Experimental determination of cross-sections of various (n,xn) threshold reactions using quasi mono-energetic neutron sources

Workshop on TALYS/TENDL Developments 2017

P. Chudoba [1,2], J. Vrzalova [1] et al.

[1]Nuclear Physics Institute of the ASCR, p. r. i., Rez 130, 250 68 Rez, Czech Republic

[2]Charles University, Faculty of Mathematics and Physics, Ke Karlovu 3, 121 16 Praha 2, Czech Republic

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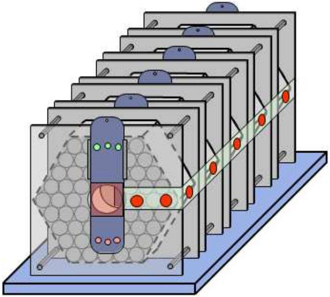
Outline

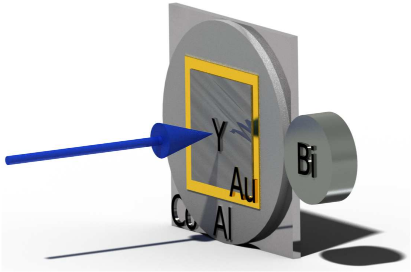
Motivation of measurement

Necessity of fast neutron field monitoring for facilities like

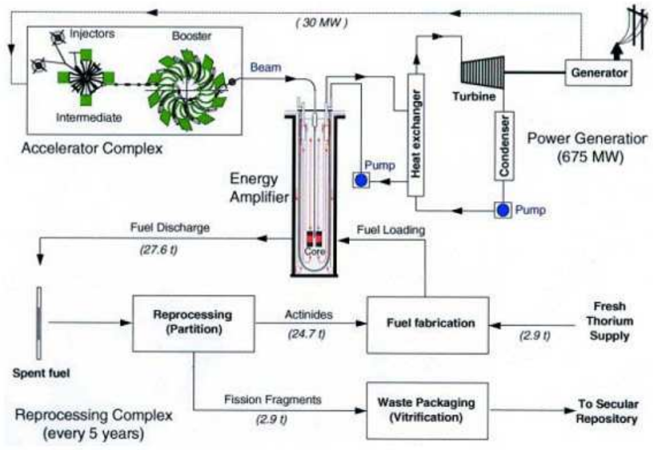
- Accelerator driven systems (ADS)
- Neutron spallation sources
- Future fusion and fast reactors

Improvement of nuclear calculation codes





Principle of ADTS



KLAPISCH, R. Accelerator driven systems: an application of proton accelerators to nuclear power industry. Europhysics News. 2000, 31, 6, s. 26–28.

Why yttrium?

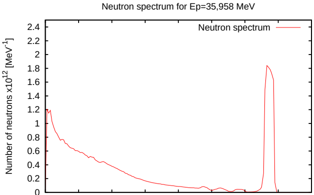
- Products of (n,xn) reactions on yttrium are easily identifiable thanks to well separated γ-transitions with good intensity.
- Half-lives with good length for γ-spectrometry.

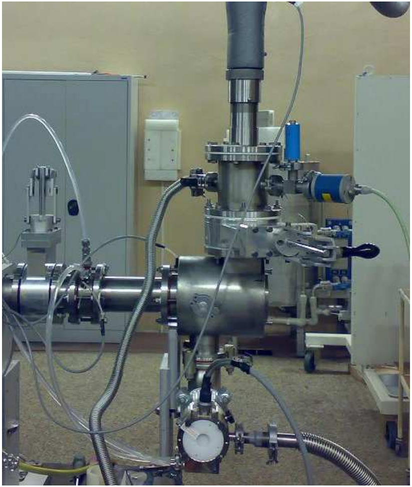
Reaction	E_{thr} [MeV]	$T_{\frac{1}{2}}$	E_γ [keV]	I_γ [%]
^{89}Y(n,2n)^{88}Y	11.6	106.626 d	898.042	93.683
			1836.063	99.24
^{89}Y(n,3n)^{87}Y	21.1	79.8 h	388.531 484.805	82.2 89.845
^{89}Y(n,3n)^{87m}Y	21.6	13.37 h	380.79	78.055

Yttrium is great example of material ideal for measurements by means of γ-spectrometry.

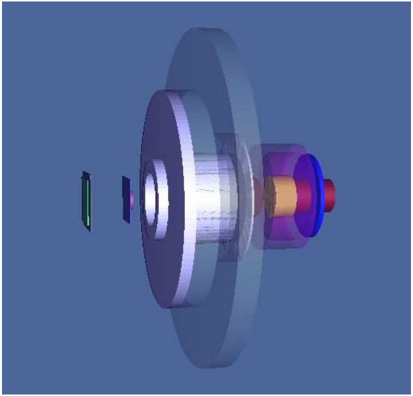
Fast neutron source - NPI CAS

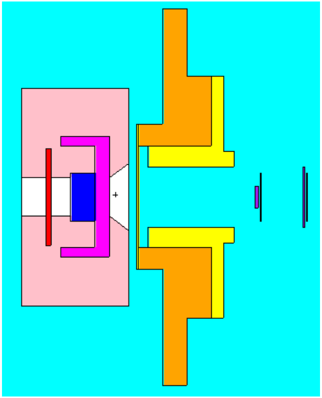
- Source based on reaction $^{7}Li(p,n)^{7}Be$
- Neutron energy range 10-37 MeV
- Source intensity at user positions $\sim 10^{8}$ cm$^{-2}\cdot$s^{-1}
- Neutron spectrum is obtained by an MCNPX simulation and TOF measurements





Model of the neutron source with samples



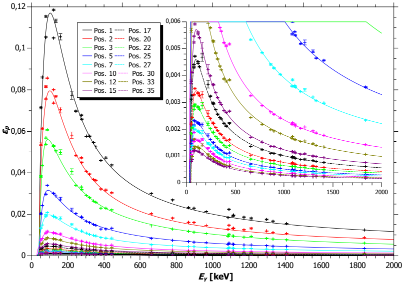


Two yttrium samples for each irradiation, each irradiated with gold foil:

- YN - 25×25×0.64 mm - solid foil, distance 123 mm
- YO - ⌀9×1.5 mm - pill, distance 103 mm

Measurement equipment

- Relative efficiency 35%
- Calibration points from 53 to 1836 keV
- Calibrated positions 1, 2, 3, 5, 7, 10, 12, 15, 17,... cm
- Complete shielding



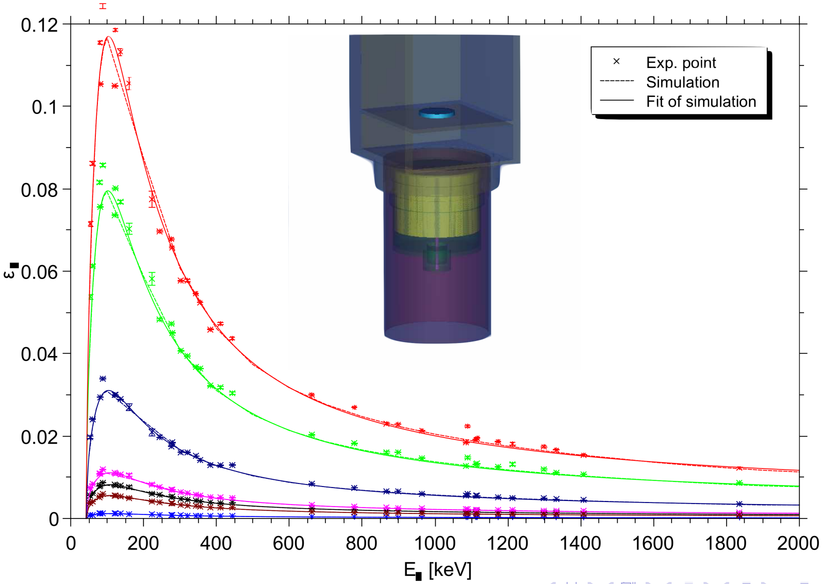
Evaluation by γ-spectrometry

- Accurate knowledge of isotopic composition is necessary for cross-section measurements.
- Vice versa, with known cross-section it is possible to use the same method for particle field/beam monitoring.
- Equations for cross-section determination in case of simple decay:

$$N_{yield} = \frac{S_{peak} \cdot C_{abs}(E) \cdot B_a}{I_\gamma \cdot \varepsilon_p(E) \cdot COI(E) \cdot C_{area}} \frac{t_{real}}{t_{live}} \frac{e^{\lambda \cdot t_0}}{1 - e^{-\lambda \cdot t_{real}}} \frac{\lambda \cdot t_{irr}}{1 - e^{-\lambda \cdot t_{irr}}},$$

$$\sigma = \frac{N_{yield} \cdot S \cdot A}{N_n \cdot N_A \cdot m}.$$

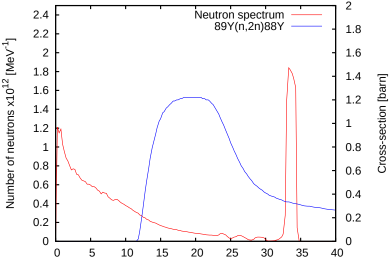
GC3018 simulation

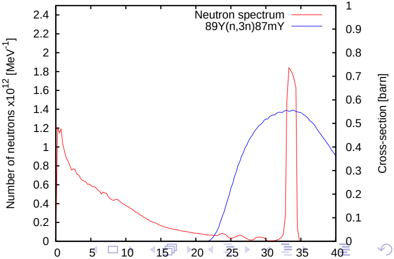


Background subtraction

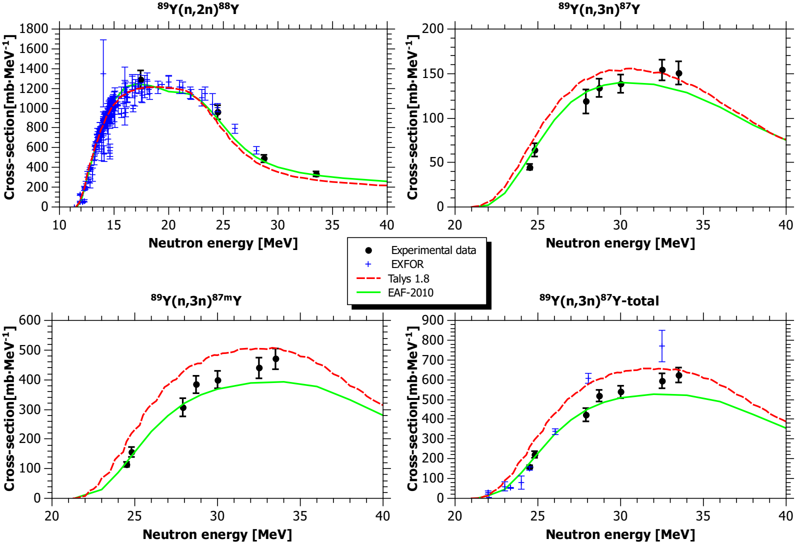
- Neutron source is quasi mono-energetic $\longrightarrow$ non zero width of the peak and presence of the low energy tail (neutron background).
- Neutron background subtraction based on folding of neutron spectrum and cross-section

$$C_{bgr} = \frac{\int\limits_{Peak} \sigma(E) \cdot N(E)\,\mathrm{d}E}{\int\limits_{Spectrum} \sigma(E) \cdot N(E)\,\mathrm{d}E} \longrightarrow C_{bgr} = \frac{\sum\limits_{i \in Peak} \sigma_i \cdot N_i}{\sum\limits_{i} \sigma_i \cdot N_i}$$

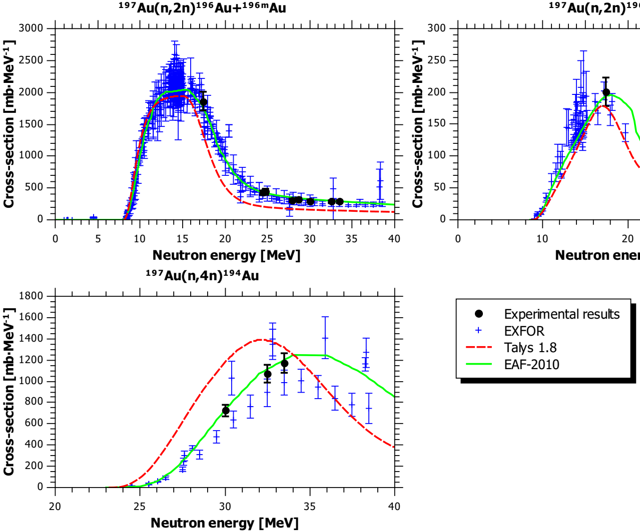




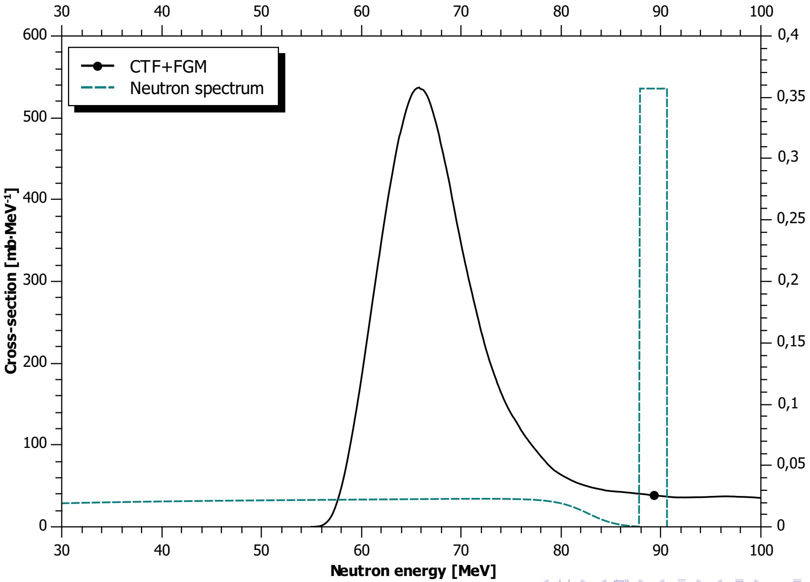
Cross-section of $^{89}Y(n,xn)$ reactions



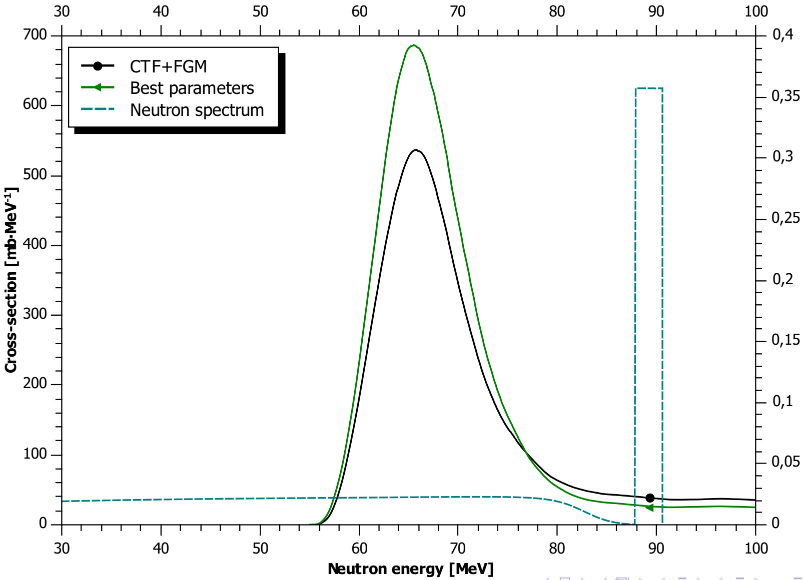
Cross-section of ^{197}Au(n,xn) reactions



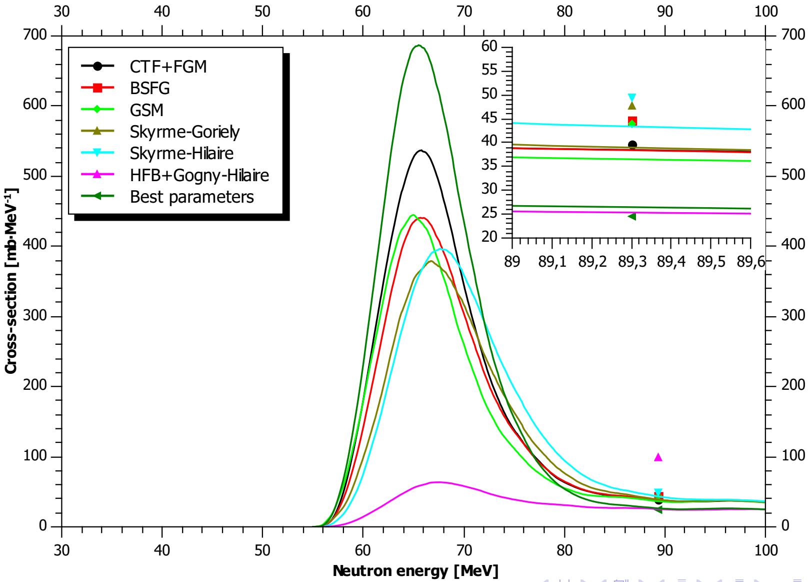
$^{197}Au(n,8n)^{190}Au$ - Step 1



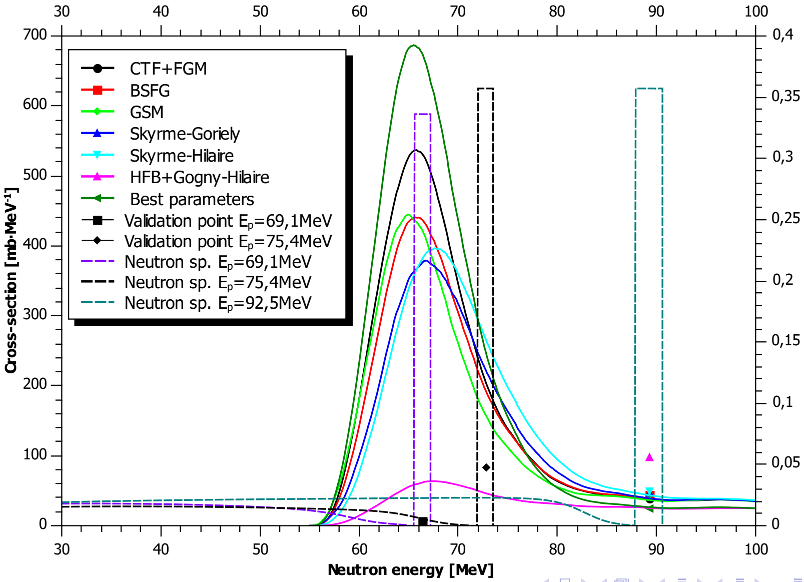
$^{197}Au(n,8n)^{190}Au$ - Step 2



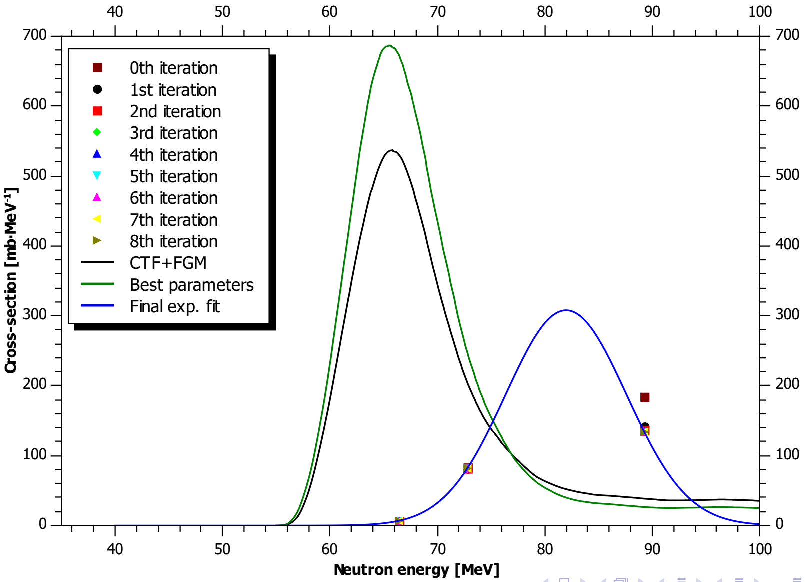
$^{197}Au(n,8n)^{190}Au$ - Step 3



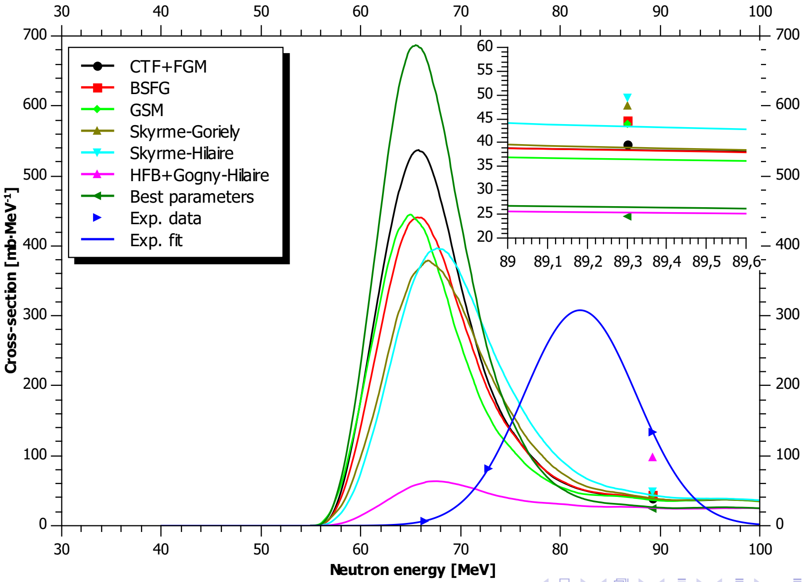
$^{197}Au(n,8n)^{190}Au$ - Step 4



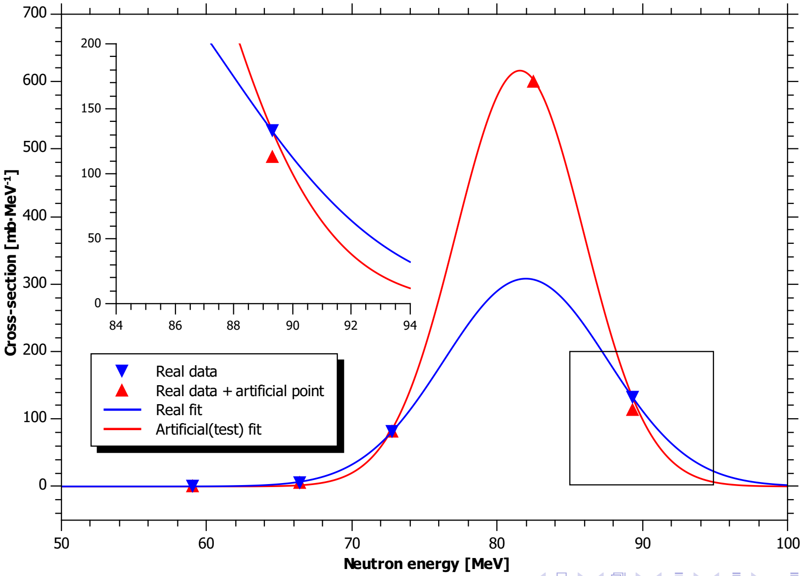
$^{197}Au(n,8n)^{190}Au$ - Excitation function evolution



$^{197}Au(n,8n)^{190}Au$ - Final comparison



$^{197}Au(n,8n)^{190}Au$ - Validation



Conclusion

- Lower degree (n,xn) reactions are described quite well in both ways - experimental data coverage and agreement with calculations.
- It is necessary to test multiple parametrization.
- The data suggest that there is still plenty of work with nuclear models and the nuclear calculation codes.

Thank you for your attention!

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EFNUDAT, ERINDA and the CANAM program of the NPI CAS.