Measurement of cross-sections of yttrium (n,xn) threshold reactions by means of gamma spectroscopy

The ERINDA Worskhop 2013

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Motivation of measurement

Necessity of fast neutron field monitoring in facilities like

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

Why yttrium?

- Products of (n,xn) reactions on yttrium are easily identifiable
- Half-lives of the products have good length for γ-spectrometry
- γ transitions are intensive enough for detection and are well separated from each other

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 1836.063	93.683 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

γ-spectroscopic methods

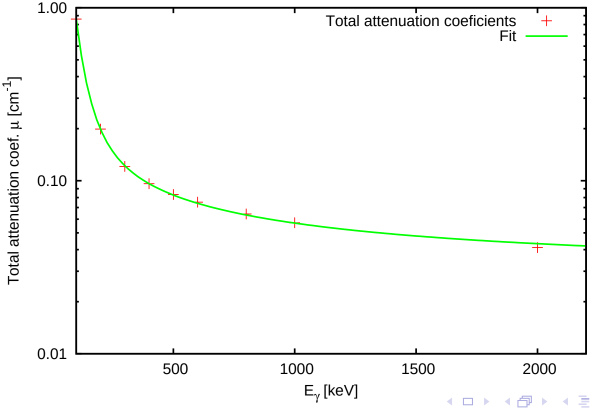
- With accurate knowledge of isotopic composition, it is possible to measure cross-section
- With known cross-section the integral of the beam is possible to determine
- Investigated reactions: $^{89}Y(n,2n)^{88}Y$, $^{89}Y(n,3n)^{87}Y$
- Equations for determining of cross-section in case of simple decay

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

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

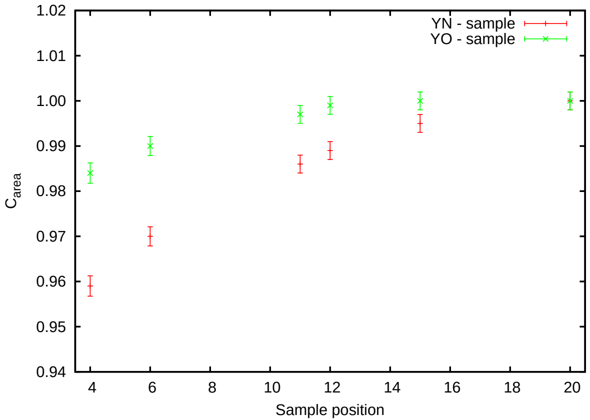
Self-absorption correction - $C_{abs}(E)$

$$C_{abs} = \frac{\int_0^D \frac{I_0}{D} \mathrm{d}x}{\int_0^D \frac{I_0}{D} \mathrm{e}^{-\mu \cdot x} \mathrm{d}x} = \frac{\mu \cdot D}{1 - \mathrm{e}^{-\mu \cdot D}}.$$



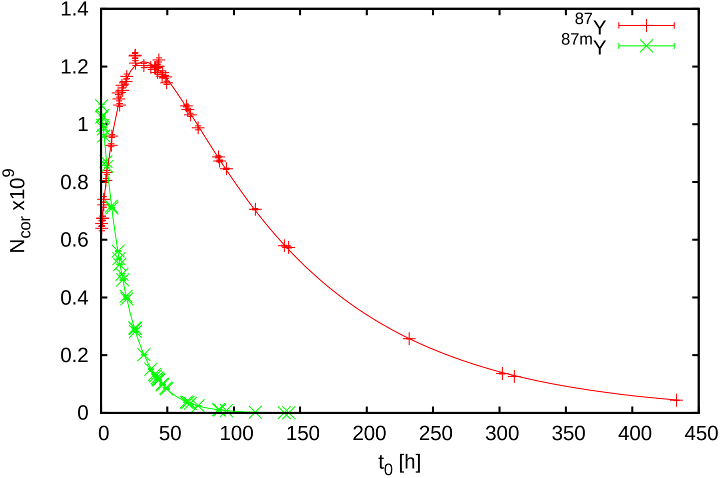
Square emitter correction - C_{area}

$$C_{area} = \frac{\varepsilon_{foil}}{\varepsilon_{point}}.$$



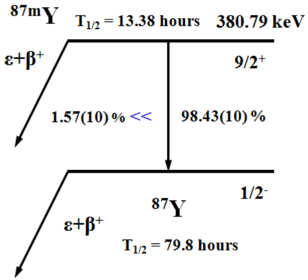
Decay of ^{87}Y and ^{87m}Y

In case of decay of ^{87}Y and ^{87m}Y



Correction for decay during cooling and irradiation

- In case of ^{89}Y(n,3n)^{87}Y reaction the ground and isomeric states are produced simultaneously
- For determination of ^{87}Y ground state production it is necessary to involve ^{87m}Y decay to the ground state.



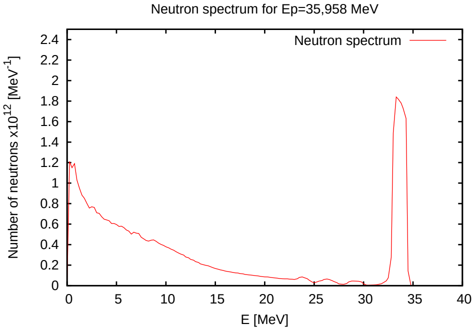
$$N_{g0} = \frac{S_{peak} \cdot C_{abs}(E) \cdot B_a \cdot e^{\lambda_g \cdot t_0}}{I_\gamma \cdot \varepsilon_p(E) \cdot COI(E) \cdot C_{area}} \frac{t_{real}}{t_{live}} \frac{1}{\left(1 - e^{-\lambda \cdot t_{real}}\right)} + \frac{\lambda_m \cdot N_{m0}}{\lambda_g - \lambda_m}\left(1 - e^{(\lambda_g - \lambda_m) \cdot t_0}\right)$$

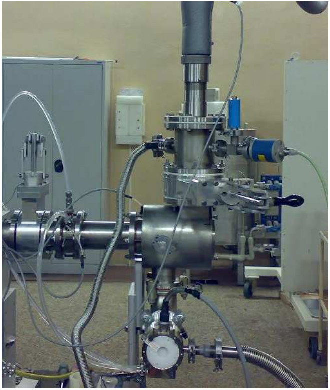
$$C_{irr} = \frac{P_g \cdot t_{irr}}{N_{g0}} = \frac{\lambda_g \cdot t_{irr}}{1 - e^{-\lambda_g \cdot t_{irr}}} - \frac{N_{yield,m}}{N_{g0} \cdot \left(1 - e^{-\lambda_g \cdot t_{irr}}\right)}\left(1 - \frac{\lambda_m \cdot e^{-\lambda_g \cdot t_{irr}} - \lambda_g \cdot e^{-\lambda_m \cdot t_{irr}}}{\lambda_m - \lambda_g}\right)$$

$$N_{yield,g} = N_{g0} \cdot C_{irr}$$

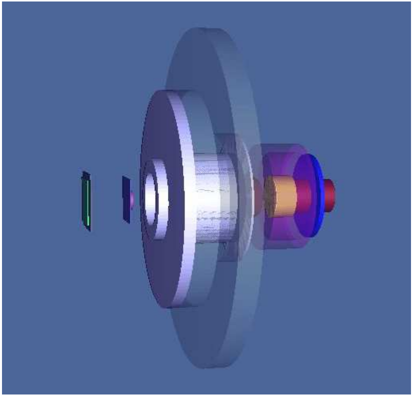
Fast neutron source

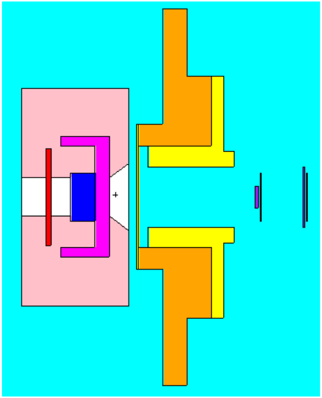
- Source based on reaction $Li^7(p,n)Be^7$
- Neutron energy range 10-37 MeV
- Source intensity $\sim 10^8 \cdot cm^{-2} \cdot s^{-1}$
- Spectrum is simulated using MCNPX





Model of the neutron source with samples





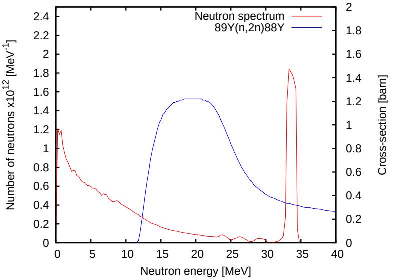
Two yttrium samples for each irradiation, each irradiated with gold foil:

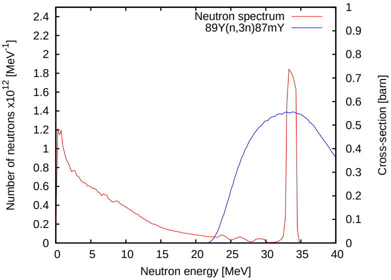
- YN - 25×25×0.64 mm - solid foil, distance 123 mm
- YO - ∅9×1.5 mm - pill, distance 103 mm

Background subtraction

- Neutron source is not monoenergetic
- Neutron background subtraction based on folding of neutron spectrum and cross-section

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

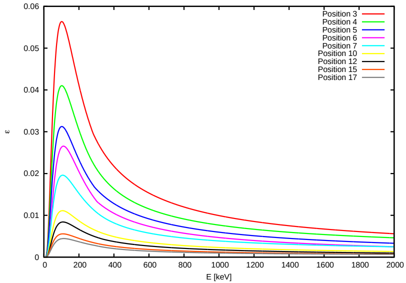




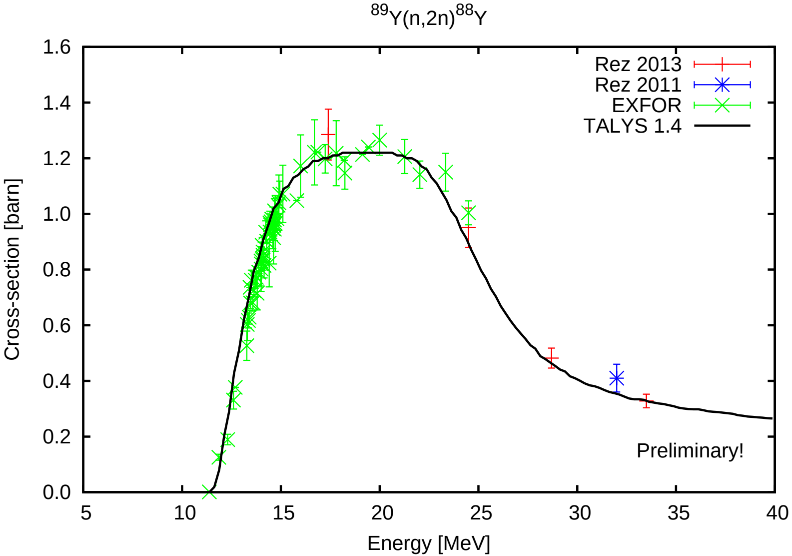
Measurement equipment

HPGe spectrometer CAN35

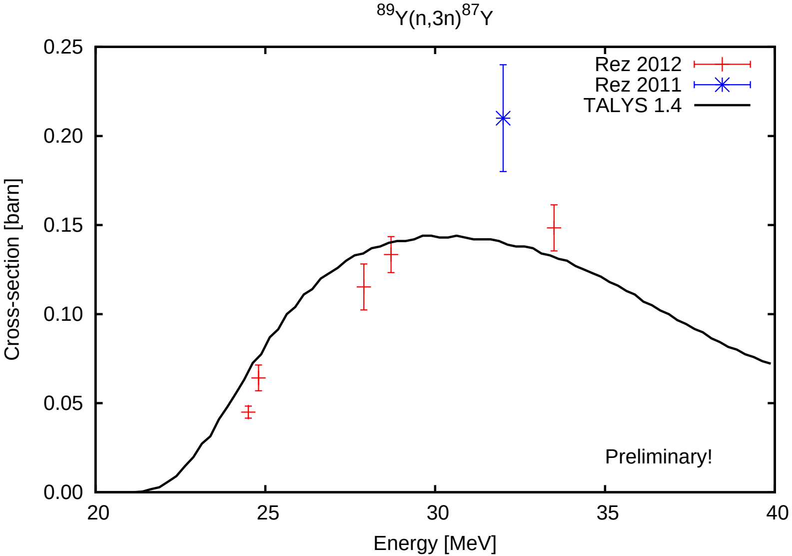
- Relative efficiency 35%
- Calibration points from 53 to 1836 keV
- Calibrated positions 3, 4, 5, 6, 7, 10, 12, 15, 17 cm
- Complete shielding



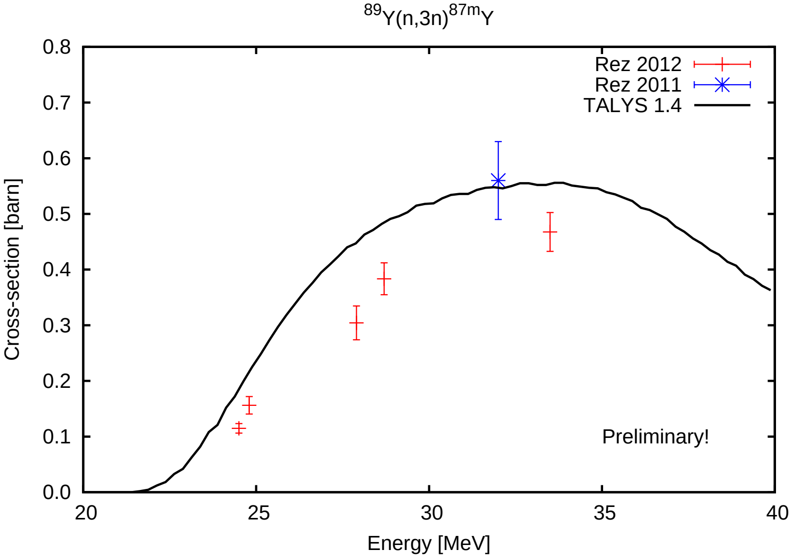
Cross-section of $^{89}Y(n,2n)^{88}Y$ reaction, $E_{thr} = 11.6$ MeV



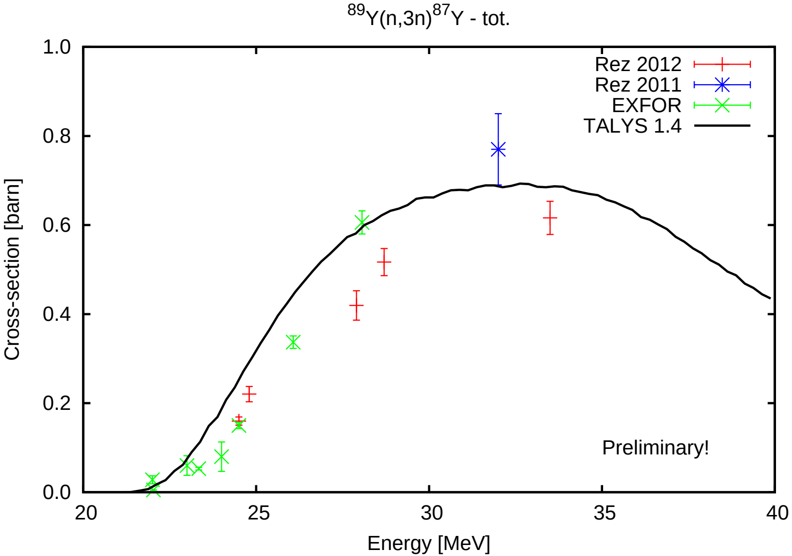
Cross-section of $^{89}Y(n,3n)^{87}Y$ reaction, $E_{thr} = 21.1$ MeV



Cross-section of ^{89}Y(n,3n)^{87m}Y reaction, $E_{thr} = 21.6$ MeV



Total cross section of $^{89}Y(n,3n)^{87}Y$ reaction

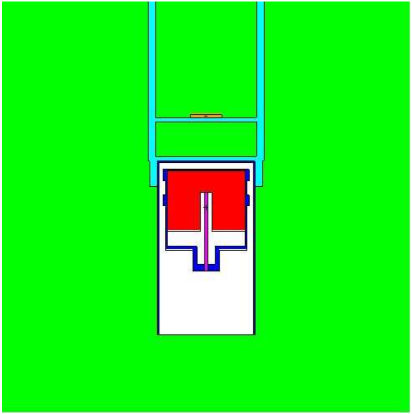


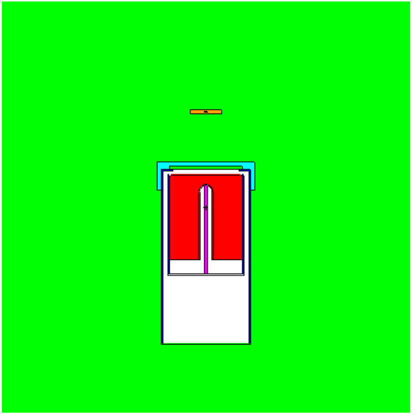
What to do next?

The data are still preliminary, but there should not be significant changes. Now we are going to concentrate on:

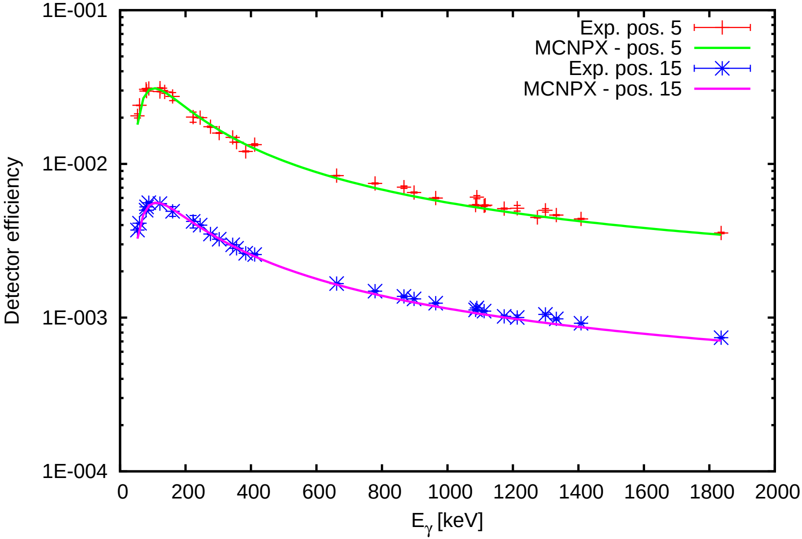
- Neutron spectra determination method
- γ-spectroscopic corrections accuracy improvement

Detector efficiency simulations

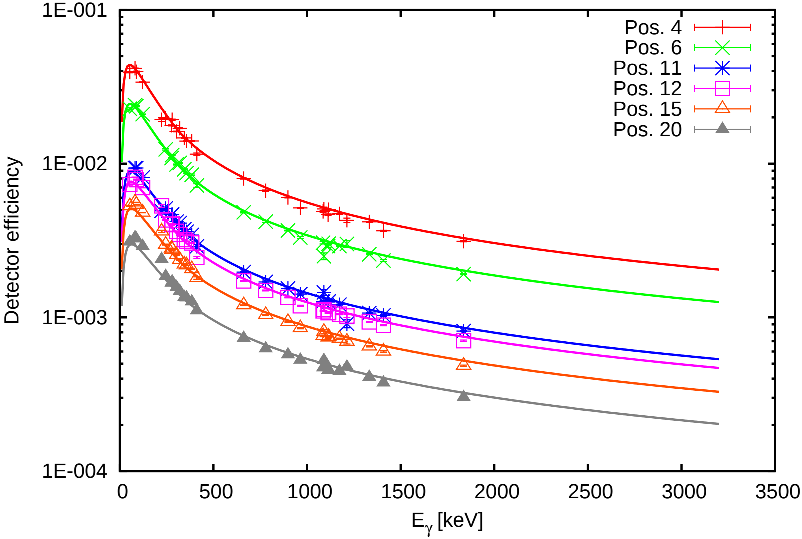




Comparison between experiment and simulation



Comparison between experiment and simulation



Thank you for your attention

The experiment was supported by ERINDA[1] and CANAM[2].

[1] http://www.erinda.org
[2] http://canam.ujf.cas.cz