Experimental study of the flux trap effect in a sub-critical assembly

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Purpose & approach

- To assess the feasibility of utilizing a neutron flux trap in the AUTH sub-critical assembly
- Obtain a picture of the vertical flux profile
- The method used is DGNAA (Delayed Gamma Neutron Activation Analysis)
- 3 materials
    - Au
    - W
    - Ni
- Final effective cross sections calculated with two methods
    - Explicit function approximation
    - Interpolation based on local procedures

The AUTH sub-critical assembly

- Student Training Reactor 9000
- Open-pool type, water moderated, zero-power
- 1350 U_{nat} fuel slugs in 270 rods
- Hexagonal lattice, pitch=44.45 mm
- $V_M/V_F = 1.52$
- $k_{eff} = 0.842$
- 5 Ci ^{241}AmBe source
- Max thermal flux: $2 - 4 \cdot 10^4\ \mathrm{cm^{-2}s^{-1}}$
- Max fast flux: $3 - 6 \cdot 10^4\ \mathrm{cm^{-2}s^{-1}}$

Top access

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Irradiation inside the fuel grid

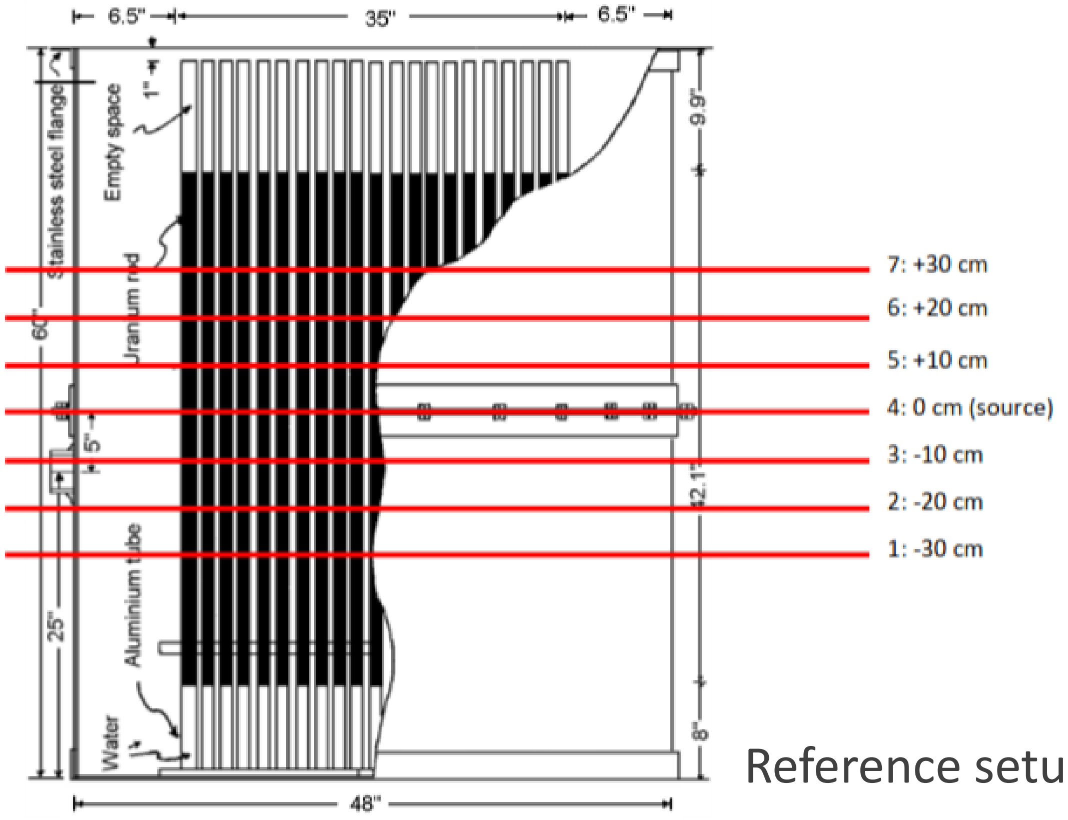
Reactions / **Flux region**

- $^{197}Au\ (n,\gamma)\ ^{198}Au$
- $^{186}W\ (n,\gamma)\ ^{187}W$

} Thermal & epithermal (+ with Cd covers)

- $^{58}Ni\ (n,p)\ ^{58}Co$ — Fast

Measurements taken at 29 cm radial distance from centerline, at 7 vertical levels



Reference setup

Cross section & irradiation levels

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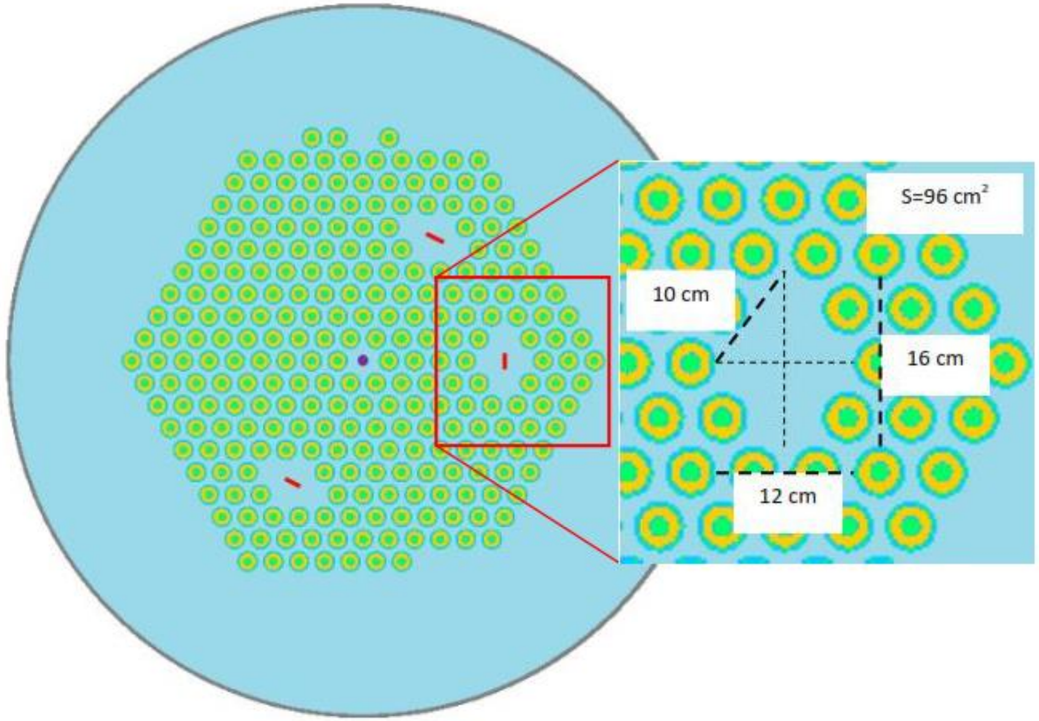
The flux traps

- Three identical flux traps
- 4 fuel rods displaced for each
- Diamond shape
- 96 cm^2 each
- Trap center at 29 cm from centerline
- Exact same irradiation setup as before



NCSR, Tripoli 4

Top view (Tripoli 4.8) &
flux trap geometry

The flux traps

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Flux trap top view

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Gamma-ray spectra

- Saturated Activities (SA) calculated through decay gamma measurements
- HPGe detector, 42 % relative efficiency
- SPECTRW software package used for peak analysis
- Depending on the case, these parameters were adjusted:
  - Asymmetry
  - Background type
  - Peak de-convolution (if needed)
  - FWHM

- The saturated activity was calculated through
- $$SA = \frac{\lambda \, Net \frac{t_{real}}{t_{live}}}{\left(1-e^{-\lambda t_{ir}}\right) e^{-\lambda t_d} \left(1-e^{-\lambda t_{real}}\right) \gamma \, \varepsilon\left(E_\gamma\right)}$$
- Where
  - γ: is the gamma-ray intensity
  - $\varepsilon\left(E_\gamma\right)$: is the detector efficiency for this energy, sample geometry and composition. Also corrects for photon self-absorption
- Self-shielding taken into account
- $SA_{thermal} = SA_{total} - SA_{epithermal}$

Cross sections & flux spectra modeling

Effective cross sections were calculated with

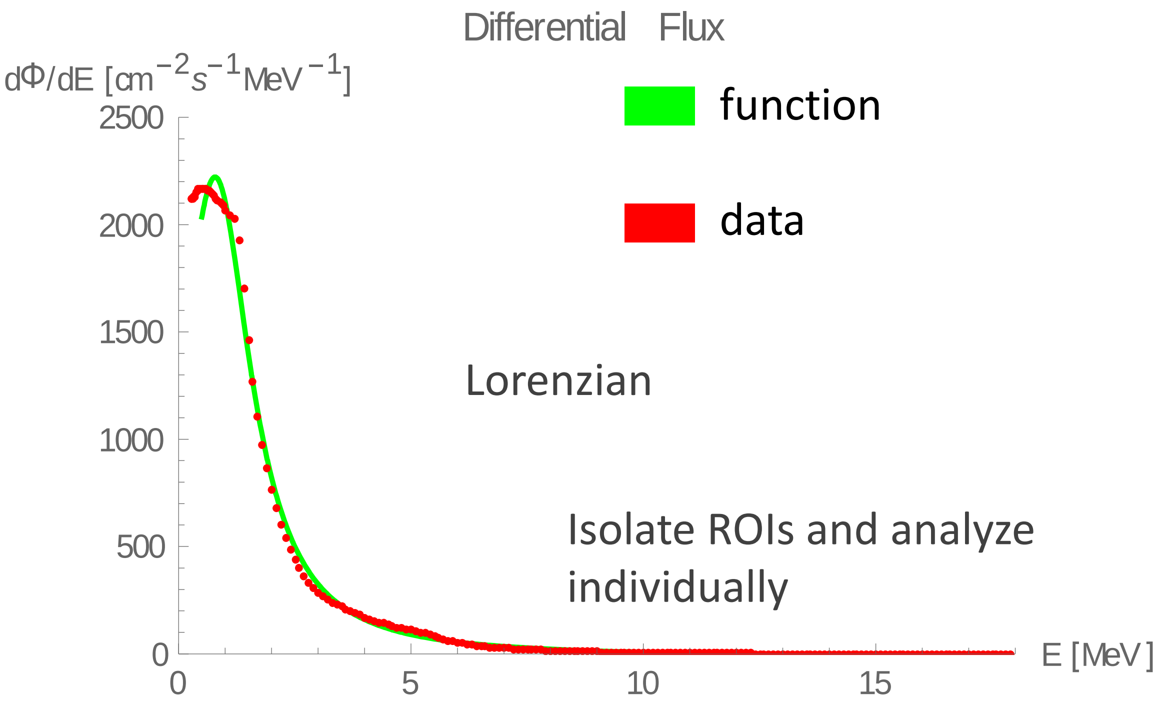
$$\sigma_{eff} = \frac{\int_{E_1}^{E_2} \sigma(E)\frac{d\Phi}{dE}\,dE}{\int_{E_1}^{E_2}\frac{d\Phi}{dE}\,dE}$$

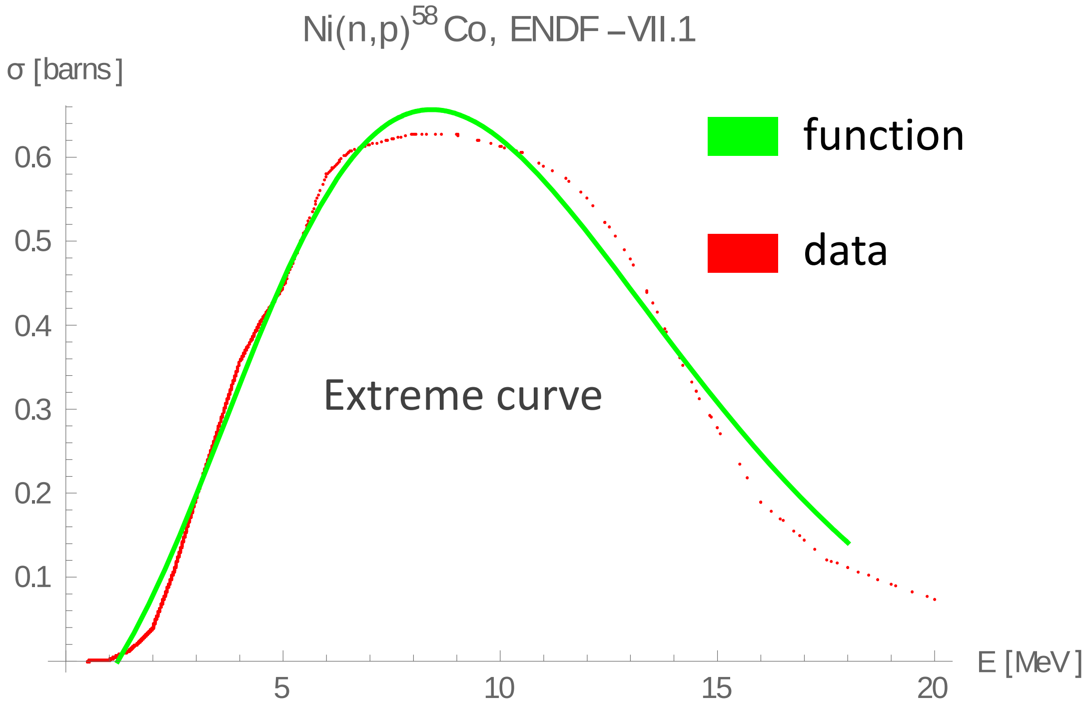
Usable functions had to be derived both for the diff. flux and the excitation functions

Two methods:

- Approximation with explicit function
- Piece-wise local interpolation

Approximation with explicit function

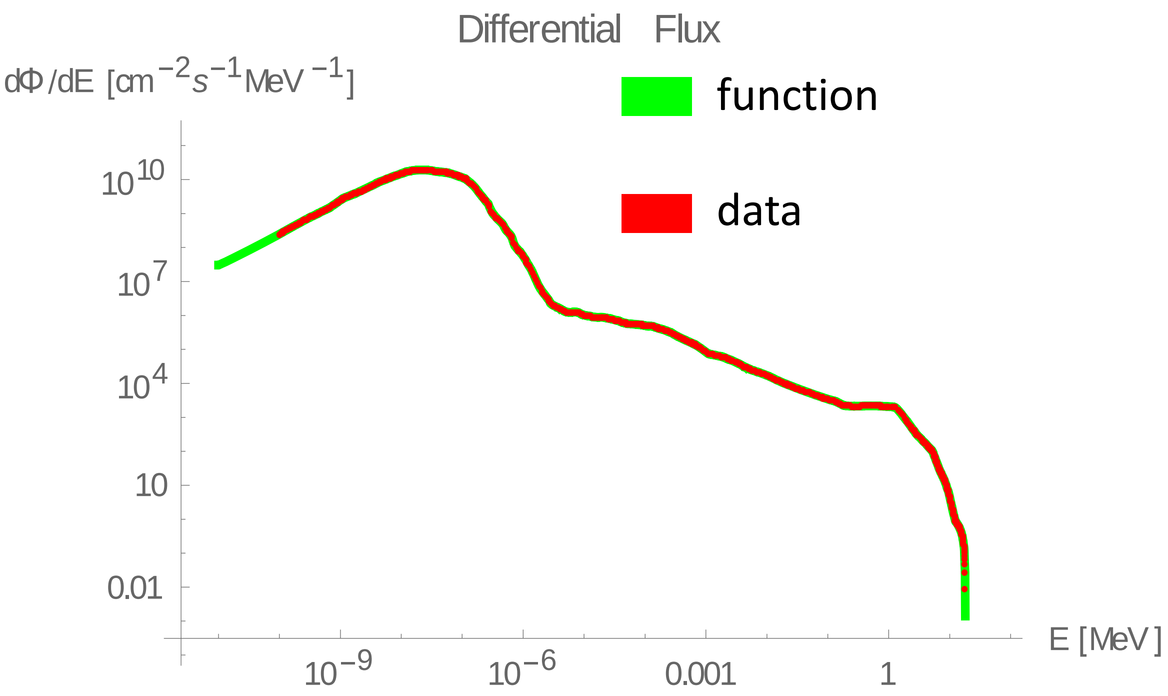


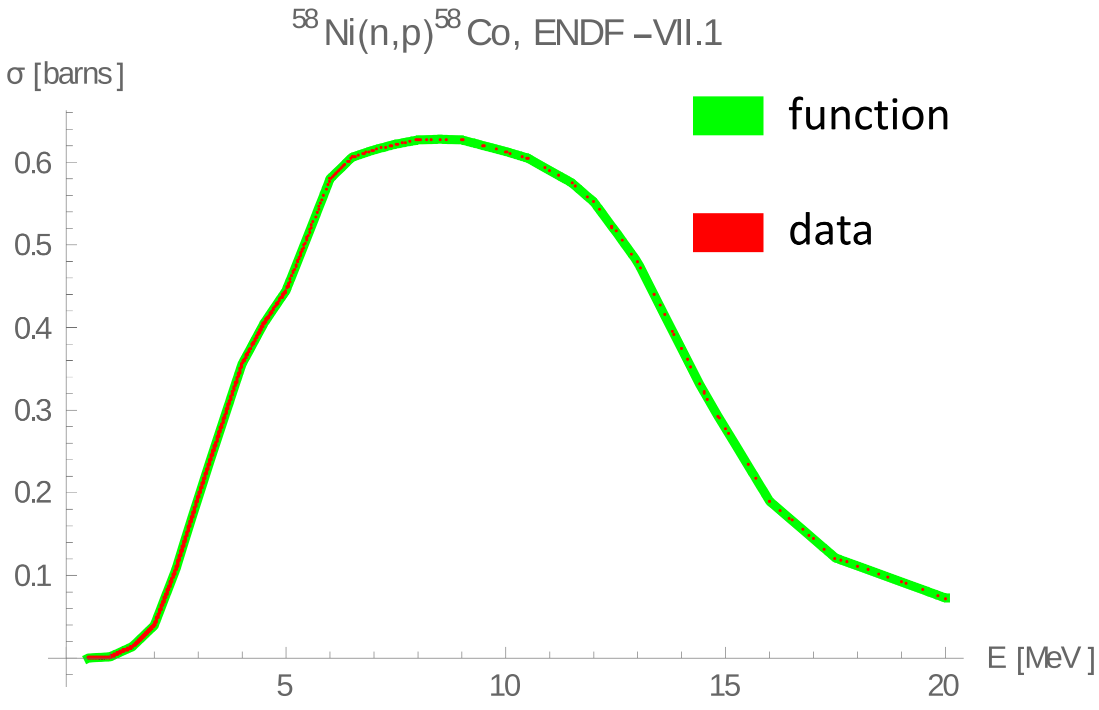


Generally OK, but fails at extremes and boundaries, especially around the 0.5 MeV mark (opening point for the ^{58}Ni(n,p) reaction.

$$\sigma_{\mathrm{eff}} = 0.072 \pm 0.018 \text{ barns}$$

Interpolation based on local procedures





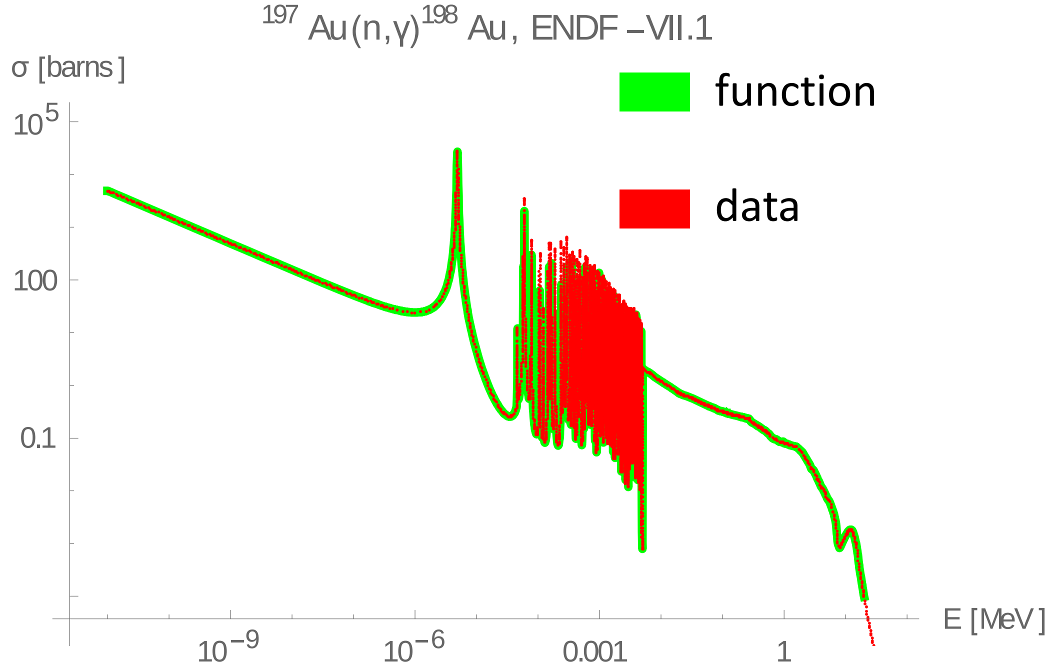
Polynomial curves are fitted between data points and combined in a machine-stored piecewise function. No analytical expression.

$$\sigma_{eff} = 0.077 \pm 0.019 \text{ barns}$$

Interpolation based on local procedures

- Fast, easy to implement (with Mathematica)
- Works on the entire data
- Provides a fully usable function (continuous, differentiable, integrable)
- Excellent approximation
- Verified with ENDF results

- No analytical expression
- Function exists only inside the specific software



^{197}Au(n,γ) excitation function

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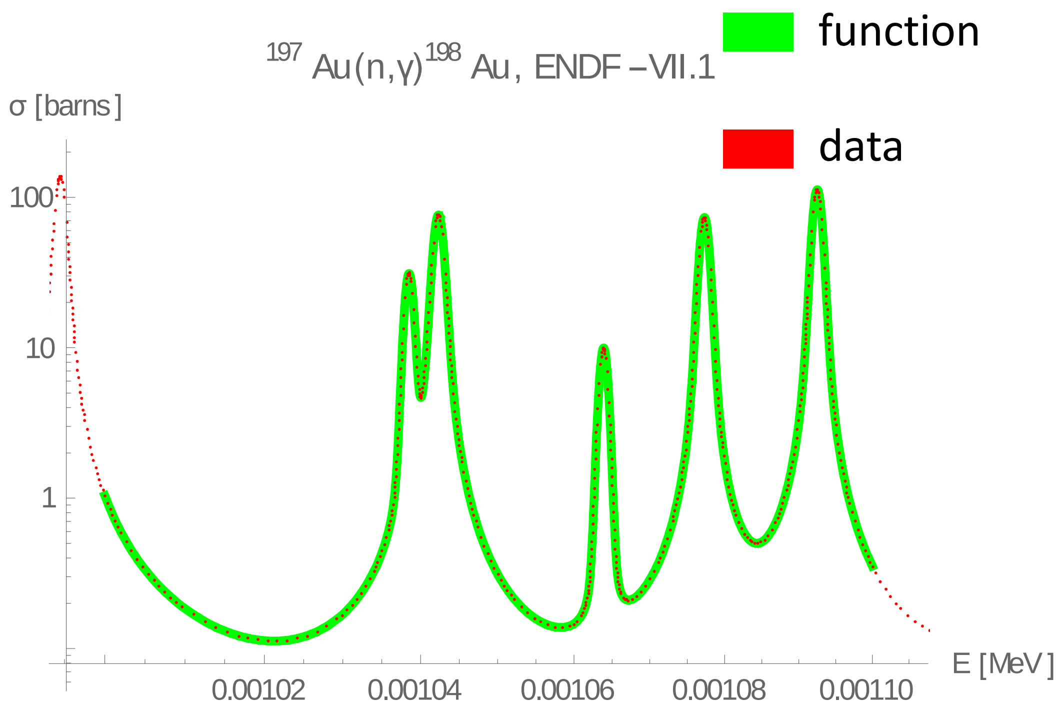
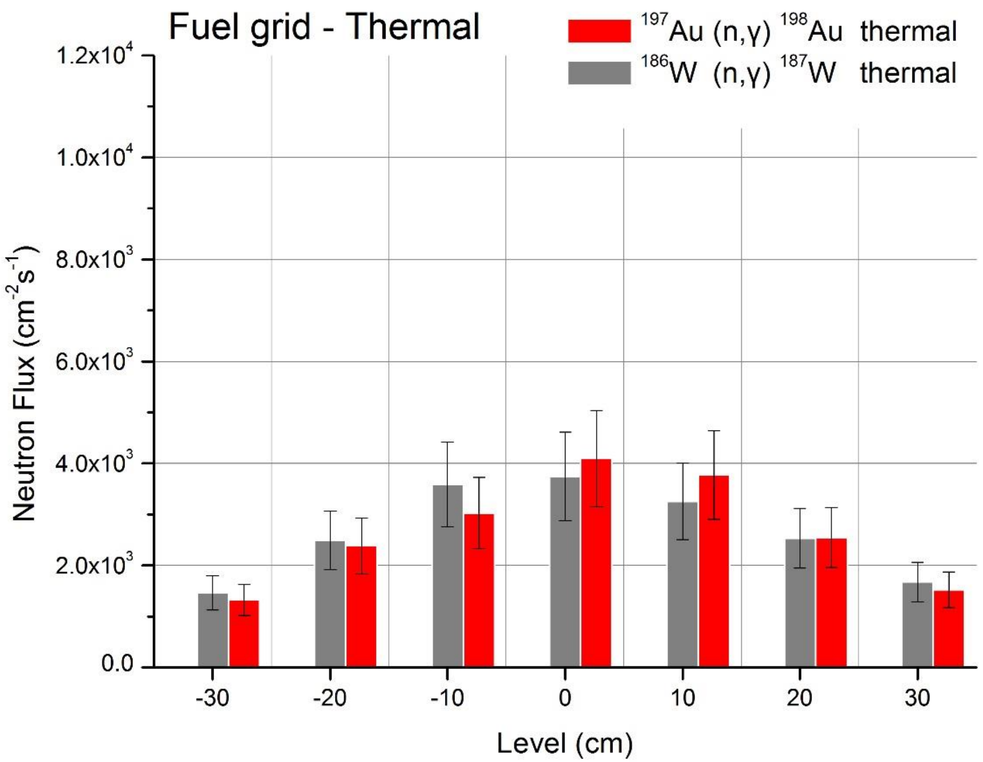
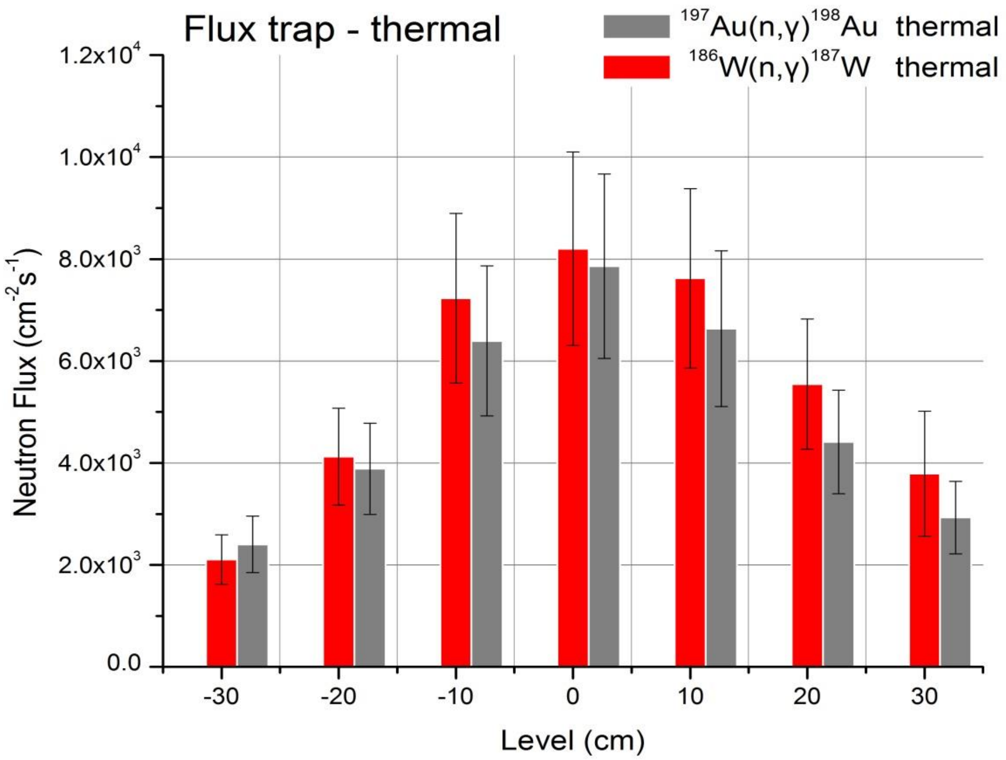


^{197}Au(n,γ) CS at resonance region
1 keV – 1.1 keV

Results – thermal flux



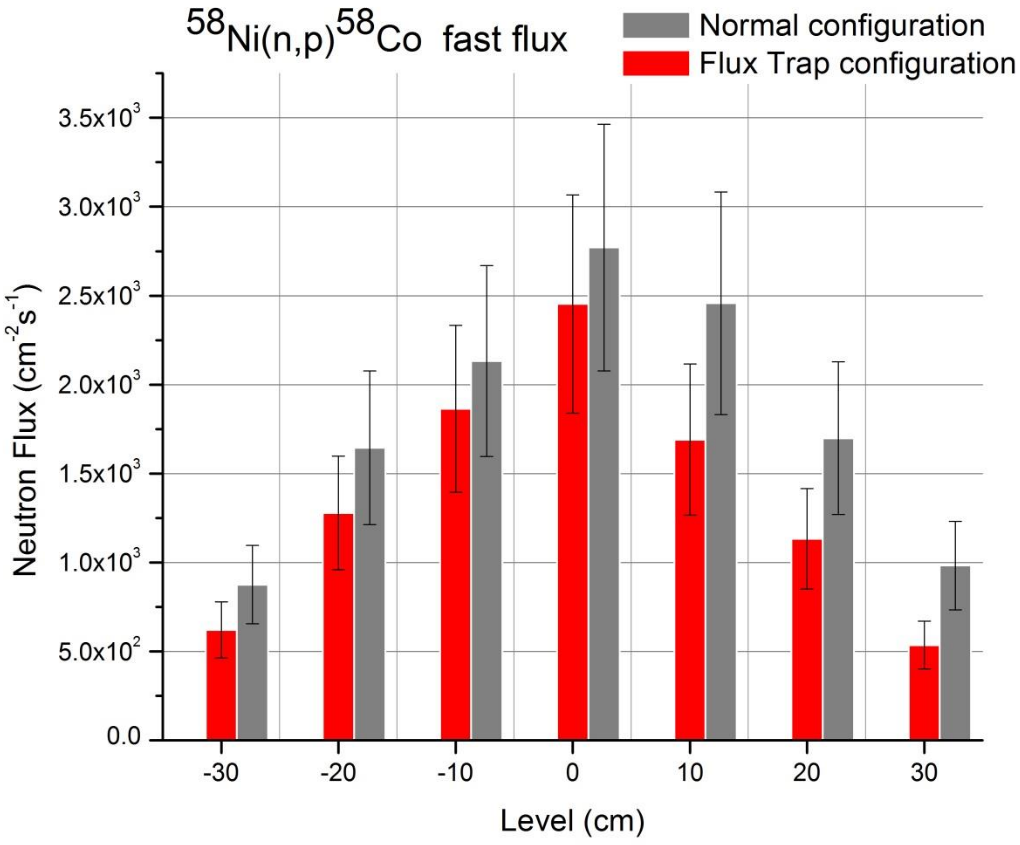
$$\mathrm{w.avg} = 3.91 \pm 0.52 \cdot 10^3\ \mathrm{cm^{-2}s^{-1}}$$



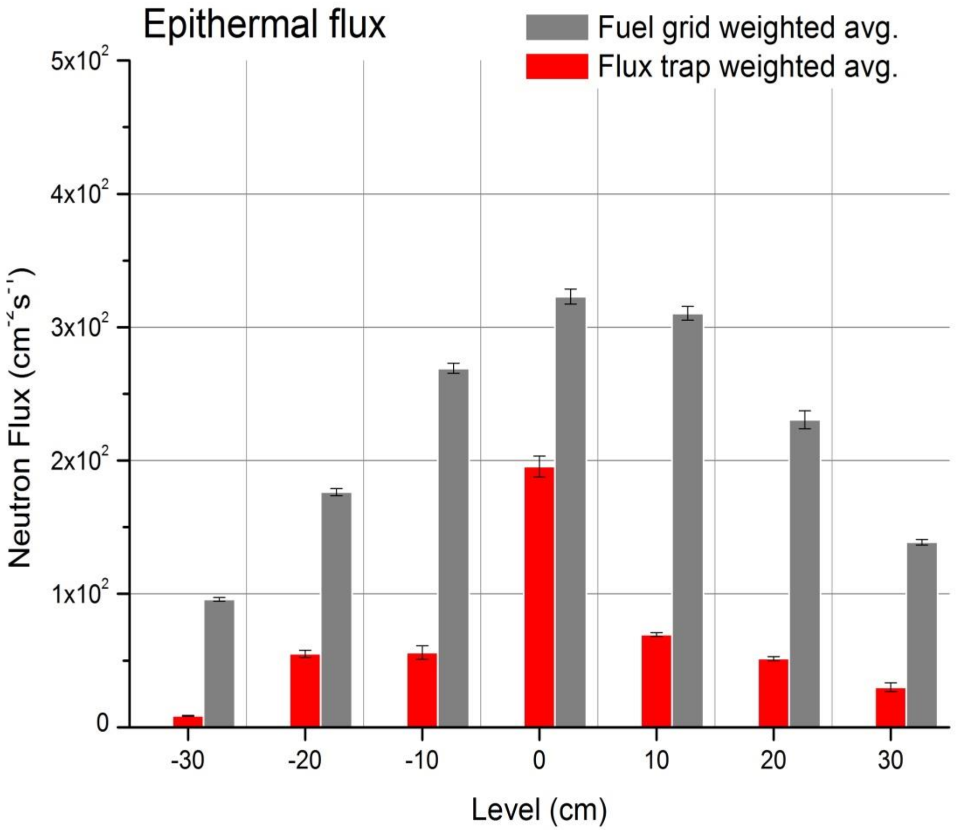
$$\mathrm{w.avg.} = 8.02 \pm 1.10 \cdot 10^3\ \mathrm{cm^{-2}s^{-1}}$$

90 % increase (105% in central)

Results – fast & epithermal flux

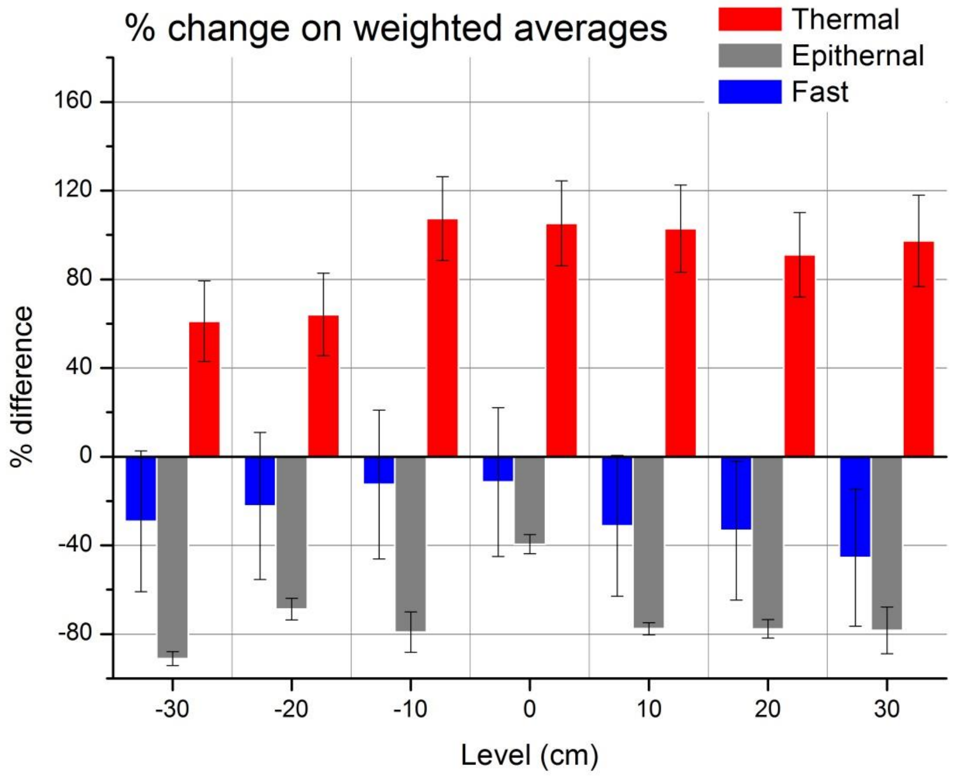


27 % fast average decrease

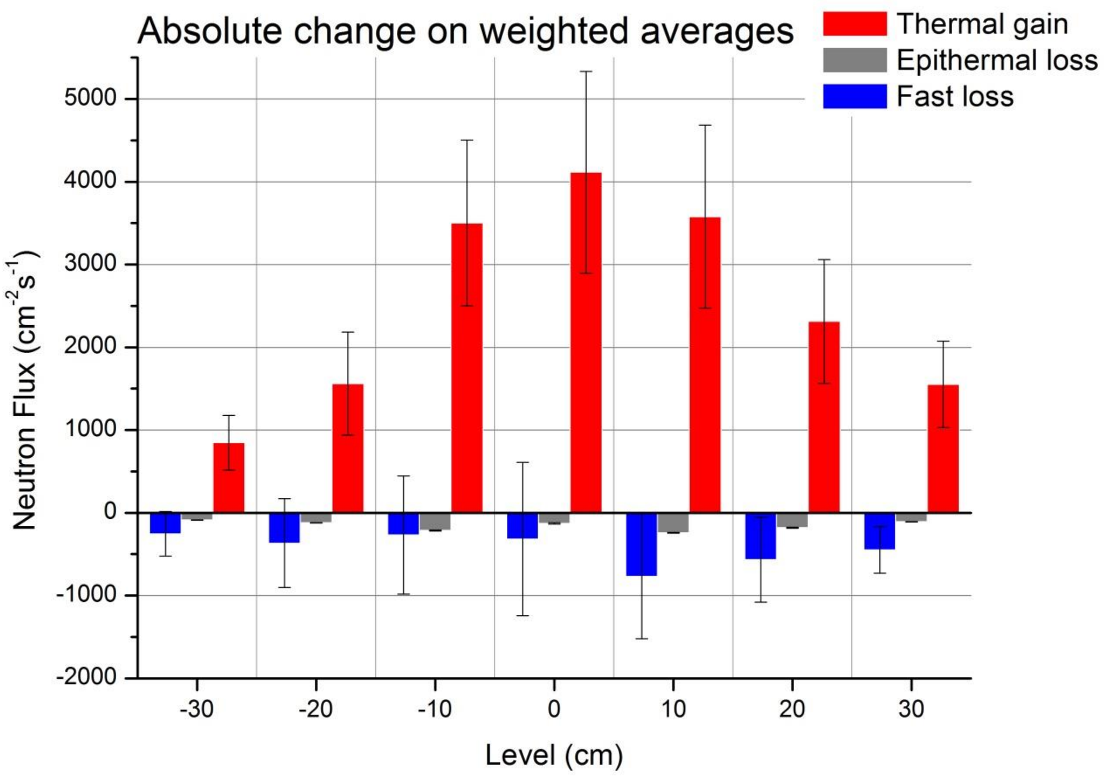


71 % epithermal average decrease

Results – flux changes

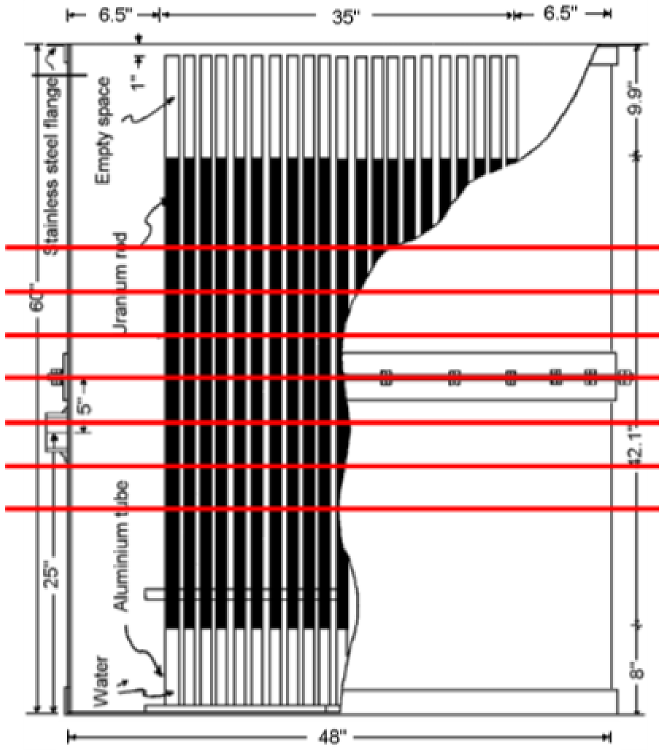


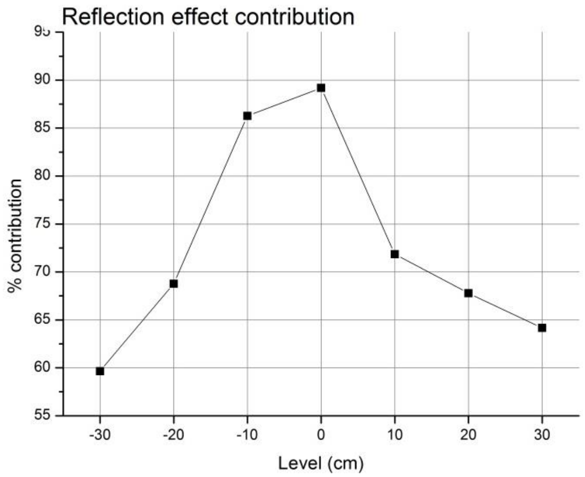
Percentage changes



Absolute changes

Results – reflection & vertical flux profile





Thermal flux gain is much higher than epithermal and fast flux losses

↓

Thermal neutron reflection plays a major role

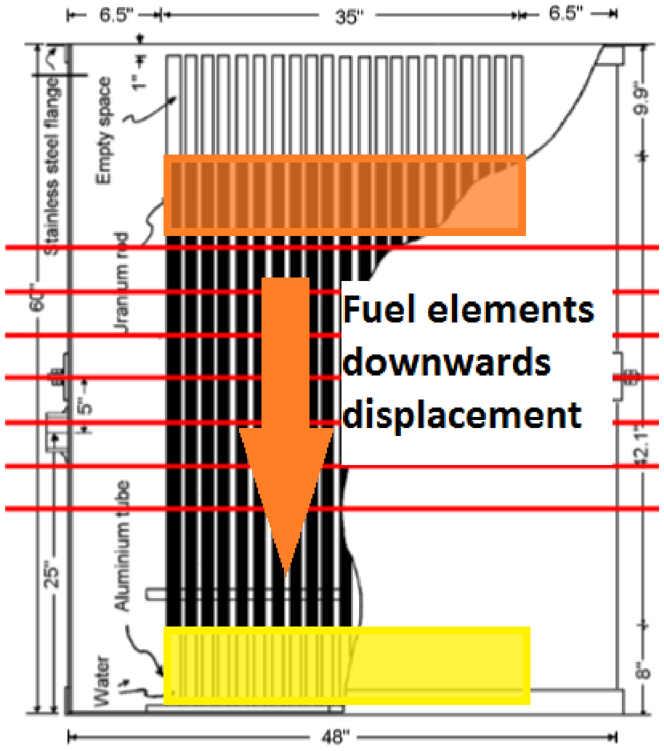
On average, reflection contributes 73 %

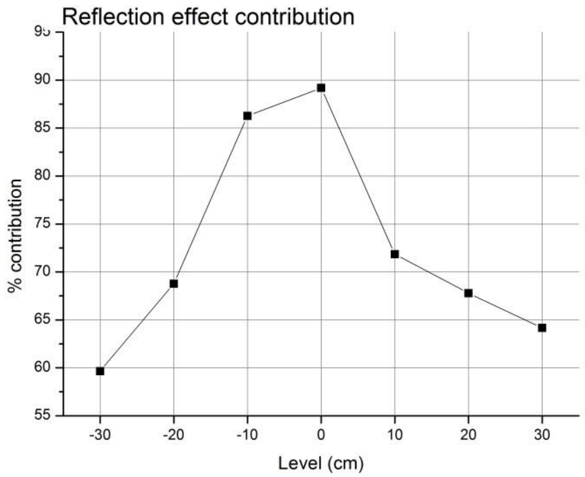
On source level (0 cm): 89 %

Top position: consistently 15 % - 40 % higher thermal flux than bottom

All results indicate a downwards displacement of the fuel elements → results influenced by axial reflection

Results – reflection & vertical flux profile





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Summary and conclusions

- DGNAA with Au, W, Ni and Cd covers
- 70 irradiations
- 29 cm distance from centerline
- 7 vertical positions
- Local interpolation approach for CS
- Average thermal flux increase in source level by 105 %
- Comparison of thermal, epithermal and fast flux, points to reflection playing a major role
- High potential to increase usable thermal flux in positions close to the ^{241}AmBe source
- Asymmetric vertical flux profile (non-cosine) → displacement of active core region