Cross section measurements for ^{103}Rh + n in the resonance region at GELINA

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Motivation

- **Spent Nuclear Fuel (SNF) criticality** calculations are required for a **safe**, **secure**, **ecological** and **economic** handling, transport, intermediate storage and final disposal.
- **Burnup credit**: accounts for reduction in reactivity of SNF due to fuel burnup. More cost-effective, but requires inventory (burnup history) and comprehensive use of nuclear data

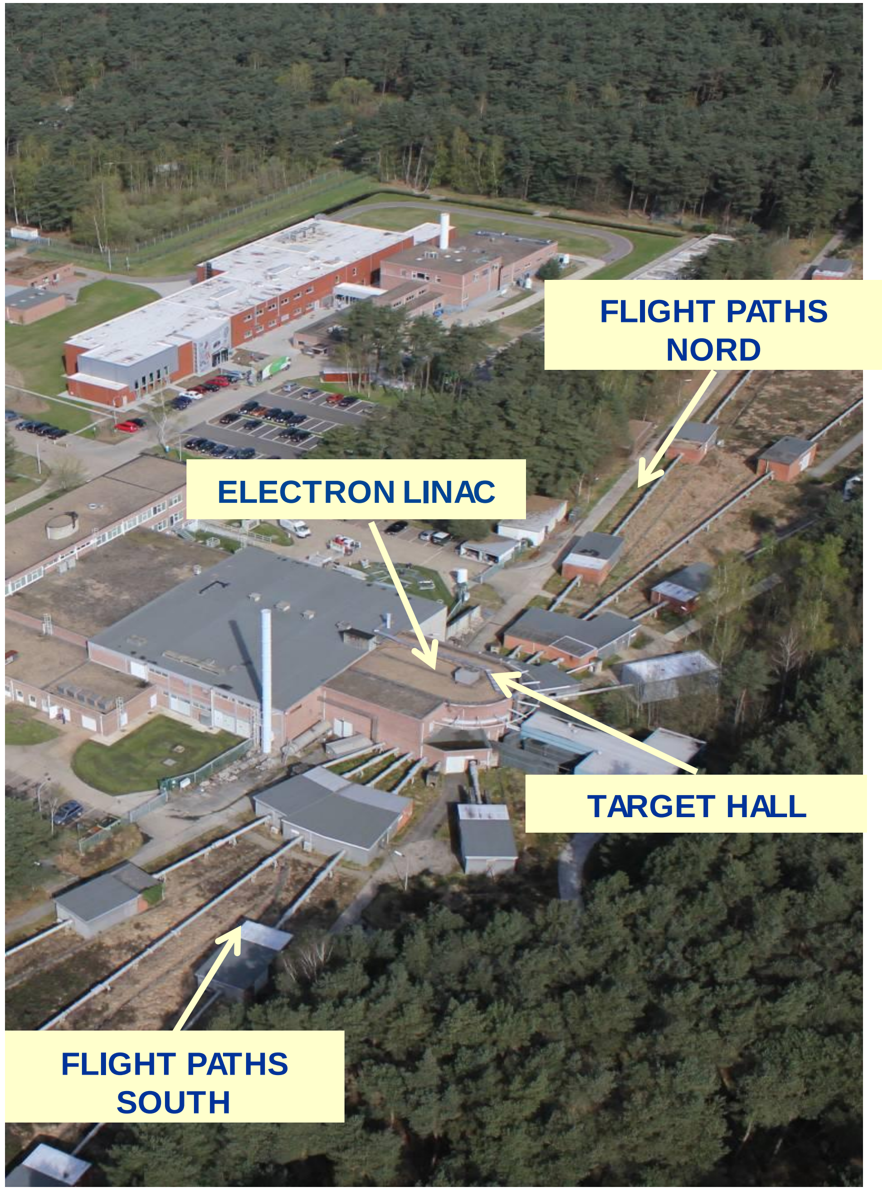
Dedicated programme [CEA Cadarache -JRC Geel] to improve the status of cross sections for fission products important for criticality safety studies. => total +capture xs

- ^{103}Rh is an important nuclide for any criticality safety assessment relying on a BUC approach including fission products.
- High absorption cross section and high production rate in nuclear reactors.
- ^{103}Rh(n,γ) cross section in the energy region important for Light Water Reactors are overestimated by about 10%.

Oscillator meas. at MINERVE. Calc. and Exp. reactivity 100*(C-E)/C

Sample	Over-thermalized	BWR	PWR-UO2	PWR-MOX
^{103}Rh	-0.4 (81)	8.3 (29)	11.7 (33)	10.8(40)

GELINA: Geel Electron LINear Accelerator



- **Electron linac** driven pulsed white neutron source **(10 meV < En < 20 MeV)**
- Neutron energy : **time – of – flight** (TOF)
- **Multi-user facility**: 12 flight paths (10 m – 400 m)
- Measurement stations with **special equipment**:
  - Total cross section measurements
  - Partial cross section measurements

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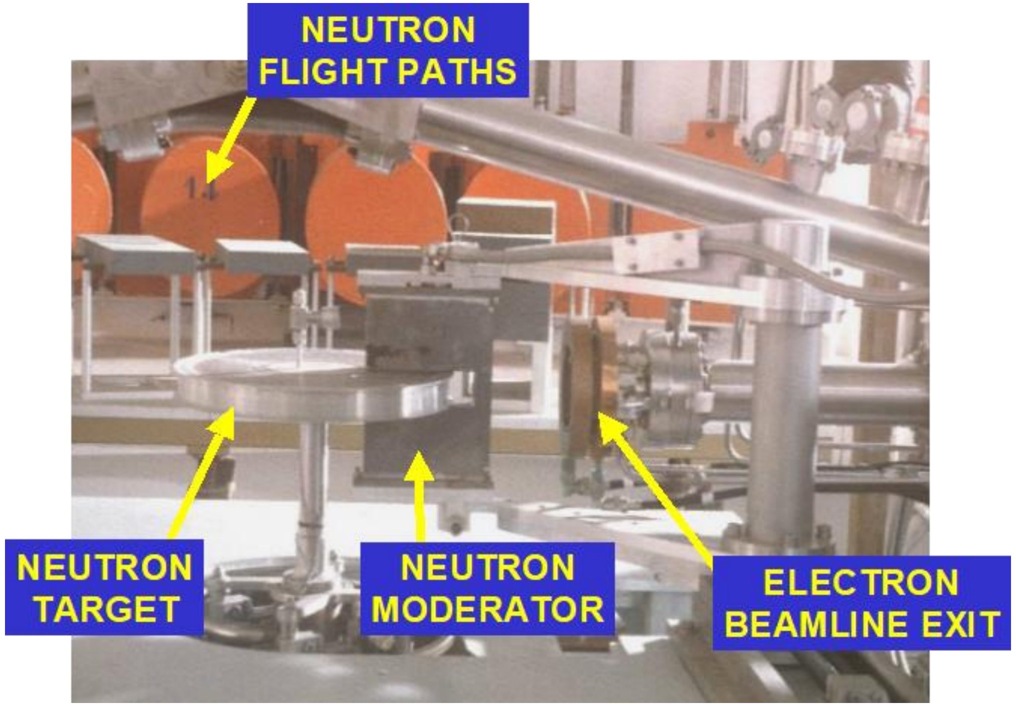
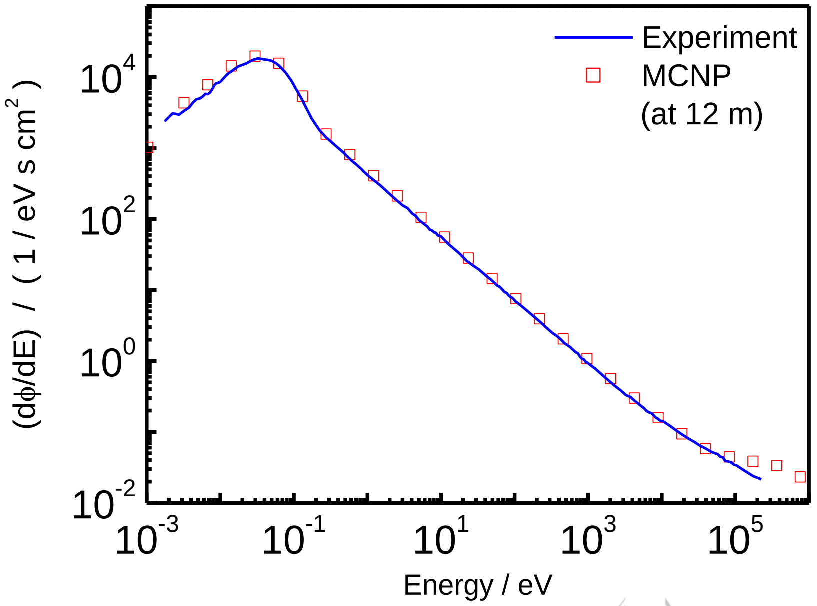
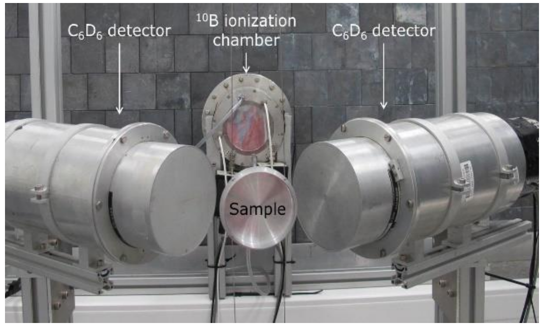
GELINA : neutron production

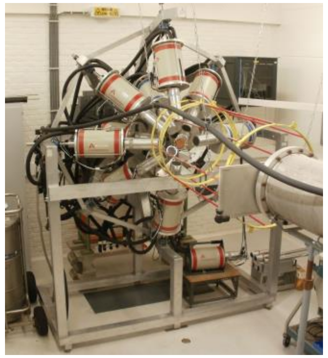


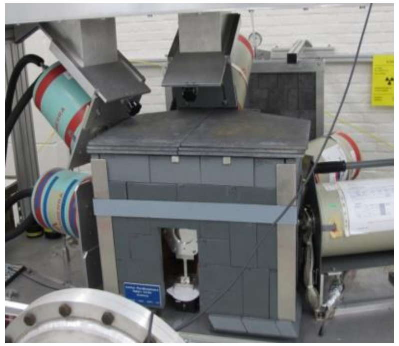
- e^- accelerated to $E_{e-,max}$ ≈ 140 MeV
- Bremsstrahlung in U-target
  - (rotating & cooled with liquid Hg)
- (γ , n) , (γ , f) in U-target
- Low energy neutrons by moderation
  (water moderator in Be-canning)



GELINA - Experimental set-ups







- Transmission
  - 10 m, 30 m, 50 m
- Capture
  - 10 m, 30m, 60 m
- Elastic, in-elastic scattering
  - 30 m
- In-elastic scattering (n,n'γ)
  - 30 m, 100 m
- Fission, (n,p), (n,α)
  - 10 m

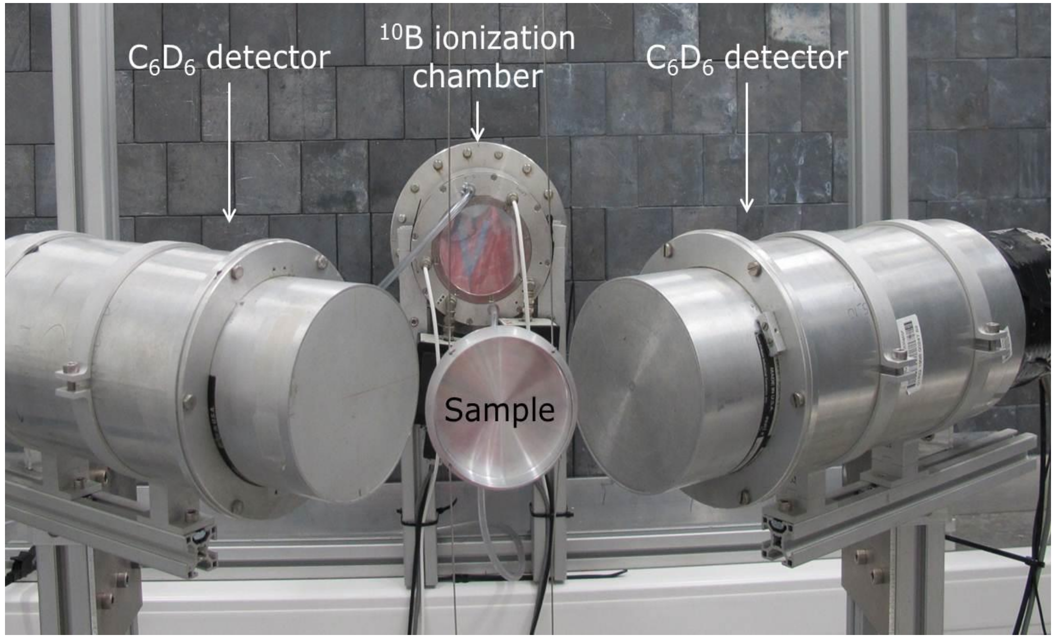
GELINA – (n,γ) at FP5- 12.5 m

- Total energy detection principle
  - C_6D_6 liquid scintillators
    (Boron free quartz window!)
  - 125º
  - Pulse Height Weighting Technique

$$C_w = \int C_c(E_d)\, WF(E_d)\, dE_d$$

$$\varepsilon_\gamma \propto E_\gamma \quad \Rightarrow \quad \varepsilon_c \propto S_n + E_n \frac{A}{1+A}$$

- WF: from MC simulations
- Fluence rate measurements (IC)
  - **$^{10}B(n,\alpha)$**



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

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Total energy detection principle

Probability to detect capture event = efficiency to detect at least one γ-ray

$$\varepsilon_c = 1 - \prod_i (1 - \varepsilon_{\gamma,i})$$

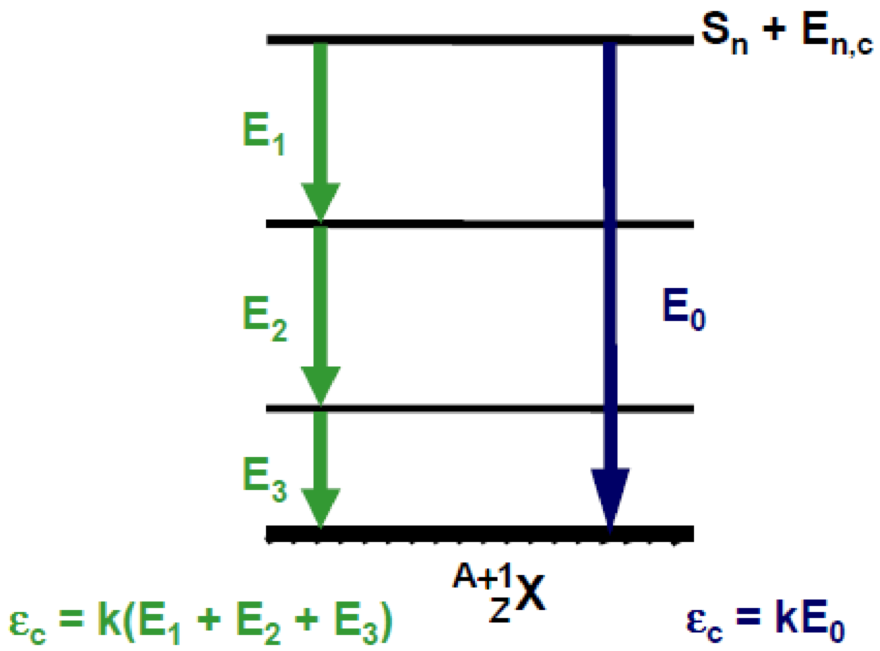
1) Detection efficiency: $\varepsilon_\gamma << 1$

$$\varepsilon_c \approx \sum_i \varepsilon_{\gamma,i}$$

2) Detection efficiency: $\varepsilon_\gamma = kE_\gamma$

$$\Rightarrow \varepsilon_c \approx \sum_i \varepsilon_{\gamma,i} = k \sum_i E_{\gamma,i} \approx k(S_n + E_{n,c})$$

independent of γ-ray cascade



Capture measurements

- Moderated neutron beam, 50Hz, 15 days
- ^{103}Rh - 80 mm diameter metallic disc, 0.26 mm thickness, 15.663 g
- ^{197}Au - 0.5 mm thick (normalisation)
- ^{208}Pb (neutron induced background)
- Cd 0.05mm (flight path length determination)
- No sample meas.(sample independent bkg characterisation)
- Black resonance filters (S, Na, Co(fixed))
- Black resonance filters W, Ag for flux bkg
- Pb filters to attenuate the γ-flash

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Data reduction

<u>A</u>nalysis of <u>G</u>eel <u>S</u>pectra (AGS)

- Transforms count rate spectra into observables (transmission, yields)
- Full uncertainty propagation starting from counting statistics
- Output: complete covariance matrix

- Special format for covariance matrix
  - Reduce space for data storage (<u>EXFOR</u>)
  - Document the sources of uncertainties due to each step in the data reduction process
  - Verify the contribution of <u>each quantity</u> introducing <u>a correlated uncertainty component</u>!

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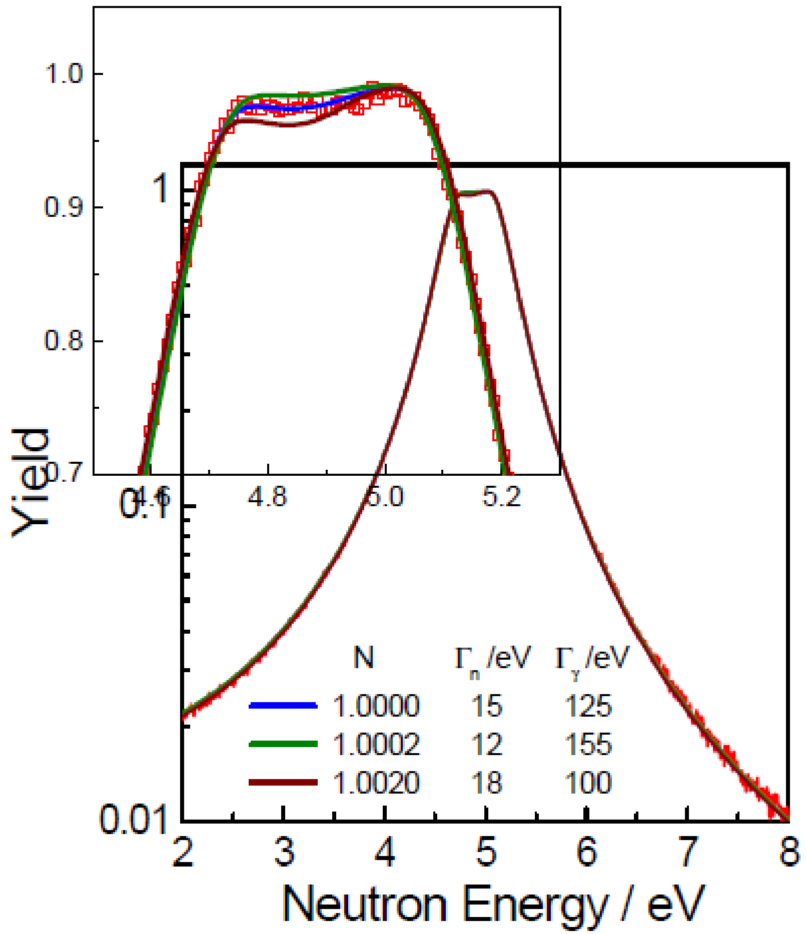
Normalization



$n\sigma_{tot} >> 1$ and $\sigma_\gamma \approx \sigma_{tot}$

$$Y_\gamma \cong \frac{\sigma_\gamma}{\sigma_{tot}}(1 - e^{-n\sigma_{tot}}) + \ldots$$

$$Y_\gamma \cong 1$$

$$\Rightarrow \quad N = \frac{1}{Y_\varphi} \frac{C_\varphi - B_\varphi}{C_w - B_w}$$

N is independent of :

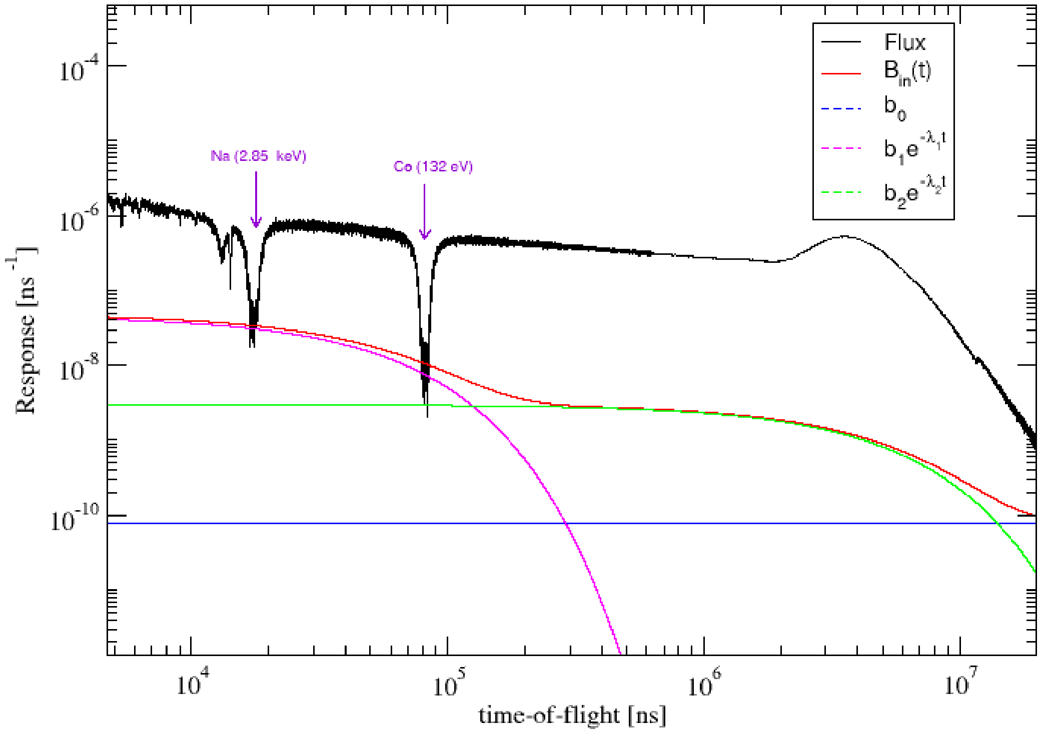
- **sample thickness**
- **nuclear data**

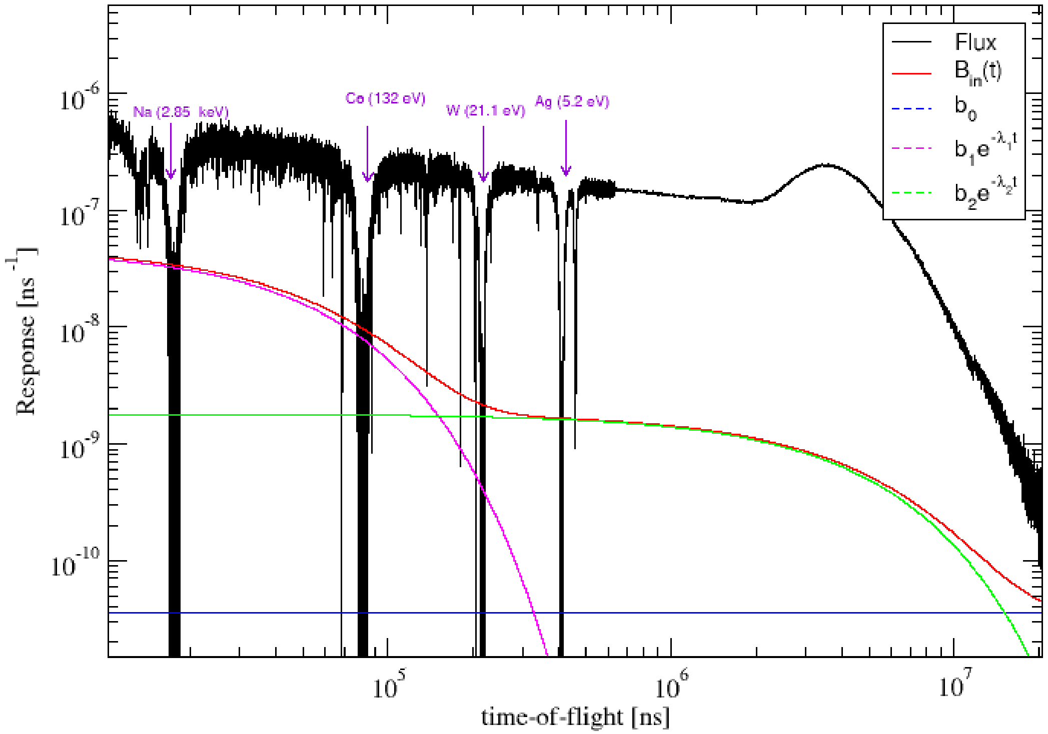
σ_φ : only the relative energy dependence is required

$\Rightarrow {}^{10}B(n,\alpha) \sim 1/v$

$$\frac{u_{Y_{exp}}}{Y_{exp}} \leq 2\ \%$$

Flux: background





$$B(t) = b_0 + b_1 e^{-\lambda_1 t} + b_2 e^{-\lambda_2 t}$$

0-ambient radiation+bkg contributions without time correlation
1- n scatt. inside the detector station and n scatt from other FP
2- slow neutrons coming from previous accelerator pulses

Capture: background

$B_c(t) = b0 + b_1(t) + b_2(t)$ t =time of flight

b_0 : TOF independent background, due to ambient background and activity
(*determined just after the neutron beam is switched off)*

$b_1(t)$: TOF dependent, but sample independent background
(*estimated from measurements without sample in the beam)*

$b_2(t)$: *Dominated by prompt TOF and sample dependent background due to neutron and γ-ray scattering in the sample*

$b_{2n}(t) = b_{2n,1}(t) + b_{2n,2}(t)$
$b_{2n,1}(t)$ *: direct or prompt component,*
follows resonance structure of (n,X) cross section
$b_{2n,2}(t)$*: delayed component*
neutron is scattered from the sample and creates a detected event after several scatterings in the measurement station or detector environment

⇒The complicated part of the procedure (measurement + data reduction)
In particular time and sample dependent component $b_2(t)$

Capture: background

(1) (2) (4) (3)

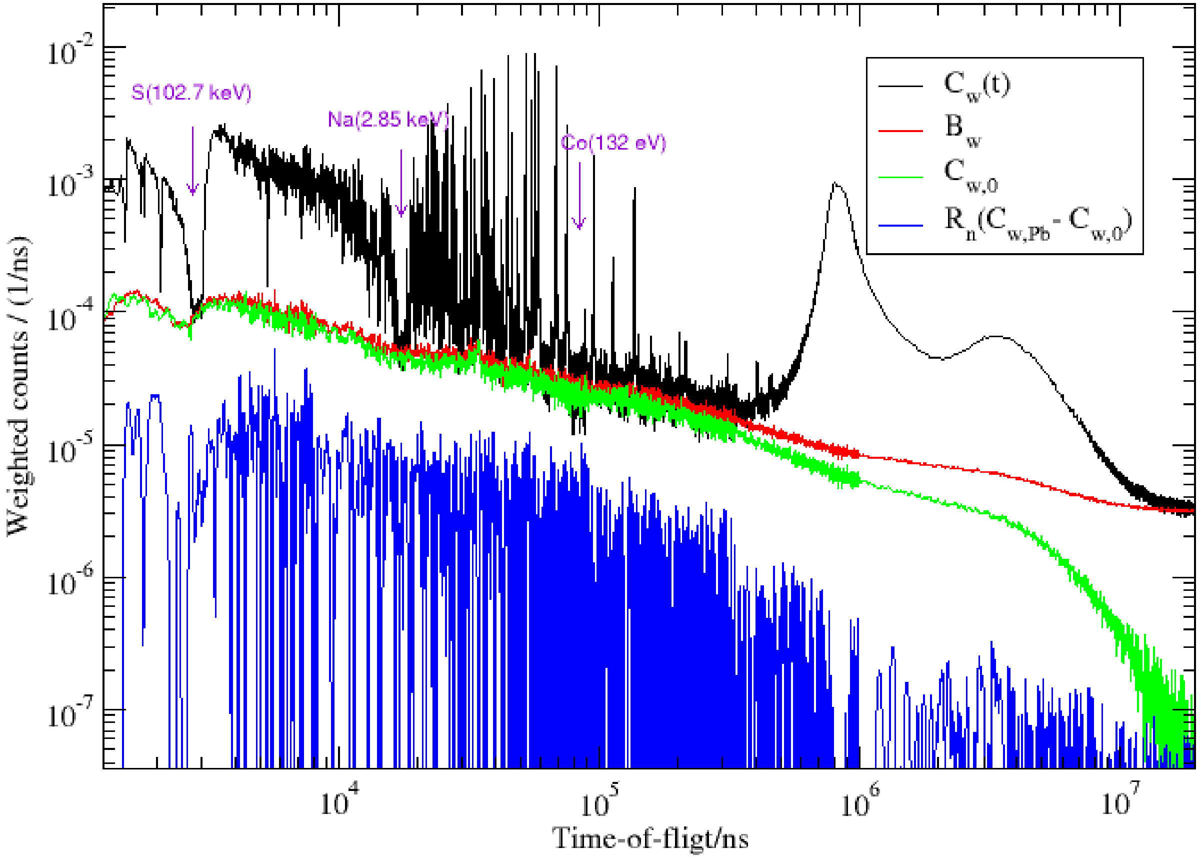
$$B_w(t) = \underbrace{b_0 + k_1 C_{w,0}(t)}_{} + \underbrace{k_2 R_n(t)[C_{w,Pb} - C_{w,0}]}_{}$$

(1) : ambient (or activity)
(2) : weighted response without sample (corrected for ambient)
(3) : weighted response with a ^{208}Pb sample

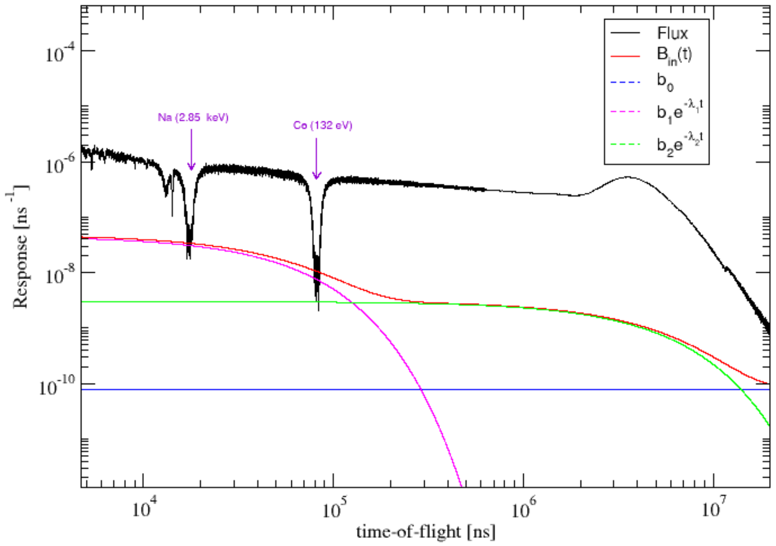
All spectra are weighted using the weighting function for the sample under investigation and corrected for dead time

(4): correction factor (TOF-dependent) accounts for difference in Y_n for X and ^{208}Pb (or carbon for light samples)

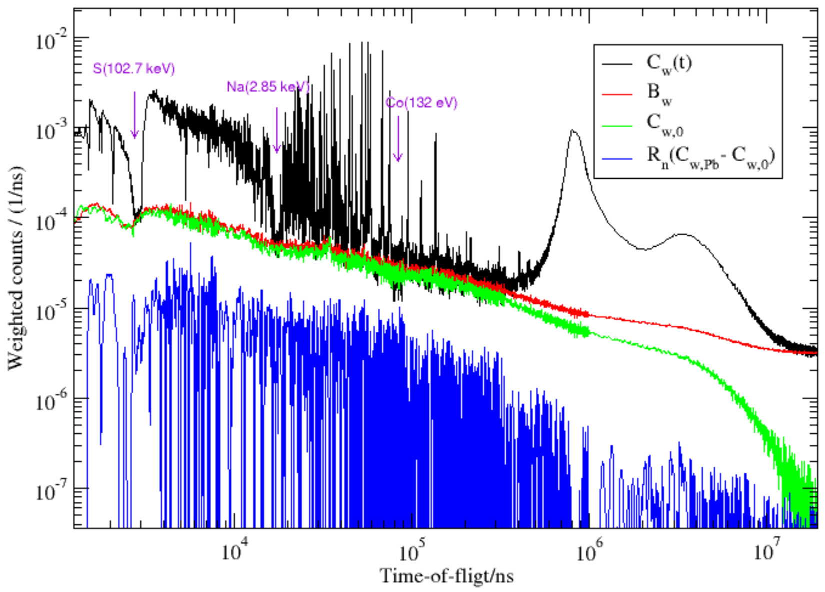
$$k_2 R_n = \frac{Y_n(^{A}X)}{Y_n(^{208}Pb)}$$

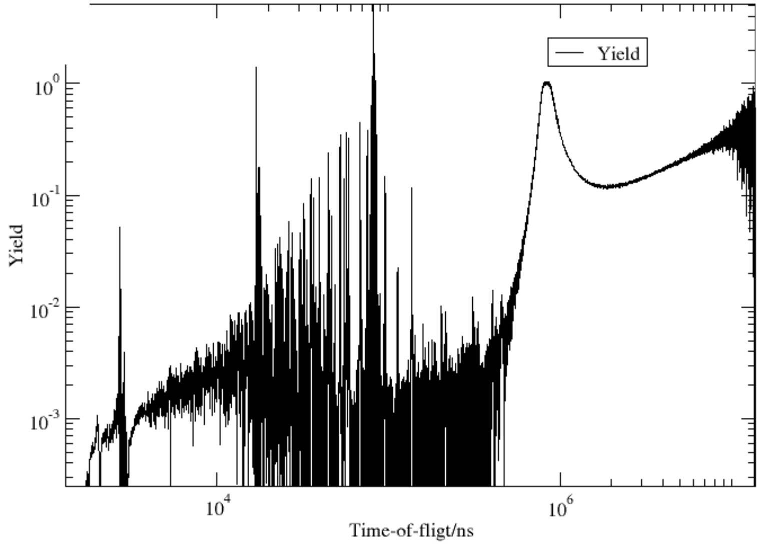


Y_{exp} for $^{103}Rh(n,\gamma)$



$$Y_{exp} = N \frac{C'_r - B'_r}{C'_\varphi - B'_\varphi} Y_\varphi$$



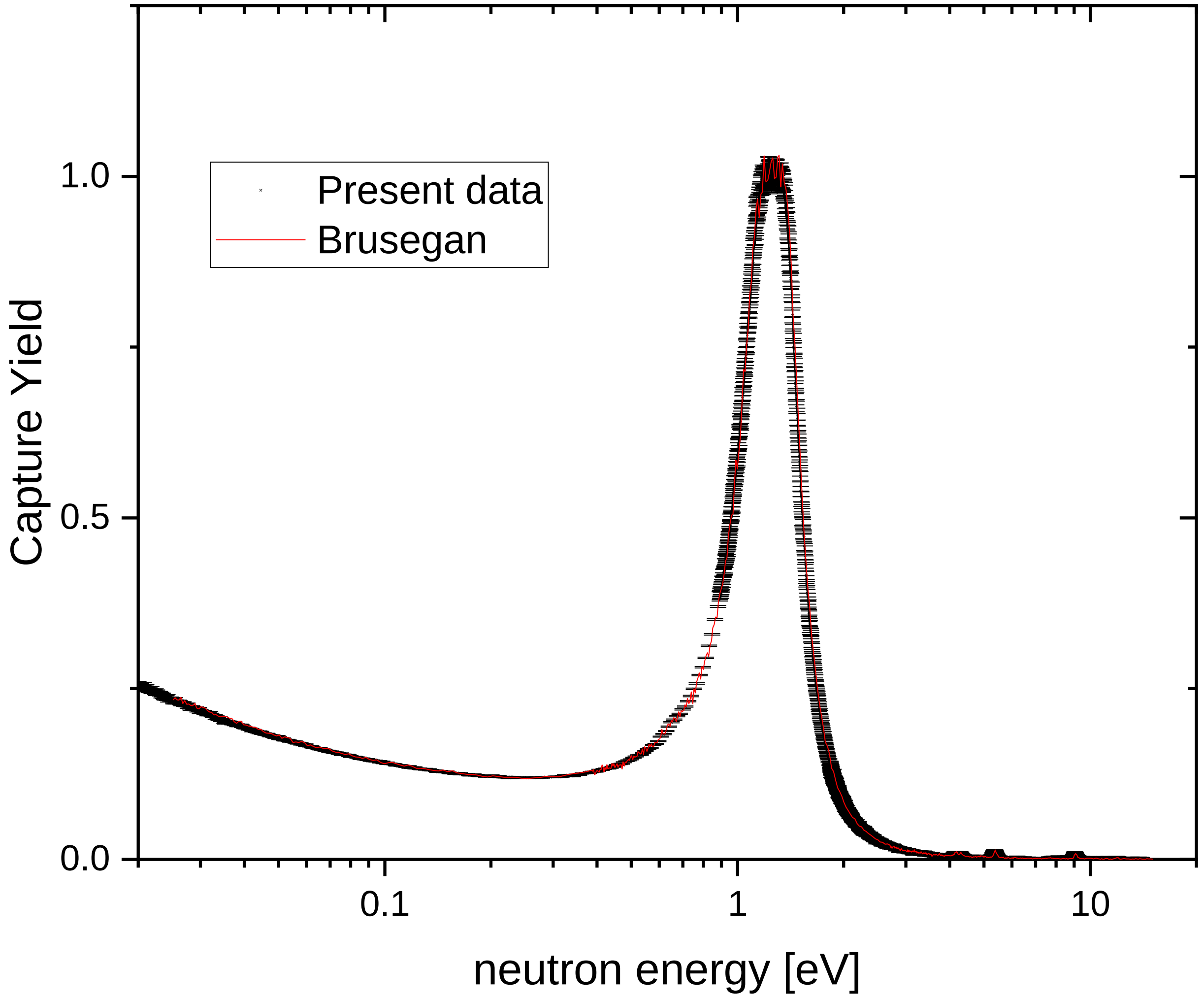


Fixed background filters
=>$\delta B'_\varphi / B'_\varphi \leq 3\%$
With
B'_φ / C'_φ ≤1% at 1.26 eV
≤0.5% 0.025eV

Fixed background filters
=>$\delta B_c / B_c \leq 3\%$
With
B_c / C_c ≤1% at 1.26 eV
≤10% 0.025eV

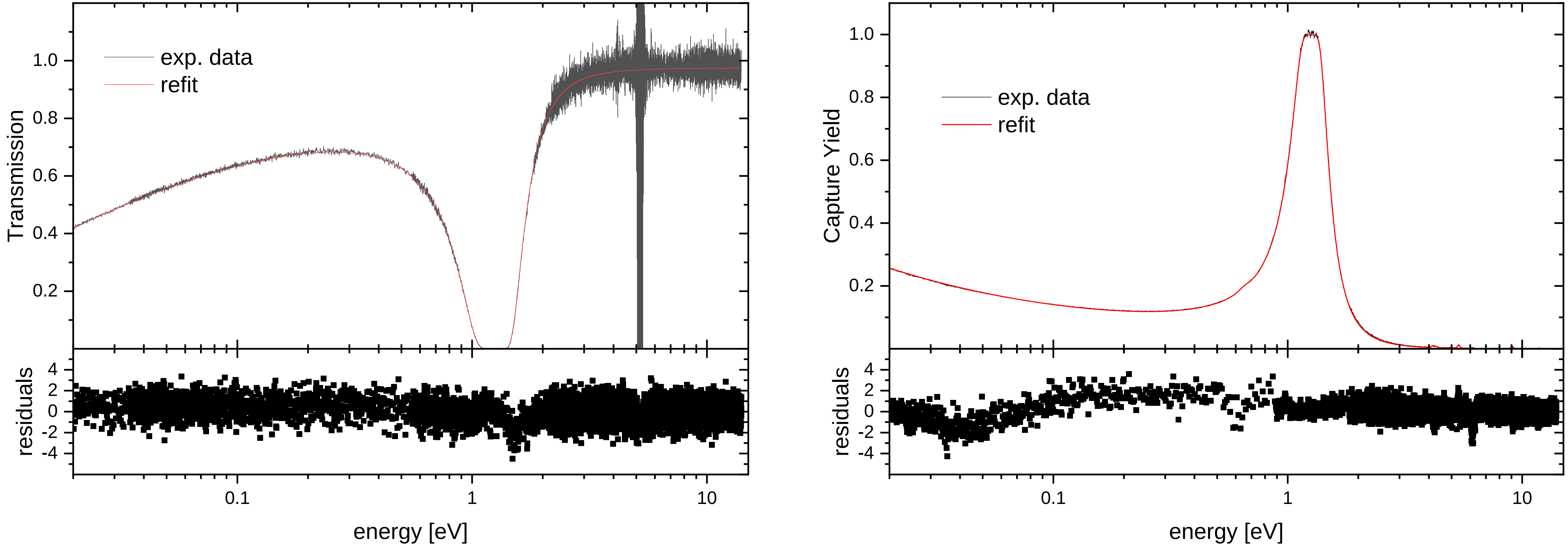
Y_{exp} for $^{103}Rh(n,\gamma)$

Reference	Year	s_0 (b)	Method
Dilg and Mannhart	[1974]	144.9 (7)	TOF (trans.)
Lee et al. (JENDL)	[2003]	133.0 (90)	TOF (capture)
Brusegan et al.(JEFF)	[2004]	142.0 (15)	TOF (capture)



The capture cross section at a neutron energy of 0.0253 eV obtained from the combined analysis of the ^{103}Rh capture and transmission data is σ_γ = 142 (1.5) b.

T_{exp} vs Y_{exp}



The resonance parameters for 103Rh were obtained from a simultaneous shape analysis of the capture and transmission data using the REFIT code.

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GELINA: (n,γ) methodology => ≤2%

Total energy principle: C_6D_6 with weighting function

- Weighting function which account for the threshold and sample properties
- Correction for neutron and γ-ray transport in the sample (Borella et al., NIMA)

Background

- Use fixed background filters
- Perform background measurements with additional filters
- Perform additional background measurements with Pb and/or carbon

Neutron fluence rate

- Double ionisation chamber (2 thin layers of ^{10}B)
- Energy dependence: traceable to $^{10}B(n,a)$ reaction cross section

Normalization

- Internal: 1.26 eV saturated resonance

Perspectives: Data evaluation

Thank you for your attention!

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