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Implementation of an analytical model accounting for sample inhomogeneities in REFIT

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EC – JRC – IRMM
Standards for Nuclear Safety, Security and Safeguards (SN3S)

Outline

- Introduction (EC - JRC- IRMM)
- Neutron Resonance Transmission and Capture Analysis
- Motivation
- Initial model validation
- Experimental model validation
- Summary

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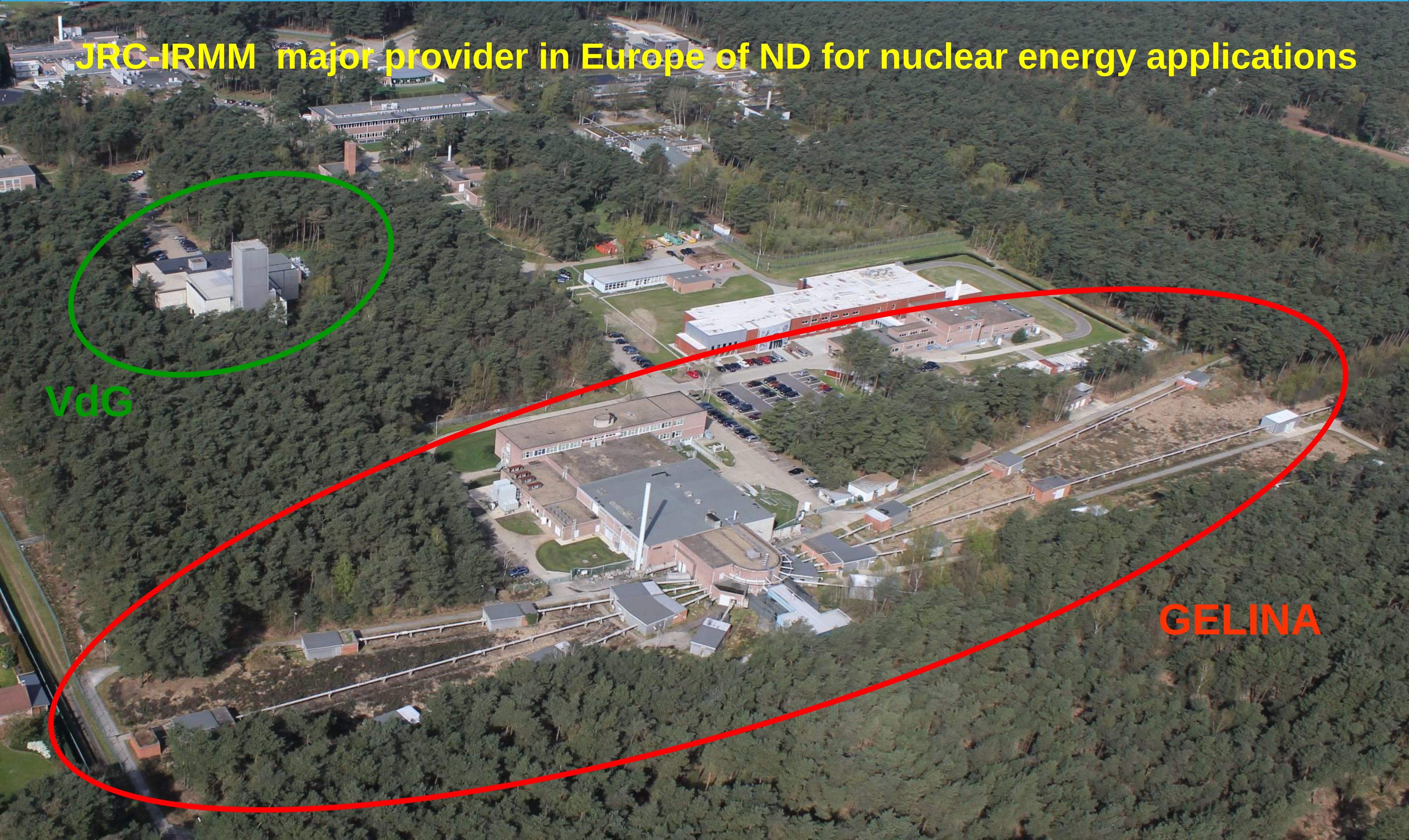
EC - JRC – IRMM neutron facilities



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EC - JRC – IRMM neutron facilities

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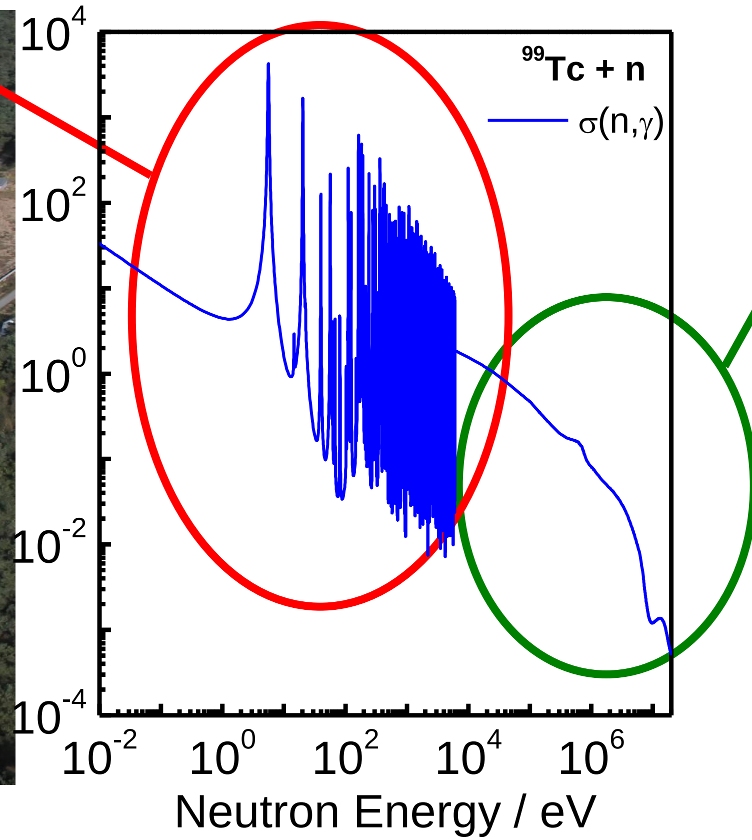
GELINA

^{99}Tc(n,γ) cross section



Van de Graaff

White neutron source
+
Time-of-flight (TOF)

Mono-energetic neutrons
(cp,n) reactions

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- **Pulsed white neutron source**

  (10 meV < E_n < 20 MeV)

- **High resolution TOF measurements**
- **Multi-user facility: 10 flight paths**
- **Flight path lengths: 10 m – 400m**
- **Measurement stations with special equipment to perform:**
  - **Total cross section measurements**
  - **Partial cross section measurements**

Mondelaers and Schillebeeckx, Notizario 11 (2006)

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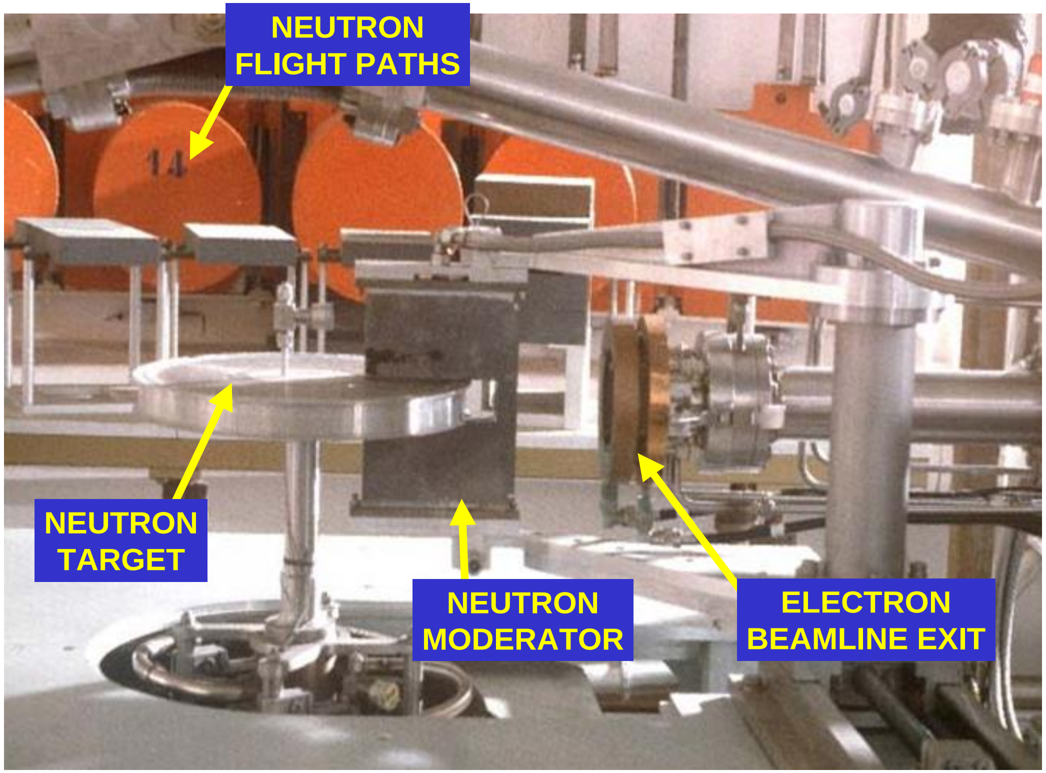


- **e^- accelerated to $E_{e-,max}$ ≈ 140 MeV**
- **Bremsstrahlung in U-target (rotating & cooled with liquid Hg)**
- **(γ , n) , (γ , f) in U-target**
- **Low energy neutrons by moderation (water moderator in Be-canning)**

Neutron Resonance Transmission and Capture Analysis

Transmission

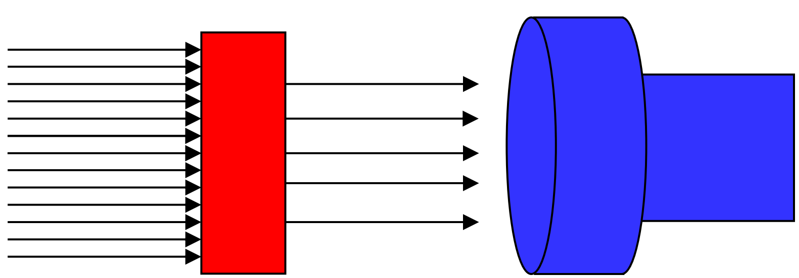
$$T \cong e^{-n\,\sigma_{tot}}$$

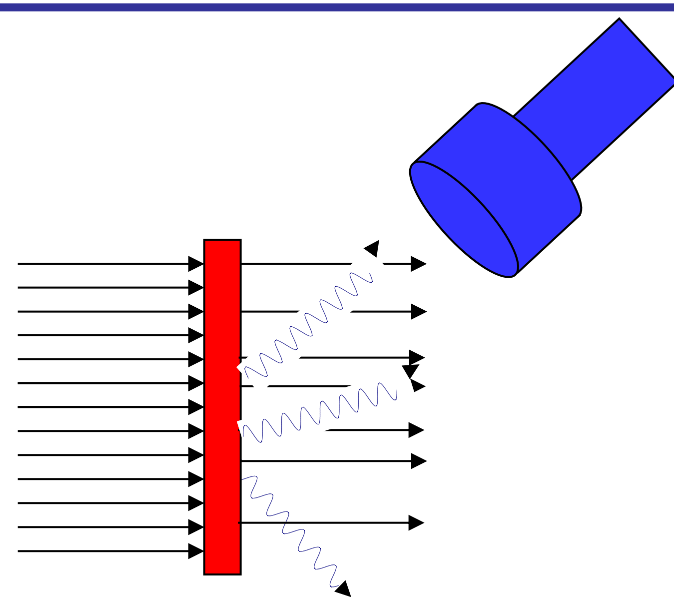
T : transmission
Fraction of the neutron beam traversing the sample without any interaction

Capture

$$Y_\gamma \approx (1 - e^{-n\,\sigma_{tot}})\frac{\sigma_\gamma}{\sigma_{tot}}$$

Y_γ : capture yield
Fraction of the neutron beam creating a (n,γ) reaction in the sample





Neutron Resonance Transmission and Capture Analysis

Transmission

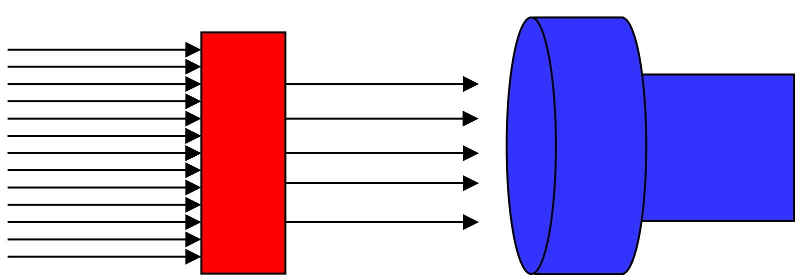
$$T \cong e^{-n\,\sigma_{tot}}$$

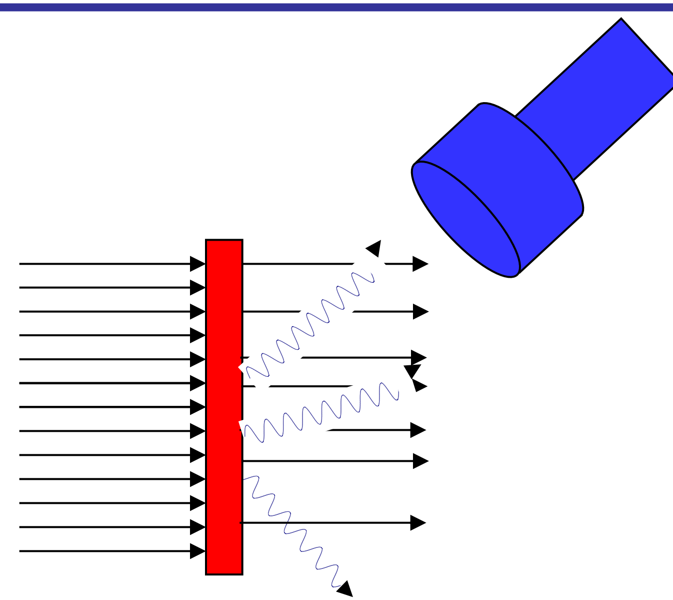
$$T_{exp} = \frac{C_{in}}{C_{out}}$$

Capture

$$Y_{\gamma} \approx (1 - e^{-n\,\sigma_{tot}})\frac{\sigma_{\gamma}}{\sigma_{tot}}$$

$$Y_{\gamma,exp} = \frac{C_{\gamma}}{\varepsilon_{\gamma}\,\varphi}$$





Schillebeeckx et al., Nuclear Data Sheets 113 (2012) 3054 - 3100

Neutron Resonance Transmission and Capture Analysis

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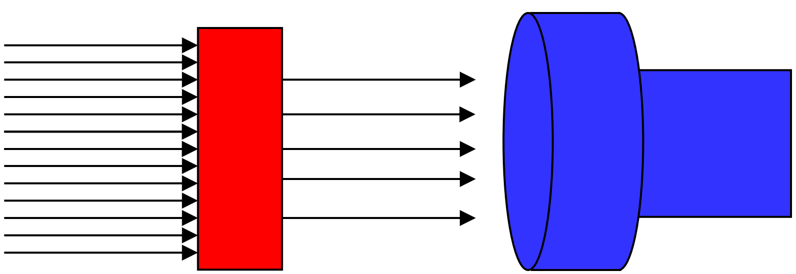

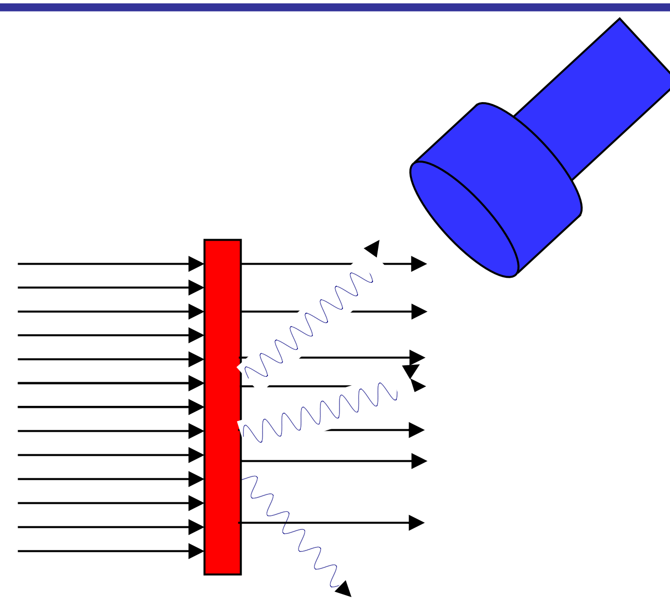

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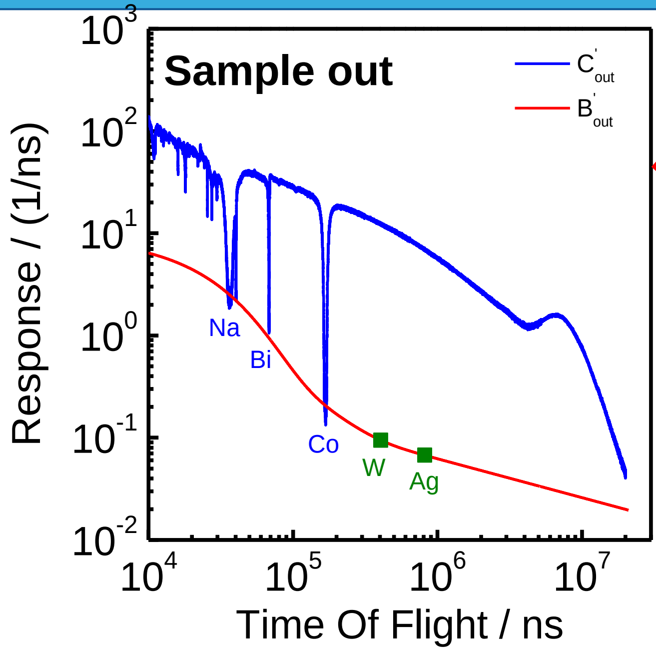
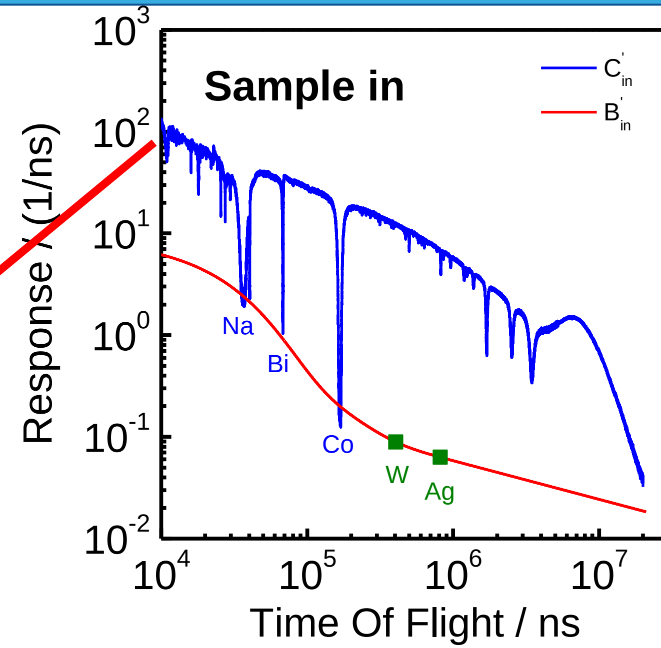
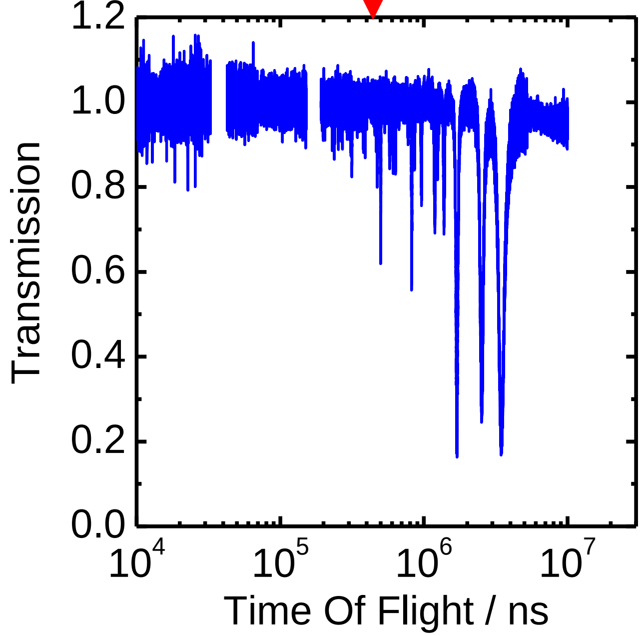
Neutron Resonance Transmission and Capture Analysis



$$T_{exp} = \frac{C'_{in} - B'_{in}}{C'_{out} - B'_{out}}$$

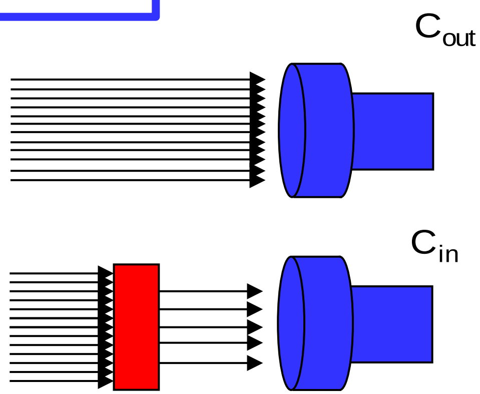




Schillebeeckx et al., Nuclear Data Sheets 113 (2012) 3054 - 3100

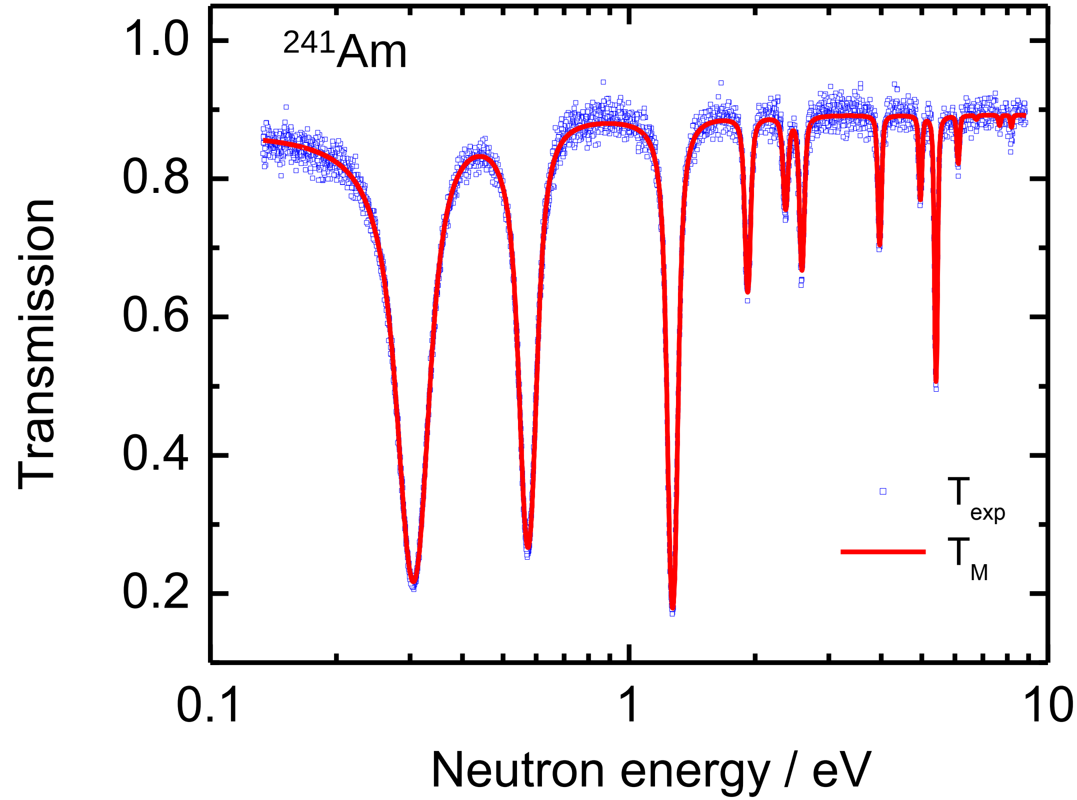
Motivation
good geometry + homogeneous sample

$$T_{exp} = \frac{C_{in}}{C_{out}}$$



$$T_M(t_m) = \int R(t_m, E)\, e^{-n\,\sigma_{tot}(E)} dE$$

$R(t_m,E)$ response of TOF-spectrometer



REFIT, M. Moxon

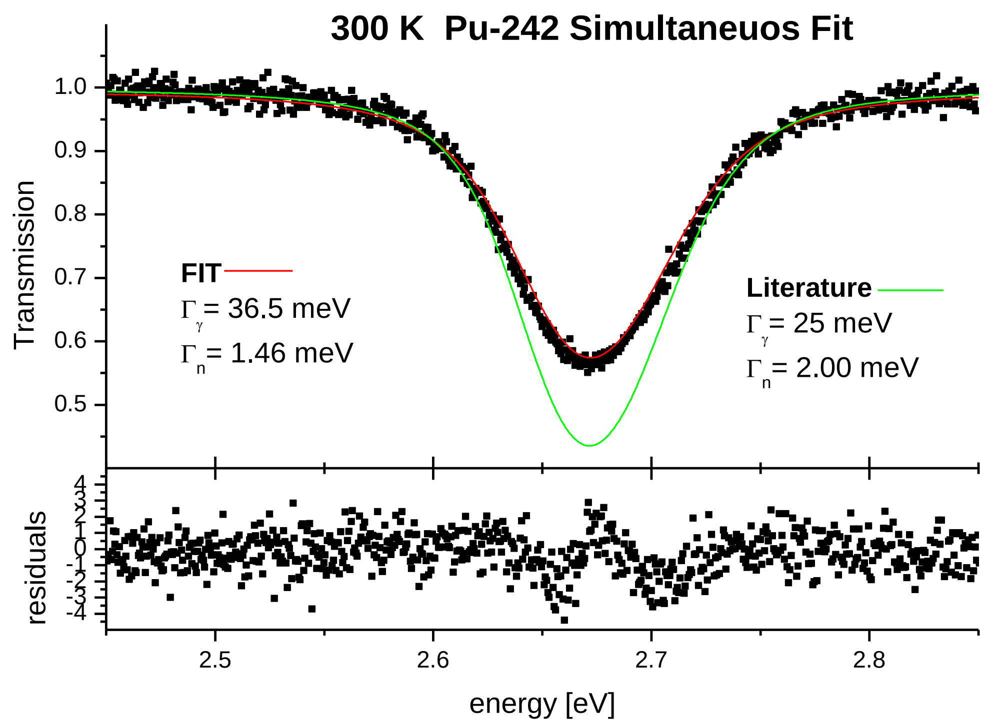
Schillebeeckx et al., Nuclear Data Sheets 113 (2012) 3054 - 3100

Motivation
heterogeneous sample

Ignoring sample inhomogeneities:

- **Underestimation of σ_{peak}**

- **Overestimation of Γ**



Motivation
good geometry + homogeneous sample

Transmission + Capture data

sample properties

resonance parameters

Motivation
heterogeneous sample

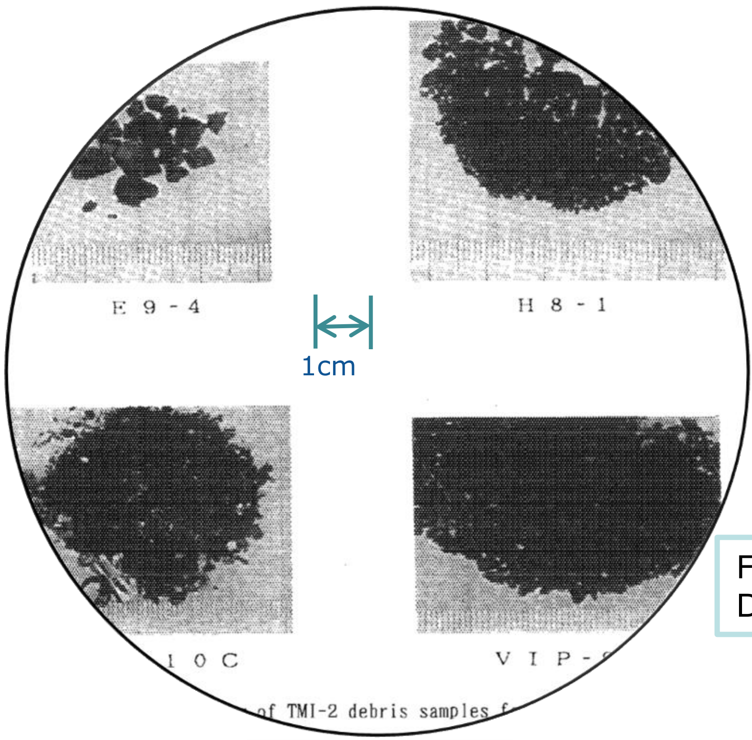
Expected transmission

- **Homogeneous sample:** $T = e^{-n\,\sigma_{tot}}$

- **Heterogeneous sample:** $\overline{T} = \int T(n')p(n')dn' = \int e^{-n'\,\sigma_{tot}}p(n')dn'$

$$\neq$$

$$T(\overline{n}) = e^{-\overline{n}\,\sigma_{tot}} = e^{-\left(\int n'p(n')dn'\right)\sigma_{tot}}$$

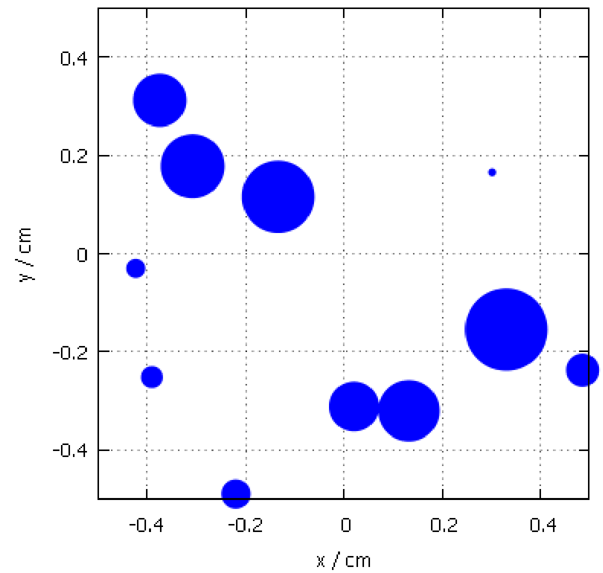


p(n') : distribution of areal density

From H. Uetsuka, et al., "Gamma Spectrometry of TMI-2 Debris" (written in Japanese), JAERI-Research 95-084.

Initial model validation

- **Analytical models to account for inhomogeneities of a powder sample:**
  - **Kopecky et al.** (ND2007)
  - **LP Model** (Levermore, Pomraning et al., J. Math. Phys. 27, 2526, 1986)
  - …
- **Comparison with transmission spectra produced by stochastic calculations (MC simulations)**
- **LP model performs the best**



Initial model validation

- **Kopecky et al.:**
  - **Macroscopic model to describe the variation of the thickness**

Kopecky et al., ND2007 , Nice , pp. 623 – 626; Schillebeeckx et al., NDS 113 (2012) 3054 - 3100

$$\bar{T} = \left[\int e^{-\sum_k n_k' \sigma_{tot,k}(E)} p(x)dx \right] (1 - f_h) + f_h$$

$$n_k' = \frac{n_k}{1 - f_h}$$

$$p(x) = \frac{1}{x\sqrt{2\pi s^2}} \exp\left(-\frac{(\ln x + s^2/2)^2}{2s^2} \right)$$

- **LP Model:**
  - **Microscopic model**

Levermore, Pomraning et al., J. Math. Phys. 27, 2526, 1986

$$\bar{T} = \left\{ \frac{r_+ - \tilde{\Sigma}}{r_+ - r_-} \right\} e^{-r_+ R} + \left\{ \frac{\tilde{\Sigma} - r_-}{r_+ - r_-} \right\} e^{-r_- R}$$

$$\tilde{\Sigma} = p_\beta \lambda_\alpha + p_\alpha \lambda_\beta + \lambda_\alpha{}^{-1} + \lambda_\beta{}^{-1}$$

$$2r_\pm = \bar{\Sigma} + \tilde{\Sigma} \pm \sqrt{(\bar{\Sigma} - \tilde{\Sigma})^2 + 4\theta}$$

$$\theta = (\Sigma^\alpha - \Sigma^\beta)^2 p_\alpha p_\beta$$

Experimental model validation

- **Experimental validation of the model**

  = based on capture and transmission measurements at GELINA:

  - **Cu powder samples with known grain size distribution**
  - **W powder samples with known grain size distribution**

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Experimental model validation

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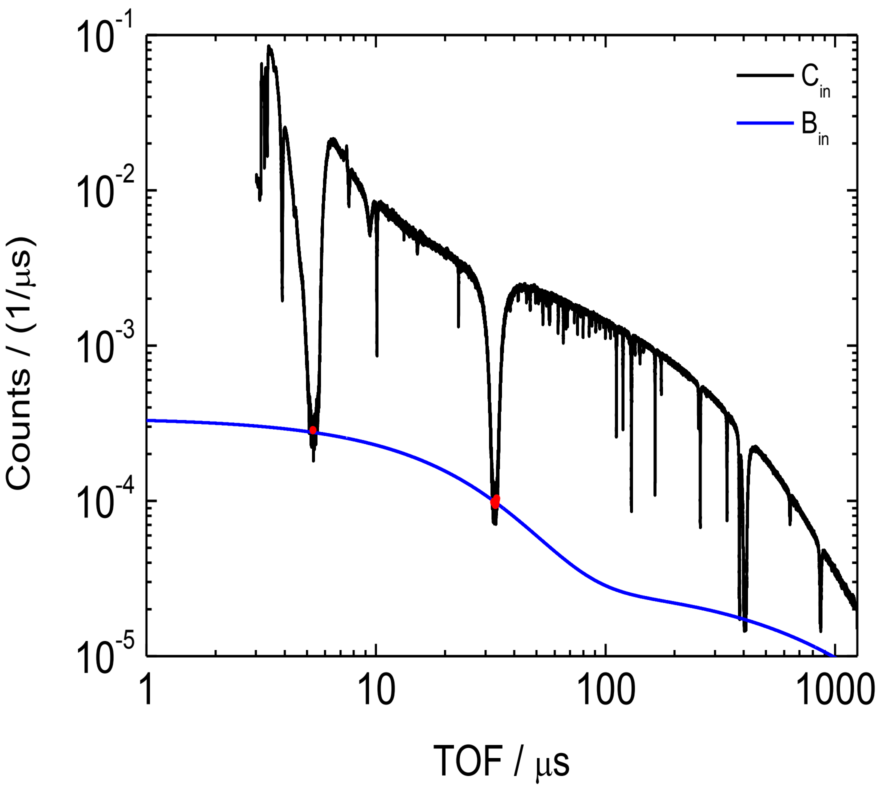
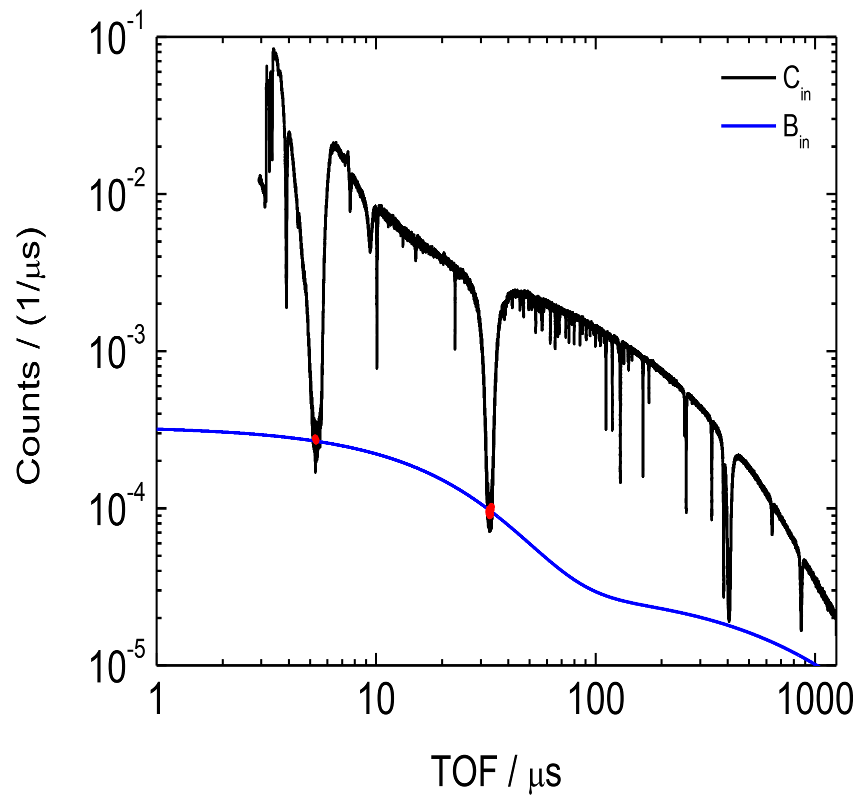
^{nat}W-metal disc
(80 cm diameter, 14 g ^{nat}W)



^{nat}W-powder mixed with ^{nat}S-powder
(80 cm diameter, 14 g ^{nat}W, 3.5 g ^{nat}S)



54th INMM 2013
Schillebeeckx et al., "Contribution of the JRC to the development of NRD"

Experimental model validation

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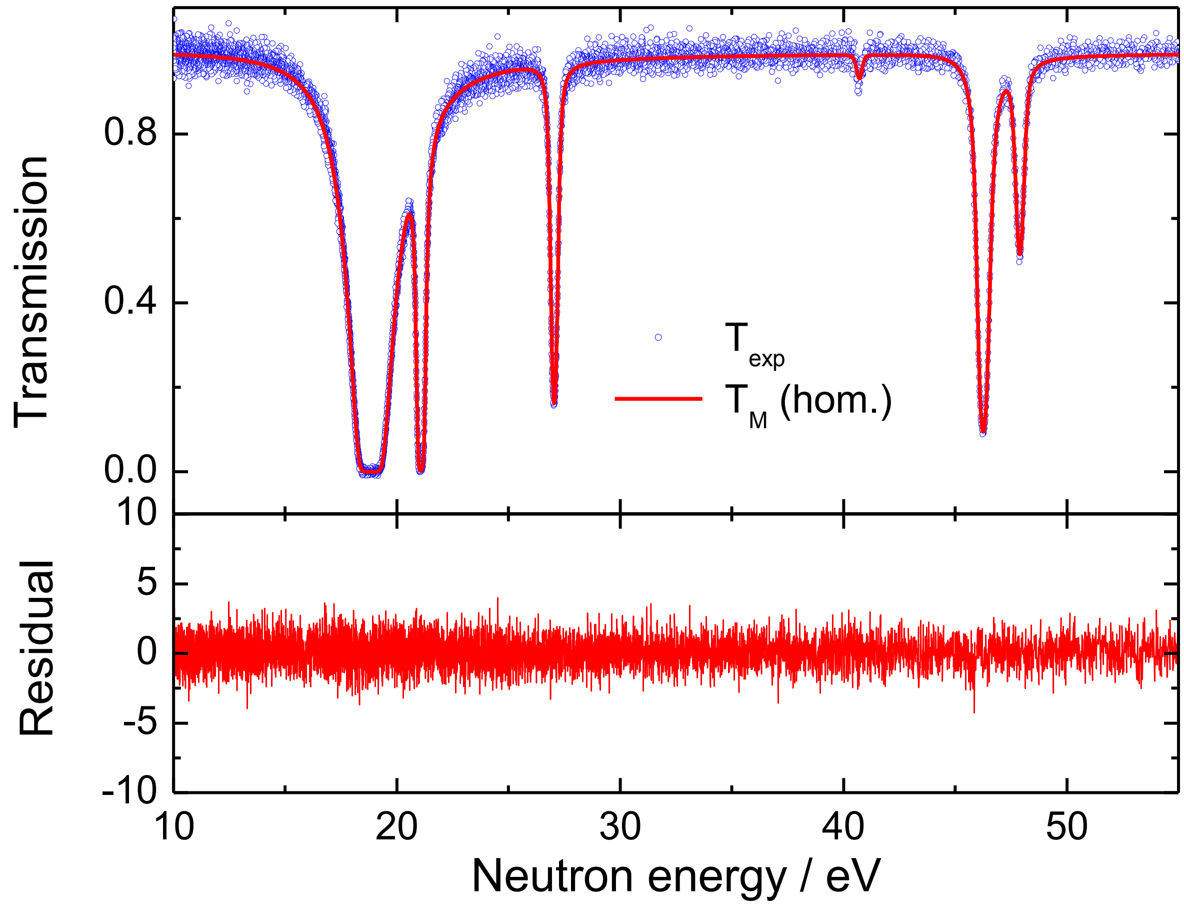

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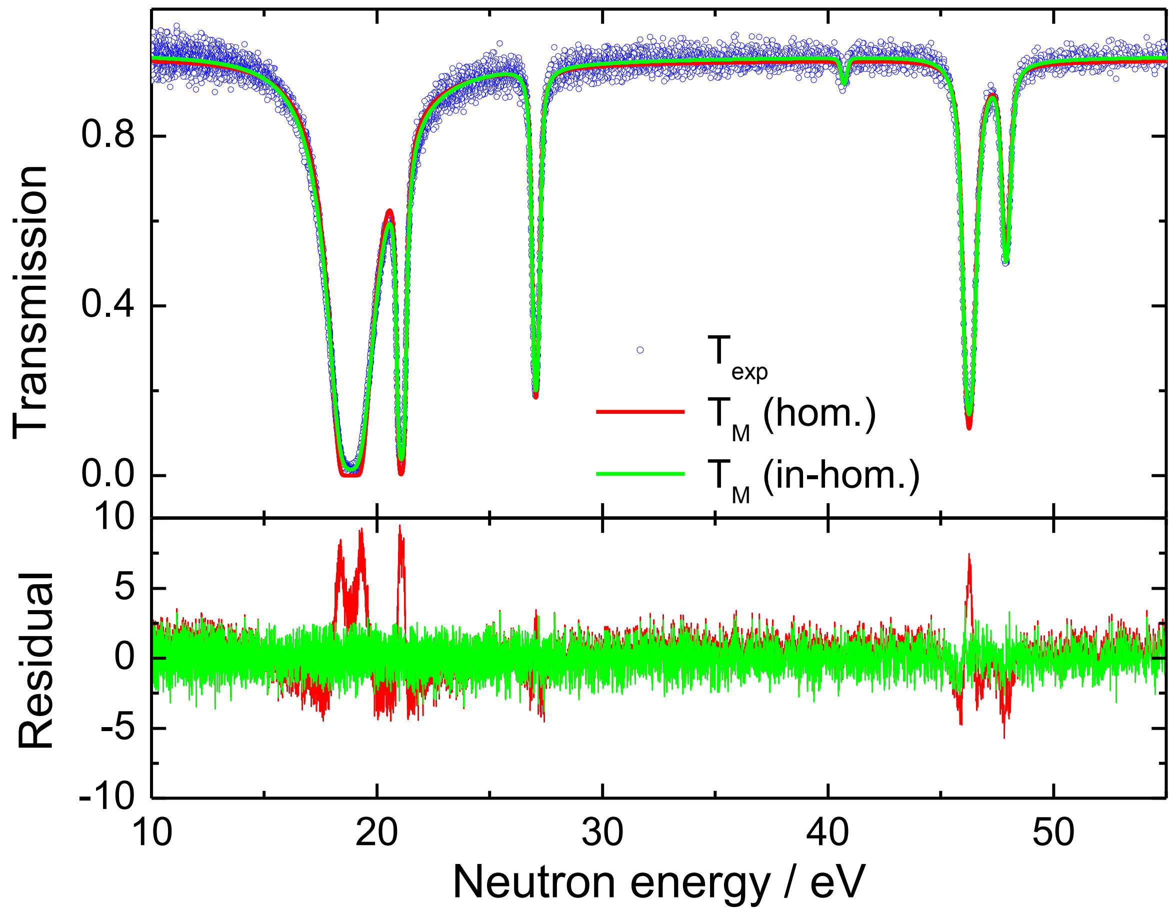

Summary

- **Model accounting for inhomogeneities of a powder sample is implemented in REFIT**

- **Initial validation of possible models with MC simulations**

  LP Model performs the best

- **Experimental validation of the model with capture and transmission measurements at GELINA**

  W powder samples with known grain size distribution

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