
- 200 keV and 2.5 MeV

^{197}Au for neutron induced reactions between 4 keV and 200 keV is on the Nuclear Data High Priority Request List (HPRL)

Reference cross section for astrophysical calculations

Test-case for many nuclear reaction model codes

Same method will be used for ^{238}U within the CIELO context

Collaboration effort

International cooperative effort to improve cross section standards

- Working Party on International Evaluation Cooperation of the Nuclear Energy Agency Nuclear Science Committee (WPEC)
- Coordinated Research Project organized by the International Atomic Energy Agency (CRP IAEA)

Results presented are based on:

- I. Sirakov et al., "Results of total cross section measurements for ^{197}Au in the neutron energy region from 4 to 108 keV at GELINA", accepted for publication in EPJA
- C. Massimi et al., "Neutron capture cross section measurements for ^{197}Au from 4 to 80 keV at GELINA", in preparation

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Measurements at GELINA

FP #	FP length m	Capt.	Trams.	Sample	Thickness mm	Thickness at/b	Black Res. Filter	Anti-overlap Filter	Frequency Hz
4	50		x	^{197}Au	3	1.757 10^{-2}	Na, Co	^{10}B	800
4	50		x	OPB	-	-	Na, Co	^{10}B	800
4	50		x	BKG			Na, Co, S, W, Ag	^{10}B	800
5	12.5	x		^{197}Au	0.01	5.754 10^{-5}	Na, S	^{10}B	800
5	12.5	x		^{197}Au	0.52	3.026 10^{-3}	Na, S	^{10}B	800
5	12.5	x		^{197}Au	1.01	6.896 10^{-3}	Na, S	^{10}B	800
5	12.5	x		^{208}Pb	0.50	1.713 10^{-3}	Na, S	^{10}B	800
5	12.5	x		OPB	-	-	Na, S	^{10}B	800
5	12.5	x		BKG			Na, Co, S, W, Ag	^{10}B	800
15	28.9	x		^{197}Au	1.01	6.896 10^{-3}	Na, S	^{10}B	800
15	28.9	x		^{208}Pb	0.50	1.713 10^{-3}	Na, S	^{10}B	800
15	28.9	x		OPB	-	-	Na, S	^{10}B	800
15	28.9	x		BKG			Na, Co, S, W, Ag	^{10}B	800

Cross section parameterization in URR

Hauser-Feshbach statistical reaction theory with width fluctuations

- Compatibility with the energy-dependent options of the ENDF-6 SLBW approach
- Energy dependent distant level parameters: energy dependent scattering radius

Independent model parameters at zero neutron energy:

- Scattering radius R' independent of the orbital angular momentum l
- Neutron strength functions $S_{n,l=0,1,2}$ for s-, p- and d-waves (l = 0,1 and 2)
- Capture transmission coefficients $T_{\gamma,0}^{2+}$ and $T_{\gamma,0}^{2-}$ for s- and p-waves

Smooth and weak energy dependence taken from optical model calculations with the dispersive coupled channel optical model (DCCOM) potential

^{197}Au(n,tot)

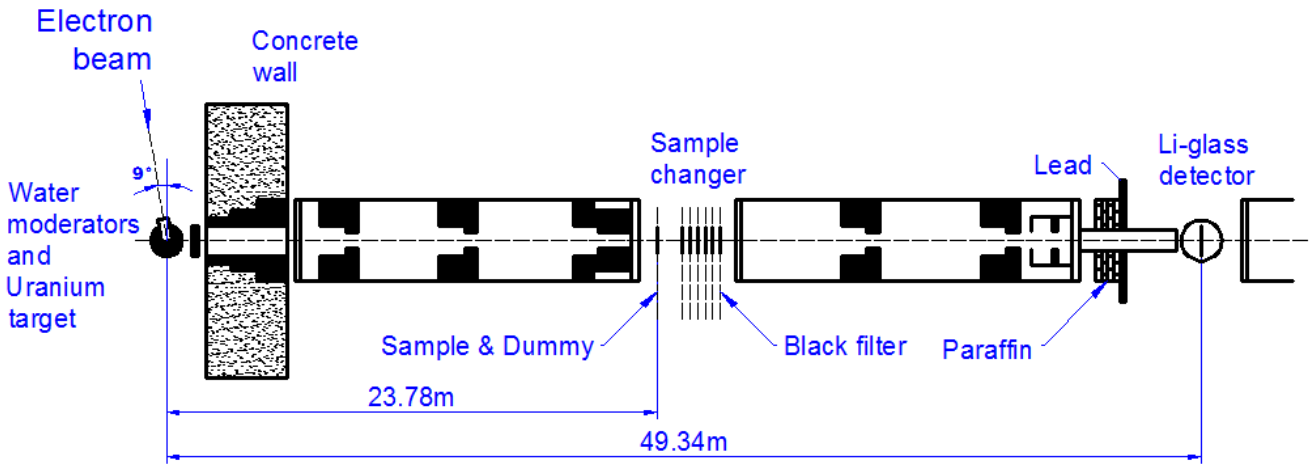
Measurement of the ^{197}Au(n,tot) cross section - Setup

Measurement at GELINA

- Flight path: 50 m

Filters:

- Anti-overlap filter: ^{10}B
- Permanent black resonance filters: Na and Co
- Additional filters: S, W, and Ag



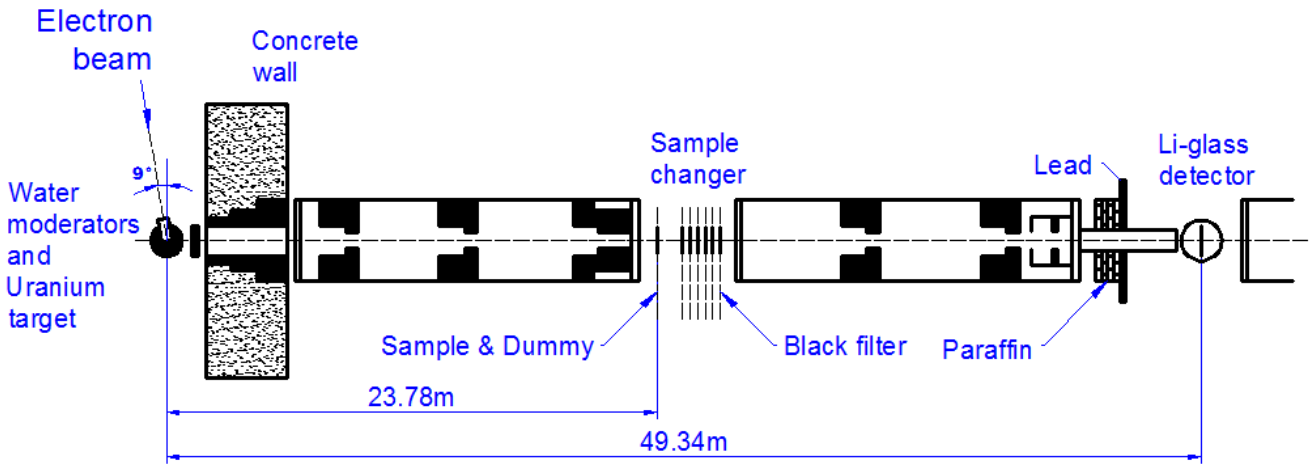
Measurement of the ^{197}Au(n,tot) cross section - Setup

Detector:

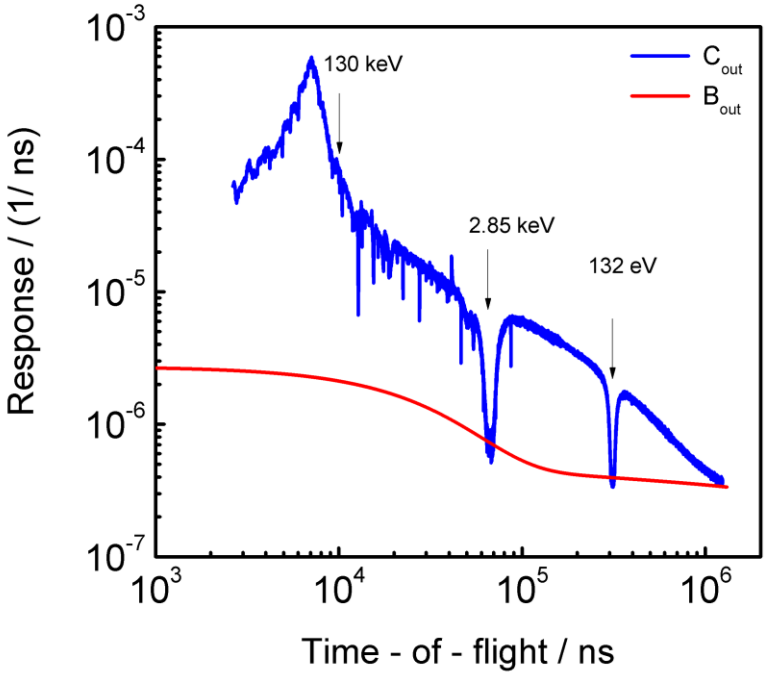
- NE912 Li-glass scintillator enriched to 95% in ^{6}Li
- EMI 9823 KQB photomultiplier

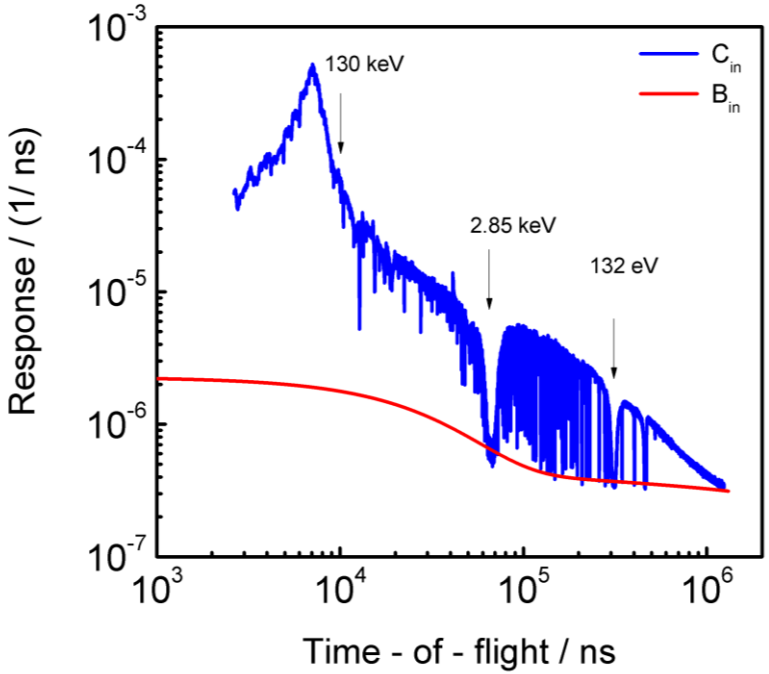
Sample details:

- Au metal foil
- 50 mm x 50 mm x 3 mm
- (1.757 ± 0.004) 10^{-2} at/b



Count rate spectra





$$T_{exp} = N\frac{C_{in} - KB_{in}}{C_{out} - KB_{out}}$$

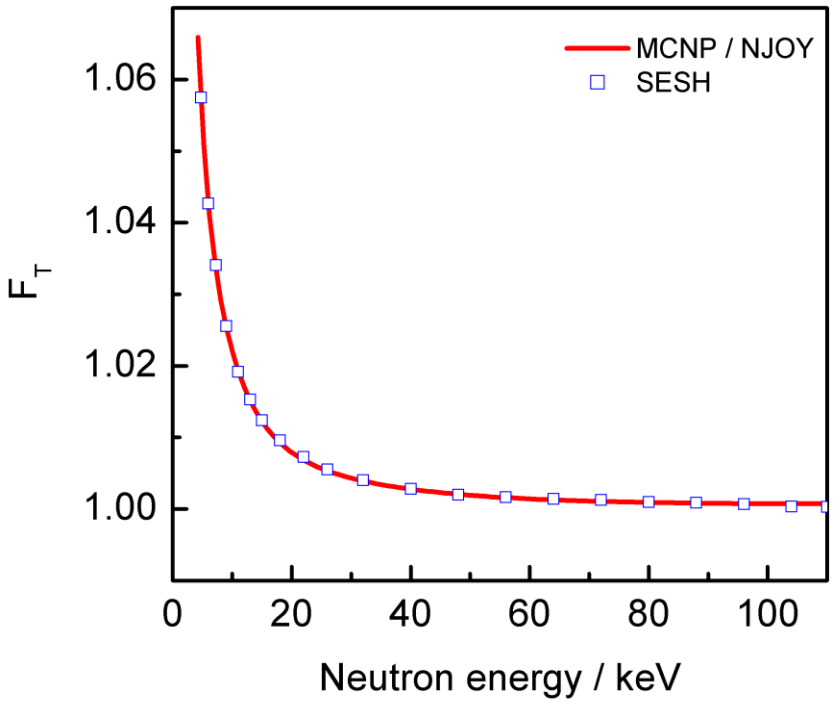
N=1.00±0.0025
K=1.00±0.03

Resonance self-shielding correction

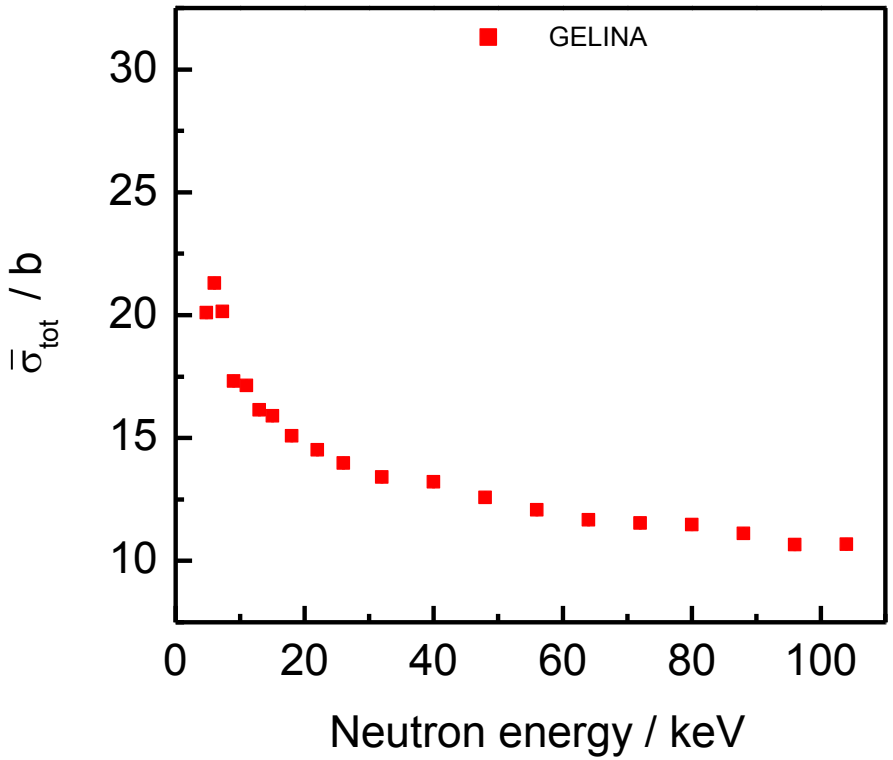
Correction factor based on:

- Resonance sampling with the SESH code
- MCNP simulation with probability tables produced by NJOY

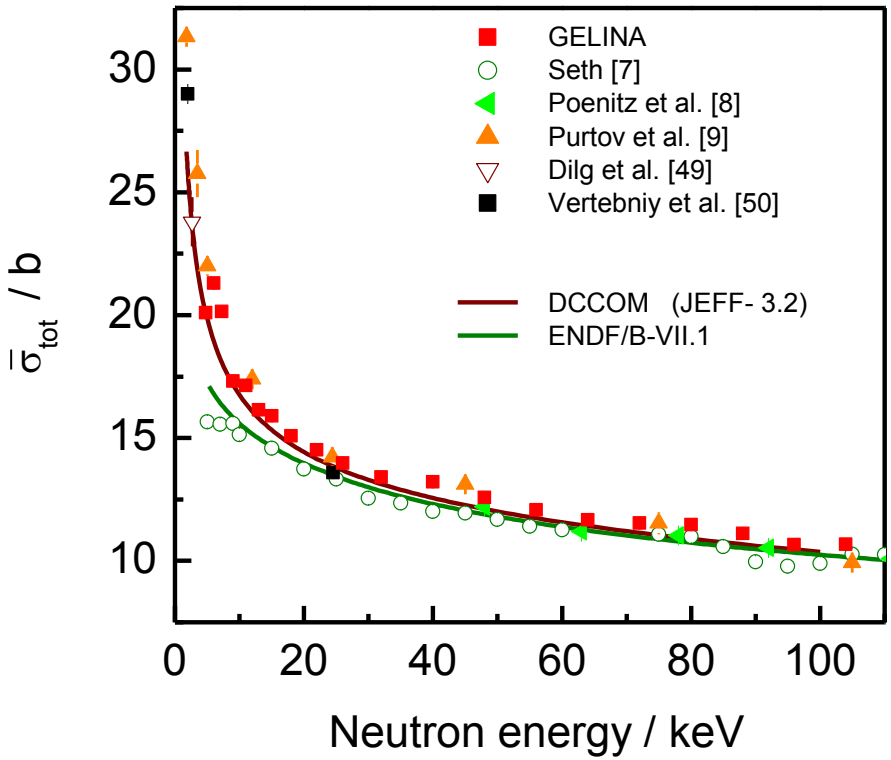
$$\overline{\sigma}_{tot} = \frac{-1}{n} \ln \frac{\overline{T}_{exp}}{F_T}$$



^{197}Au(n,tot) cross section in URR



^{197}Au(n,tot) cross section in URR



Final experimental data in AGS format

AGS format:

- Efficient for storage
- Full separation of different components
- Vectrorized uncertainty components

Final uncertainty:

less than 2.5 %

E_l / eV	E_h / eV	F_T	$\overline{\sigma}_{tot}$ / b	$u_{\overline{\sigma}_{tot}}$ / b	AGS			
					u_u / b	S_K / b	S_N / b	S_n / b
4000	5500	1.058	20.10	0.22	0.12	0.11486	-0.14226	0.04020
5500	6500	1.043	21.30	0.23	0.15	0.09843	-0.14226	0.04259
6500	8000	1.034	20.15	0.20	0.12	0.07380	-0.14226	0.04030
8000	10000	1.026	17.31	0.20	0.12	0.06558	-0.14226	0.03462
10000	12000	1.020	17.13	0.20	0.13	0.06282	-0.14226	0.03424
12000	14000	1.015	16.14	0.21	0.13	0.05627	-0.14226	0.03227
14000	16000	1.012	15.90	0.21	0.14	0.05469	-0.14226	0.03180
16000	20000	1.010	15.09	0.19	0.12	0.05188	-0.14226	0.03017
20000	24000	1.007	14.51	0.20	0.12	0.04578	-0.14226	0.02901
24000	28000	1.006	13.98	0.20	0.13	0.04452	-0.14226	0.02796
28000	36000	1.004	13.41	0.19	0.11	0.04412	-0.14226	0.02682
36000	44000	1.003	13.22	0.20	0.13	0.04263	-0.14226	0.02643
44000	52000	1.002	12.58	0.20	0.13	0.03287	-0.14226	0.02516
52000	60000	1.002	12.08	0.20	0.14	0.03249	-0.14226	0.02416
60000	68000	1.001	11.67	0.20	0.13	0.02258	-0.14226	0.02335
68000	76000	1.001	11.53	0.20	0.14	0.02152	-0.14226	0.02305
76000	84000	1.001	11.47	0.25	0.20	0.04124	-0.14226	0.02293
84000	92000	1.001	11.11	0.22	0.17	0.02326	-0.14226	0.02221
92000	100000	1.001	10.65	0.21	0.15	0.01676	-0.14226	0.02130
100000	108000	1.001	10.68	0.21	0.15	0.01376	-0.14226	0.02135

Sensitivity & Resonance Parameters

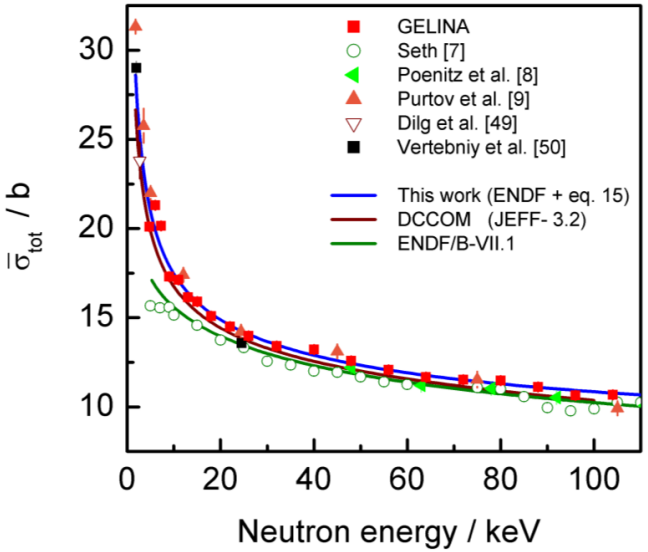
Model parameter adjustment

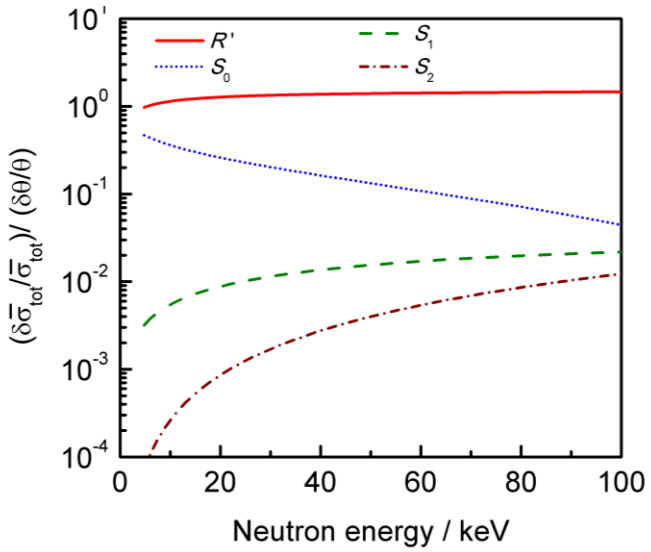
- Measurement sensitive to R' and S_0
- Fixed values for S_1 and S_2

  $S_1 = 5.64\ \ 10^{-5}$

  $S_2 = 3.48\ \ 10^{-4}$

			Correlation matrix	
R' / fm	9.12	± 0.09	1	-0.43
S_0 / 10^{-4}	1.93	± 0.03	-0.43	1



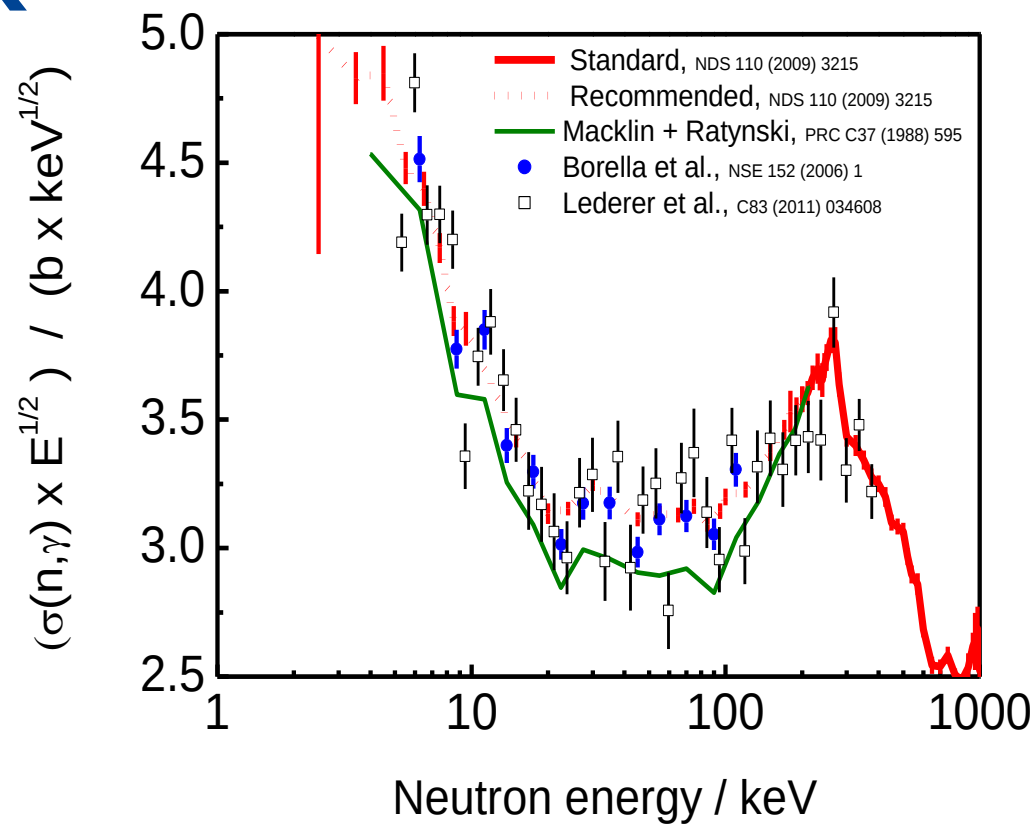


European Commission

$^{197}Au(n,\gamma)$

Joint Research Centre

Status of the ^{197}Au(n,γ) cross section in URR



Measurement of the $^{197}Au(n,\gamma)$ cross section - Setup

Measurements at GELINA:

- Flight path: 12.5 m and 30 m
- Collimation: 80 mm in diameter at the sample position
- ^{10}B anti-overlap filter
- Fixed Na and S black resonance filters
- Additional filters: Co, W, Ag

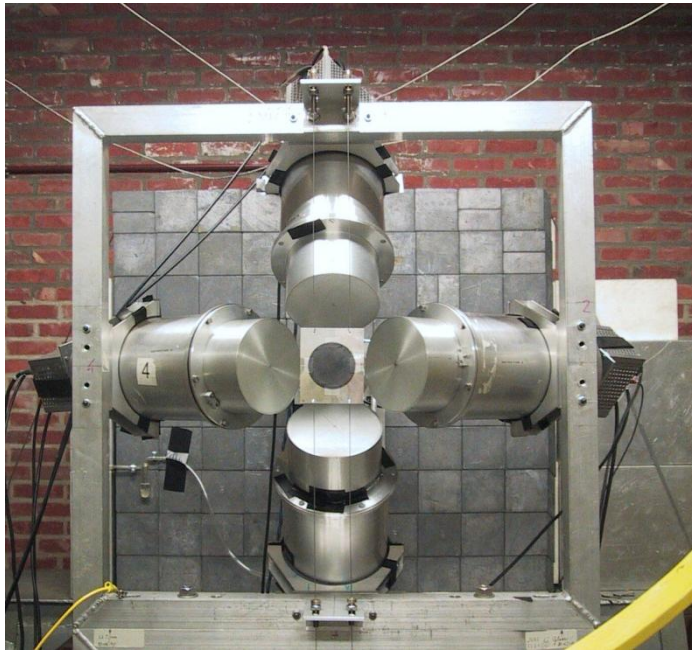
Flux measurement:

- ^{10}B Frisch gridded ionisation chamber
- Double chamber with a common cathode loaded with two layers of ^{10}B.
- 80 cm before the sample

Measurement of the $^{197}Au(n,\gamma)$ cross section - Setup

Prompt γ detection system:

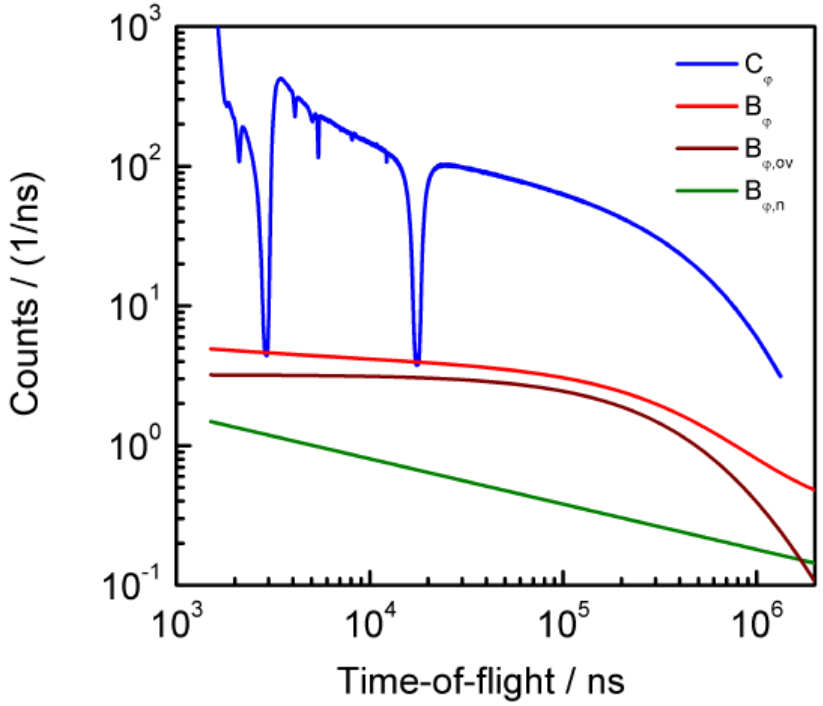
- C_6D_6-based liquid scintillators (NE230) at an angle of 125°
- boron-free quartz windowed EMI9823-KQB photomultiplier
- total energy detection principle in combination with the pulse height weighting technique

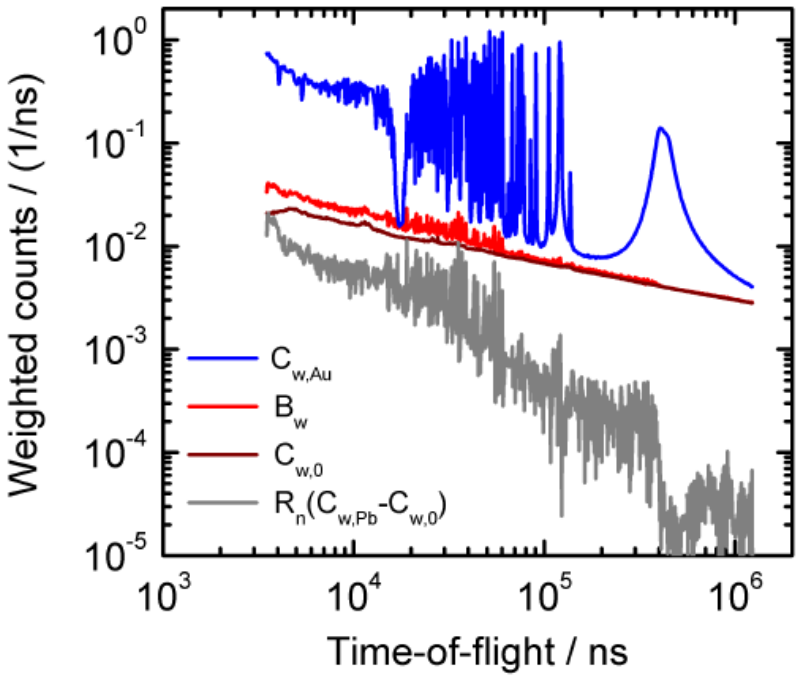


Sample details:

- 3 Au samples with different thickness
- ^{208}Pb sample for neutron sensitivity

Count rate spectra

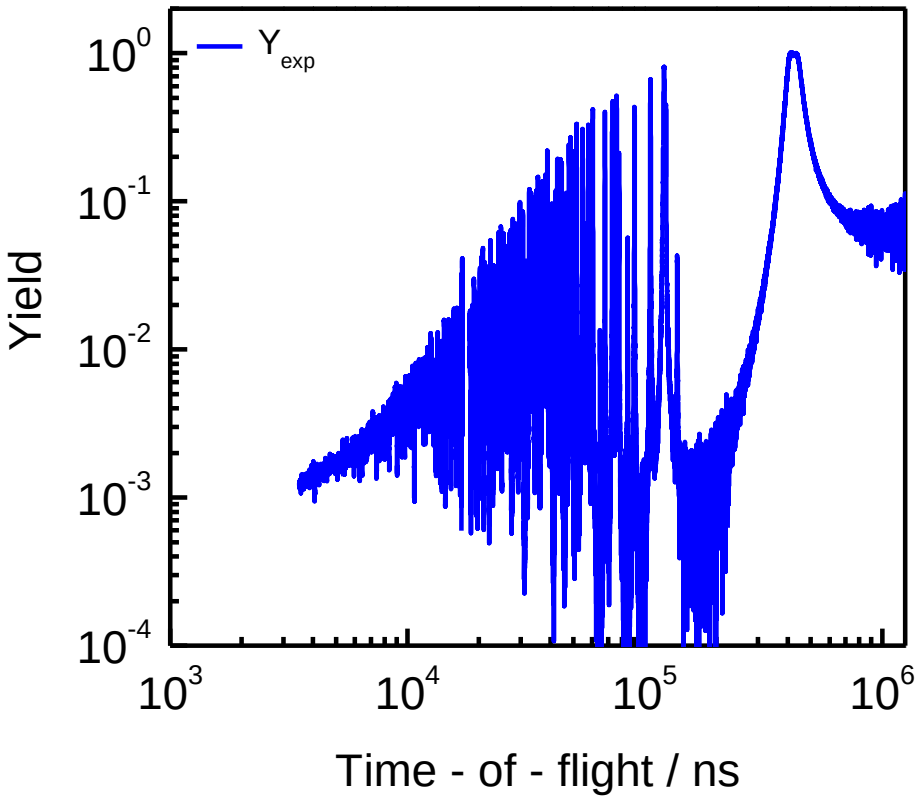




$$B_\varphi(t) = a_0 + a_1 t^{-b_1} + a_2 (t + t_0)^{b_2}$$

$$B_w(t) = b_0 + k_1 C_{w,0}(t) + k_2 R_n(t)\,[C_{w,Pb}(t) - C_{w,0}(t),]$$

Capture yield



$$Y_{\mathrm{exp}} = \frac{N_C}{S_n + E_n \frac{A}{1+A}} \frac{C_w - B_w}{C_\varphi - B_\varphi} \frac{Y_\varphi}{T_\varphi}$$

$$\frac{Y_\varphi}{T_\varphi} = e^{n_\varphi \sigma_{tot}} \left(1 - e^{-n_\varphi \sigma \mathrm{tot}}\right) \frac{\sigma_\alpha}{\sigma_{tot}}$$

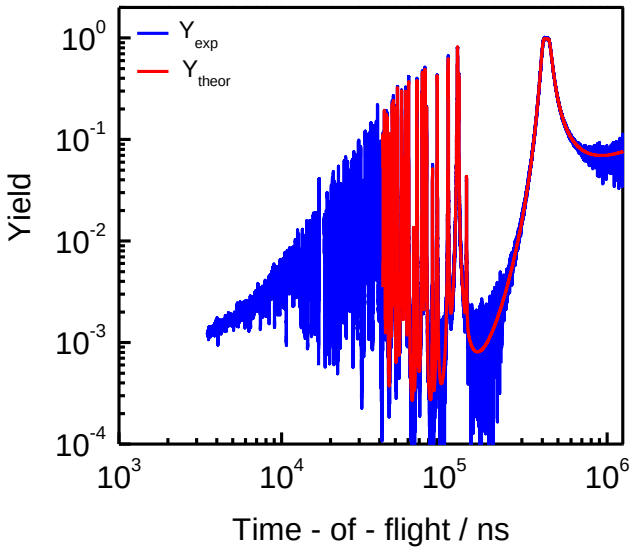
Normalization

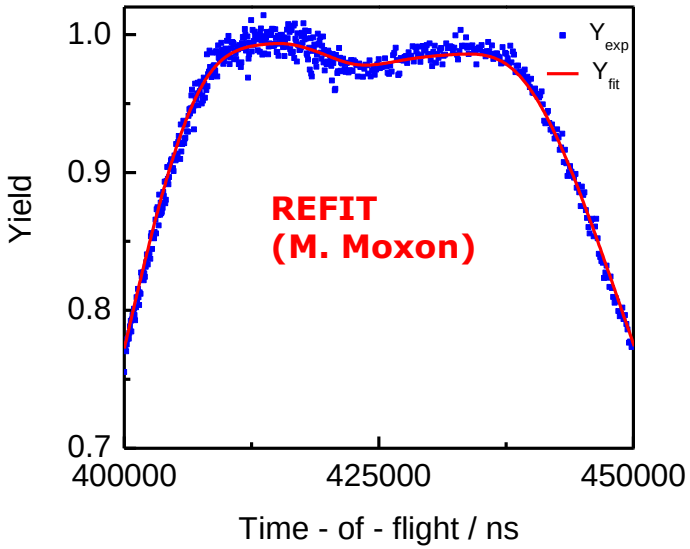
Internal normalization:

- Saturated resonance at 4.9 eV with $\Gamma_n << \Gamma_\gamma$
- No reference cross section except for shape of $^{10}B(n,\alpha)$
- Uncertainty less than 1%

$$Y_{exp} = N \frac{C_w - B_w}{C_\varphi - B_\varphi} Y_\varphi$$

Thickness mm	Area cm^2	N_C	$N'_{C,51.45}$
1.01	51.22	0.995	0.991
0.52	51.45	1.000	1.000
0.01	50.39	1.026	1.005



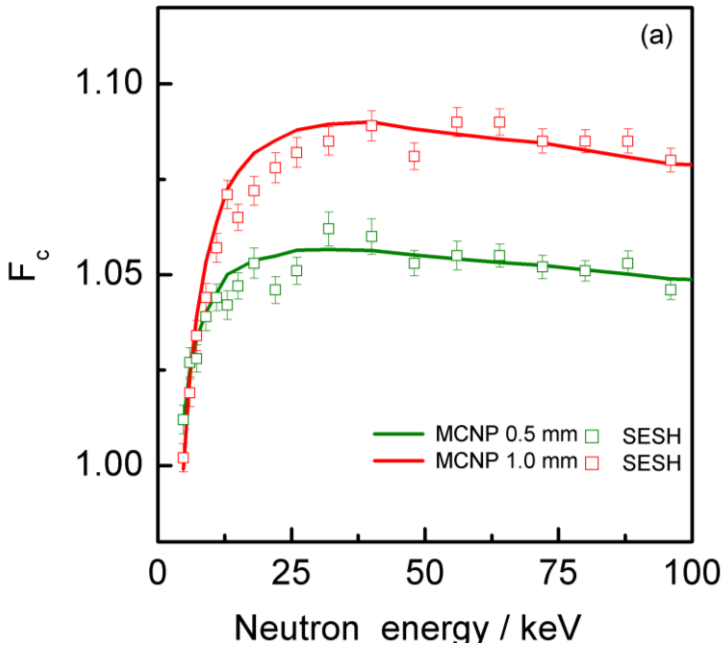


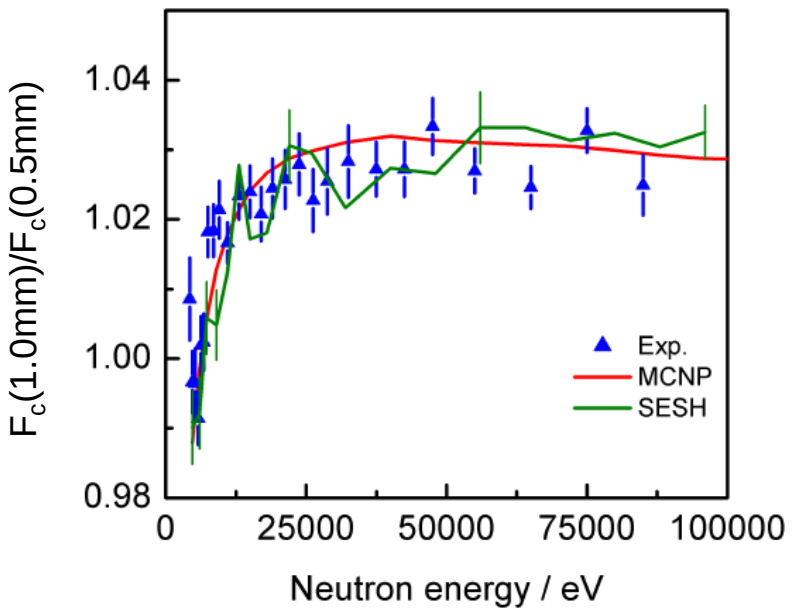
Self-shielding, multiple interaction correction

Correction factor based on:

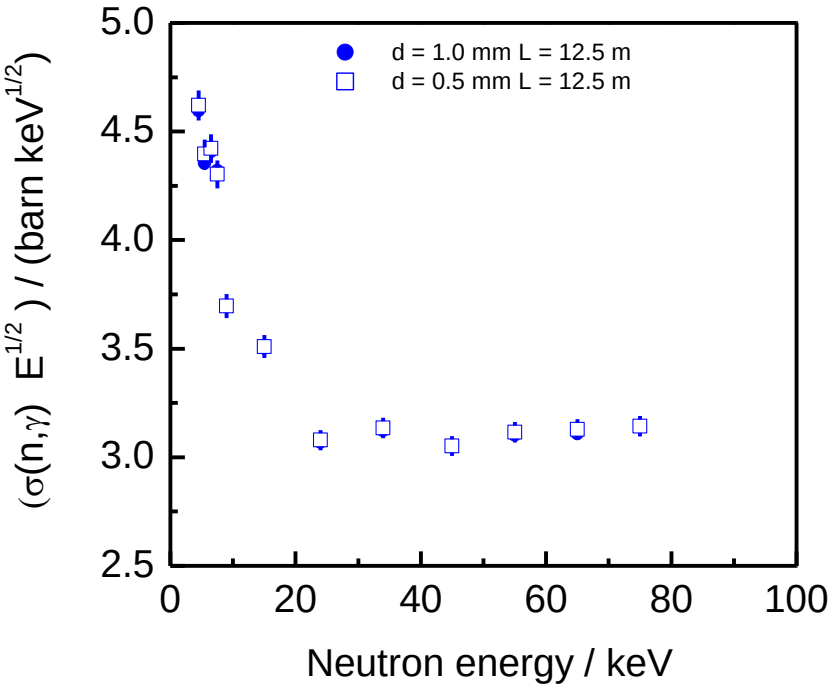
- Resonance sampling with the SESH code
- MCNP simulation with probability tables produced by NJOY

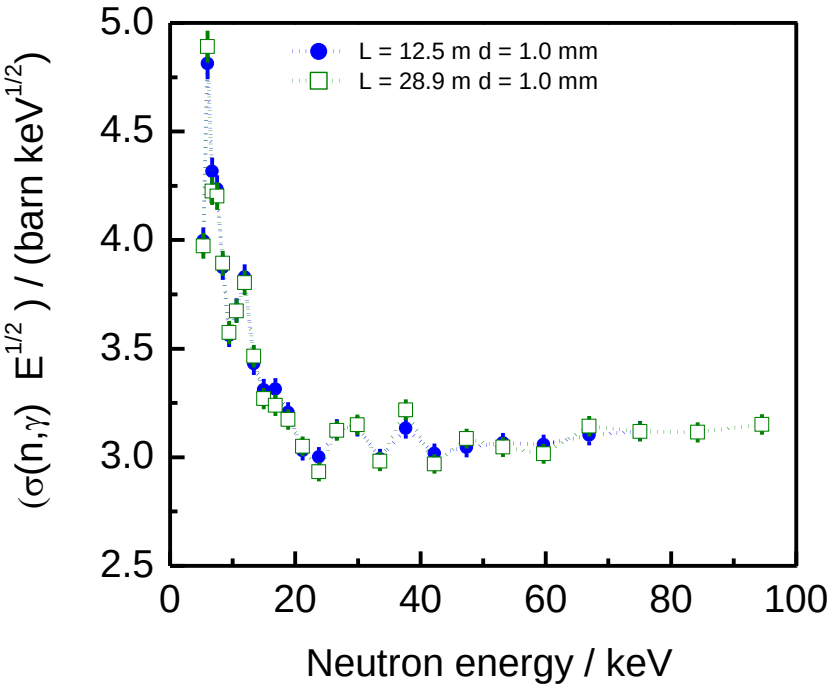
$$\overline{Y}_{\mathrm{exp}} = F_c n \overline{\sigma}_{\gamma}$$



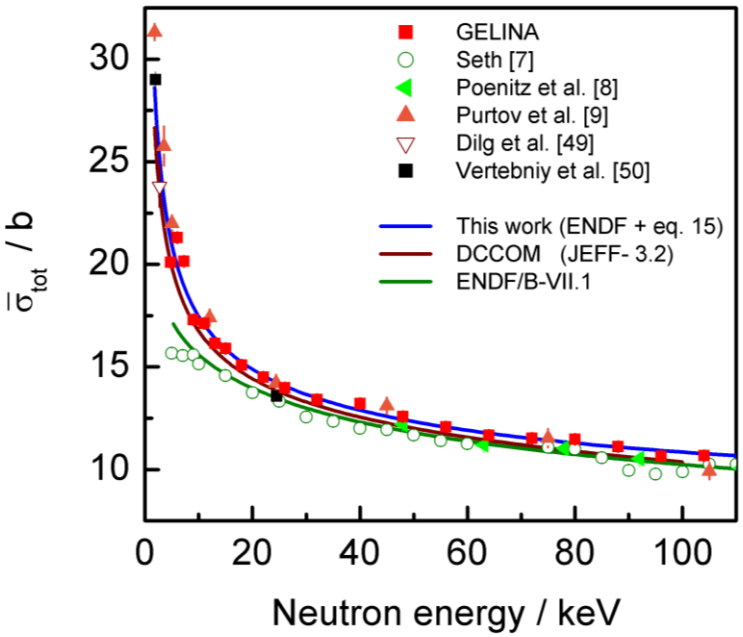


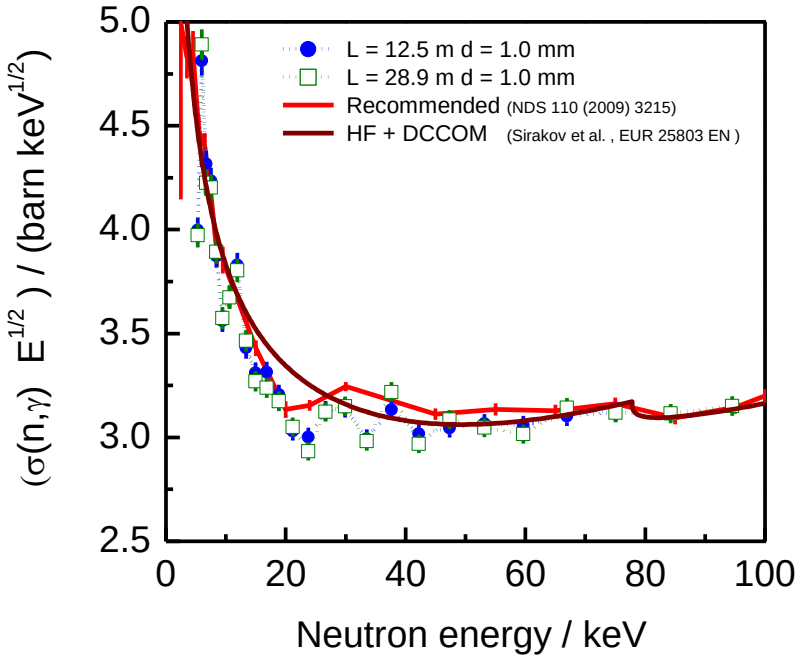
^{197}Au(n,γ) cross section





^{197}Au(n,tot) & ^{197}Au(n,γ) cross section





Both results will be used in the parameterization of the URR
(R', $S_{n,l=0,1,2}$, $T_{\gamma,0}^{2+}$, $T_{\gamma,0}^{2-}$)
+ HZDR nELBE data (100 keV to 10 MeV)

Verification of new parameters

Data processing with NJOY.99 to format and application consistency

MCNP Simulation of benchmark measurements:

- Thick sample time-of-flight capture measurement
  - Both capture and scattering sensitivity
  - Energy dependence

- Lead Slowing Down Spectrometer measurement
  - Lower resolution but still energy dependent
  - High flux

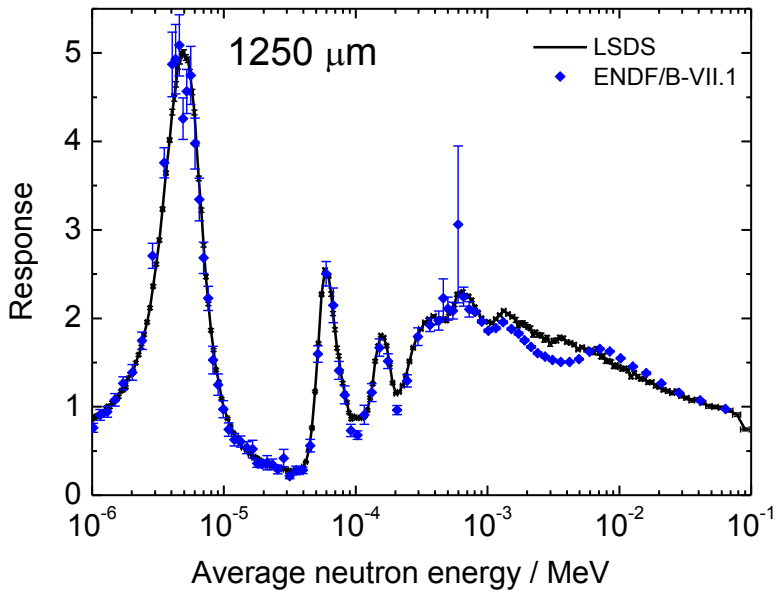
LSDS measurements

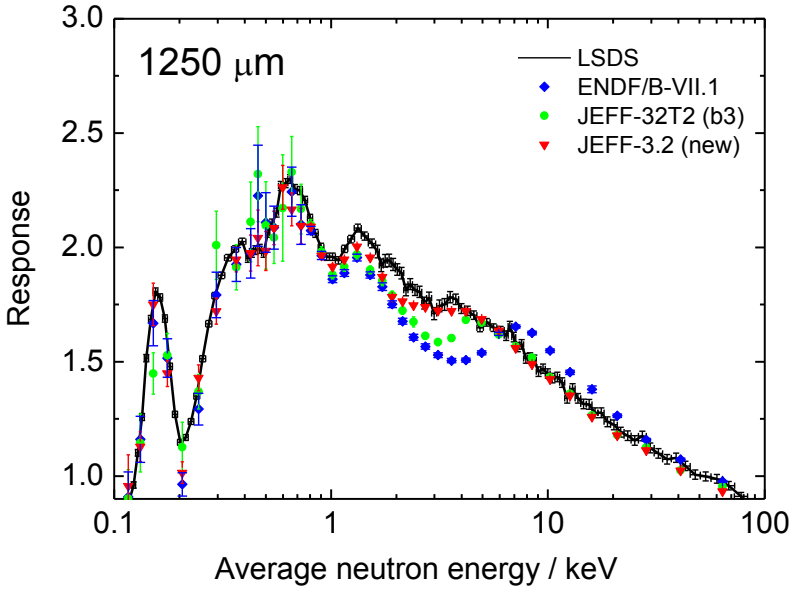
Simulation of a LSDS measurement from LPSC IN2P3:

- MCNP simulation
- Cross section data preparation with NJOY
- Simulation includes resolution of the spectrometer

Independent of the measurements to deduce the cross section.

Challenging method for capture.



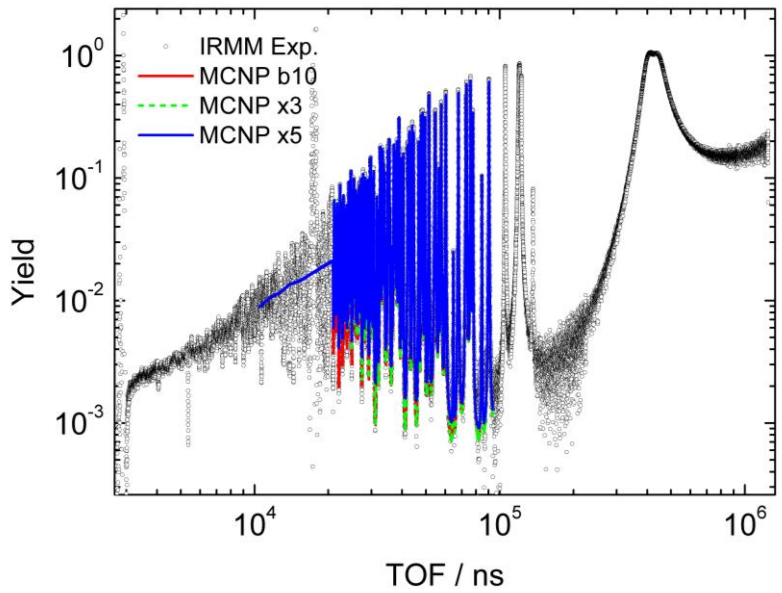


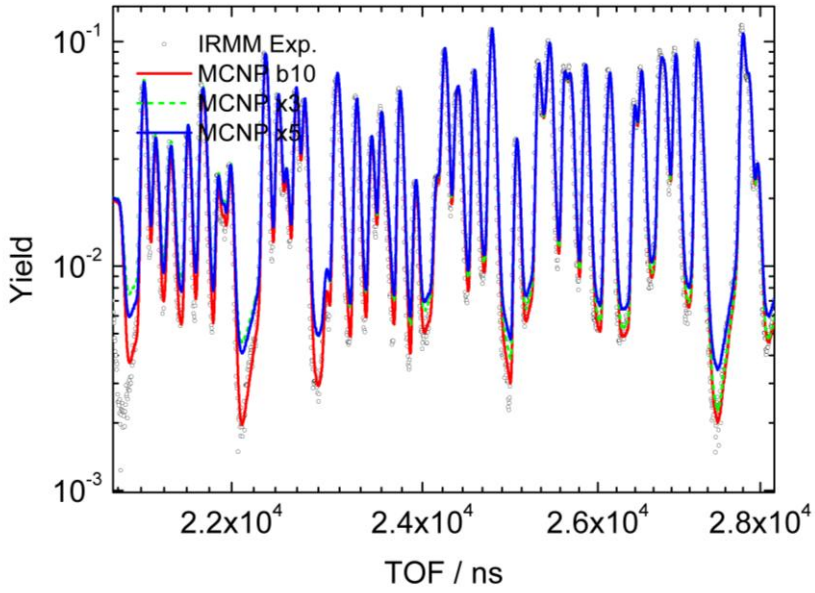
Thick sample measurements

Simulation of a thick sample measurement:

- MCNP simulation
- Cross section data preparation with NJOY
- Simulation includes resolution of the spectrometer
- Sensitive to capture and scattering

Energy dependence: advantage over integral benchmarks





Conclusion

Summarized work is the result of an international collaboration.

New evaluation of gold resonance parameters in the RRR and in particular in the URR is currently being performed.

The final parameterization is checked against thick target TOF and LSDS measurements.

European Commission

Contributors:

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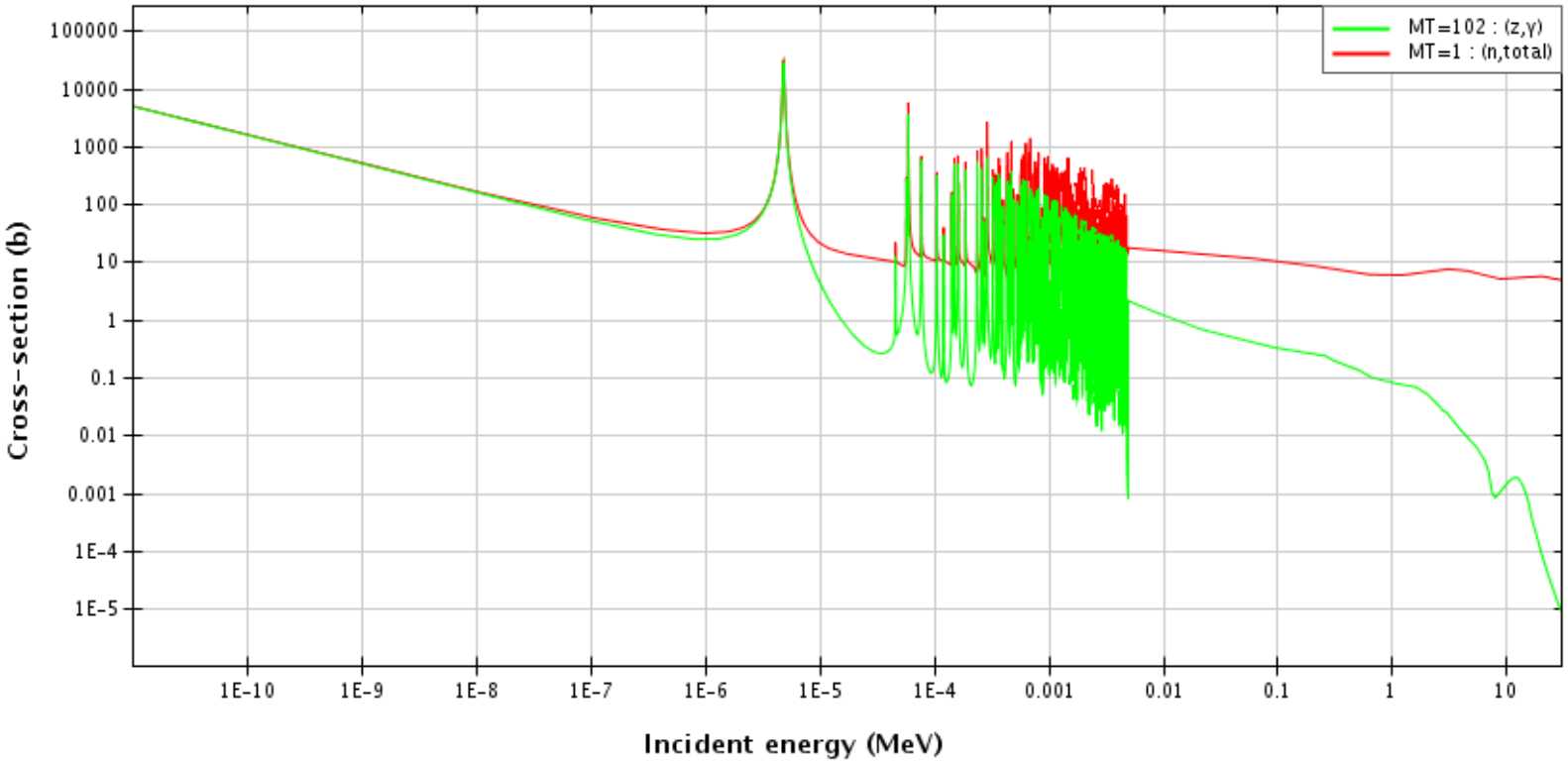
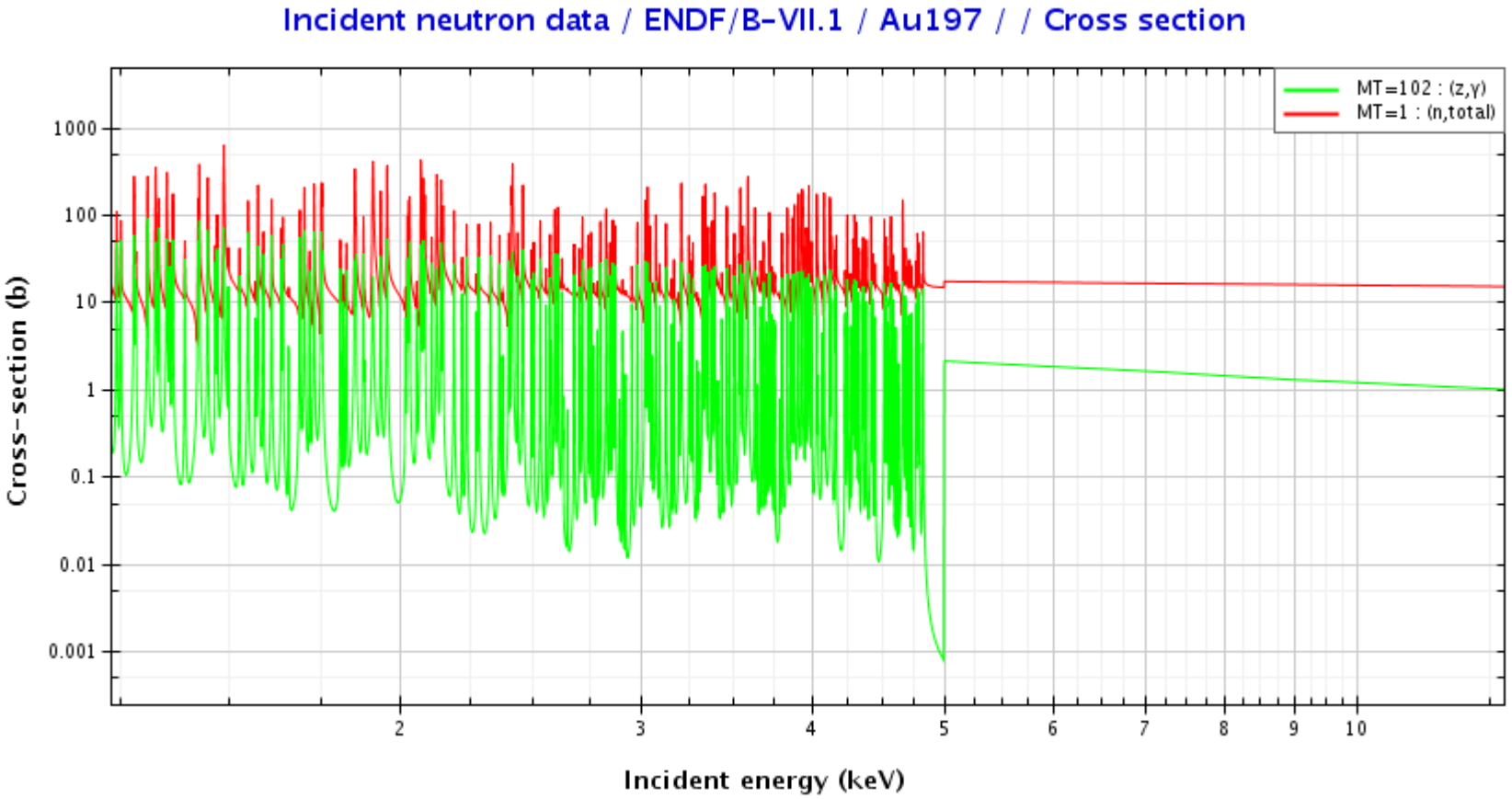
Thank you for your attention

Joint Research Centre

Incident neutron data / ENDF/B-VII.1 / Au197 / / Cross section




Incident neutron data / ENDF/B-VII.1 / Au197 / / Cross section
MT=102 : (z,γ)
MT=1 : (n,total)
Cross-section (b)
1000
100
10
1
0.1
0.01
0.001
2
3
4
5
6
7
8
9
10
Incident energy (keV)

Resonance parameters

Update of resonance parameters in the RRR (< 2keV) based on new transmission and capture measurements at GELINA

Energy eV	ℓ $\hbar$	J^π $\hbar$	Γ_γ meV	Γ_n meV	$g\Gamma_n$ meV
4.900 ± 0.002	0	2	121.4 ± 0.3	14.96 ± 0.02	
46.669 ± 0.002	0^a	1^a	127 ± 8		0.08 ± 0.01
58.078 ± 0.004	0^a	1^a	113 ± 3		1.60 ± 0.01
60.291 ± 0.001	0	2	118 ± 6	70.7 ± 0.5	
78.500 ± 0.003	0	1	124 ± 5	17.0 ± 0.2	
107.033 ± 0.004	0^a	2^a	123 ± 3		4.89 ± 0.05
122.30 ± 0.02	0^a	1^a	121^b		0.56 ± 0.013
144.410 ± 0.005	0	1	121^b	9 ± 1	
151.393 ± 0.004	0	2	121^b	22.3 ± 0.4	
163.07 ± 0.01	0	1	129 ± 10	55.2 ± 0.08	
165.08 ± 0.01	0^a	2^a	121^b		6.34 ± 0.09
190.03 ± 0.02	0^a	1^a	121^b		18.41 ± 0.03

[a] No conclusive assignment.
[b] Average radiation width.