The New Collaboration of the JINR and the iThemba LABS for Cross-Section (n,xn) Reactions Measurements

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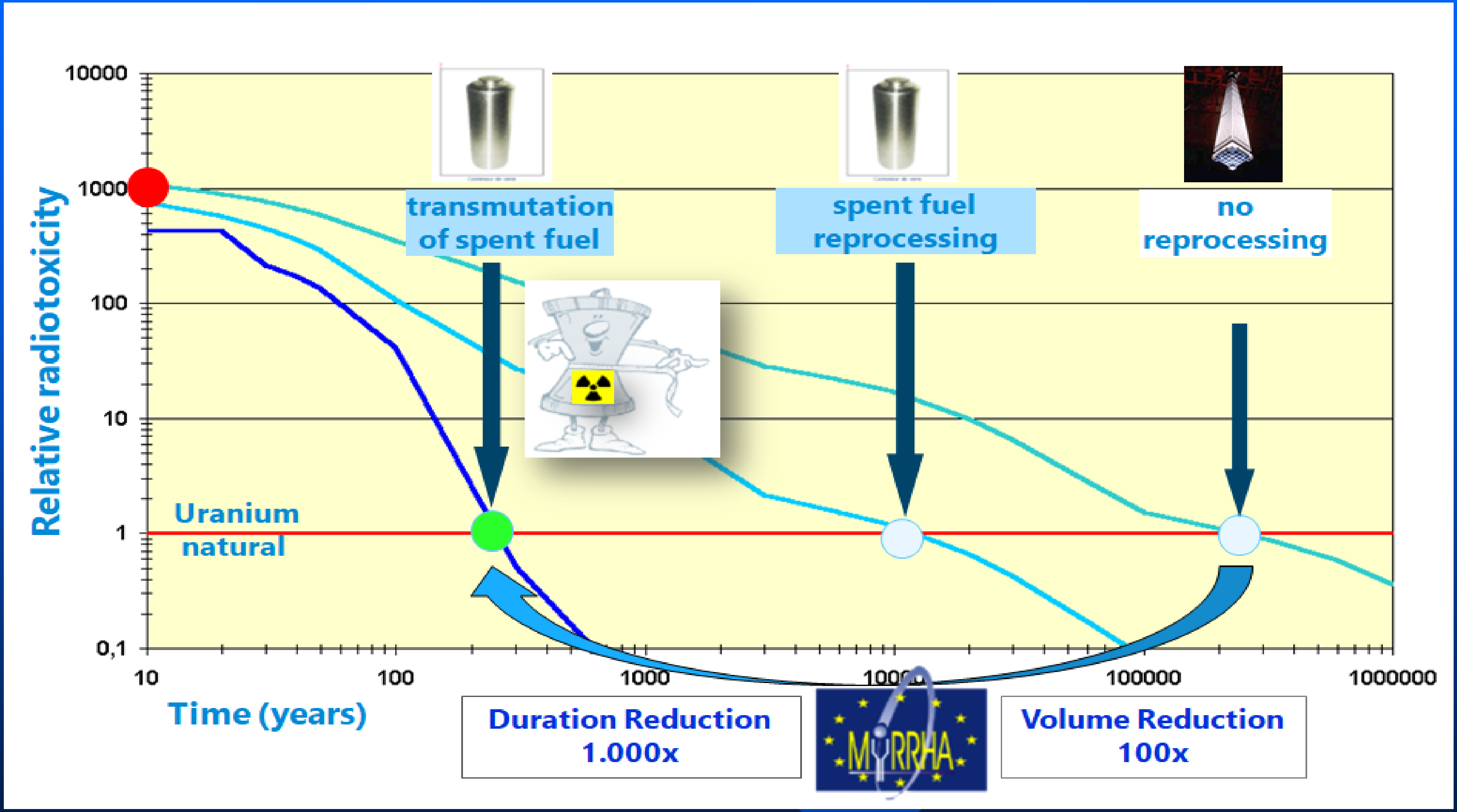
Outline

1. Motivation
2. High Energy Cross-Section problem
3. Results of previous experiments
4. Our proposal and future plans

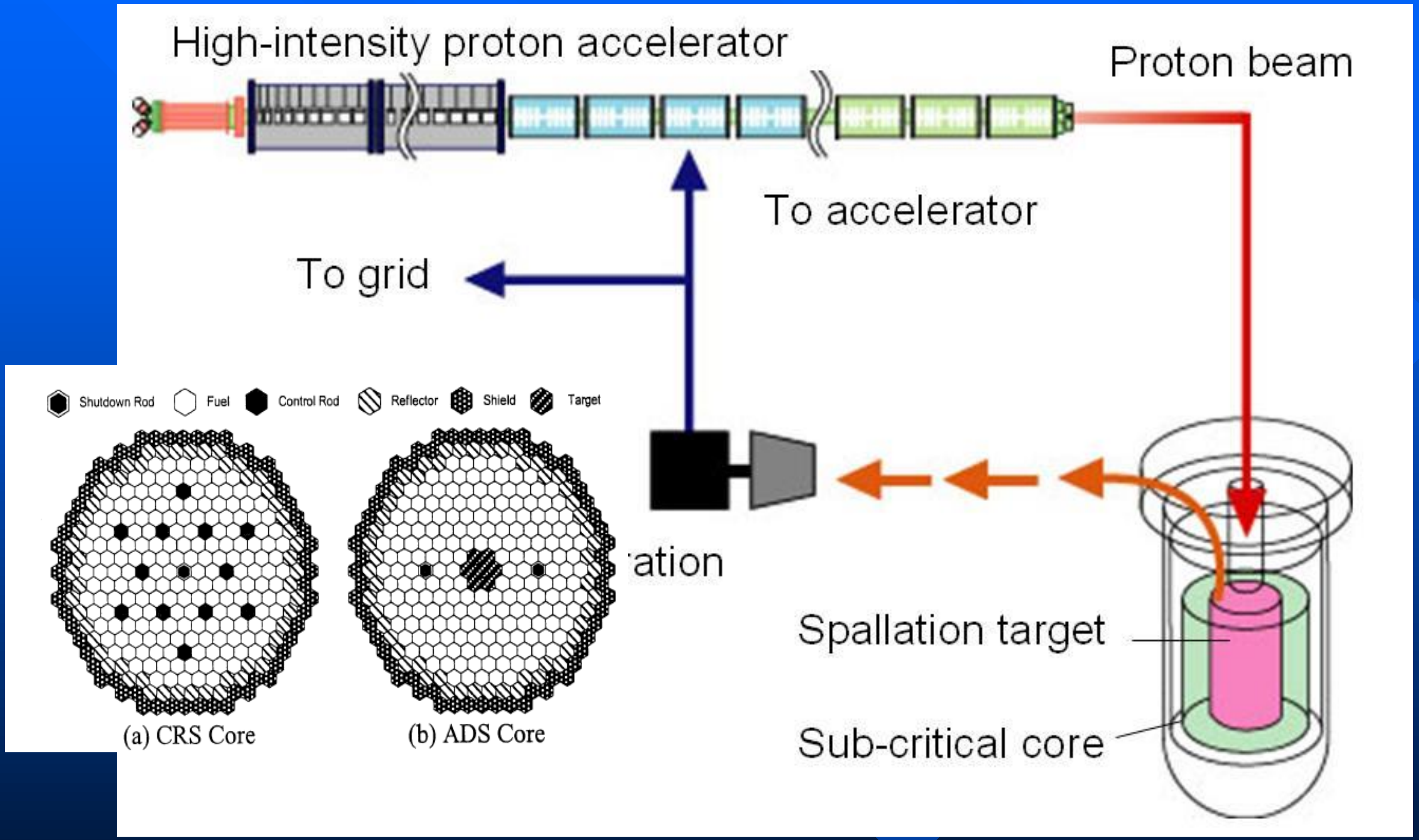
1. Motivation

1. Fast neutron field monitoring in the facilities like
  - Accelerator Driven Systems (ADS)
  - Neutron Spallation Source
  - Fast (in particular HTR) and Fusion reactors
2. Research on construction and optimal work parameters, future IVth generation reactors
3. Transmutation some of the long-lived components of radioactive wastes

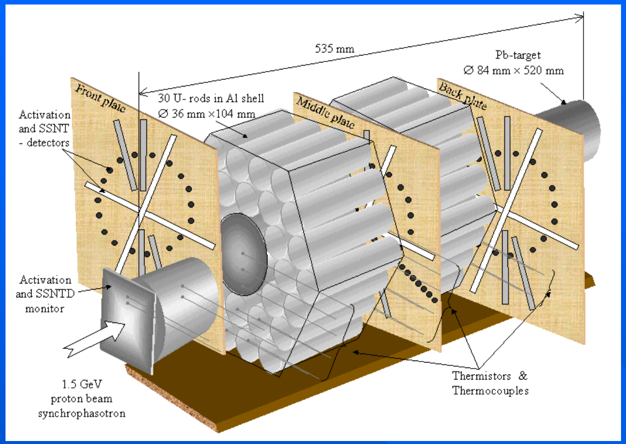
1. Radioactivity of Spent Fuel - Transmutation



1. ADS - Accelerator Driven System

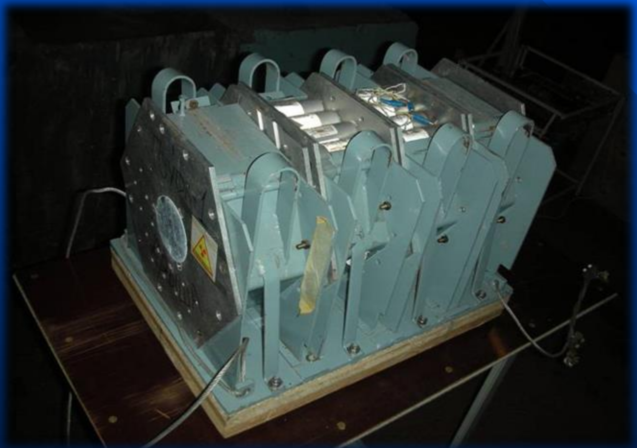


1. Dubna ADS Experiments

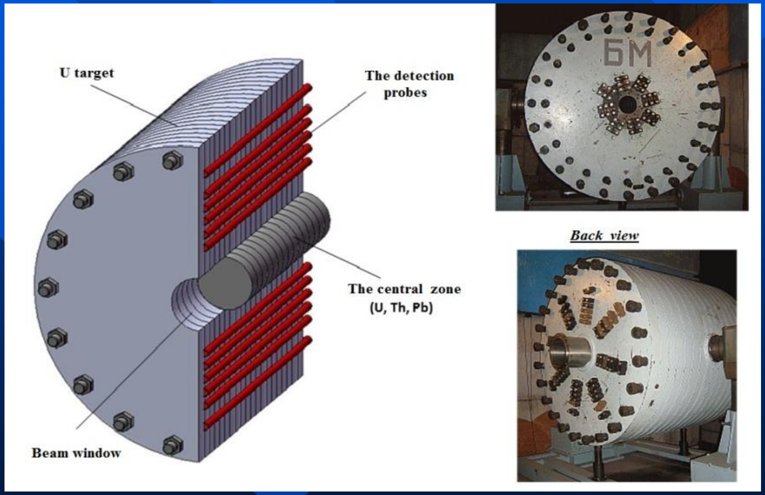


Energy plus Transmutation
(2000-2003)

QUINTA
(2011-2017)



Energy plus Transmutation
(2004-2009)



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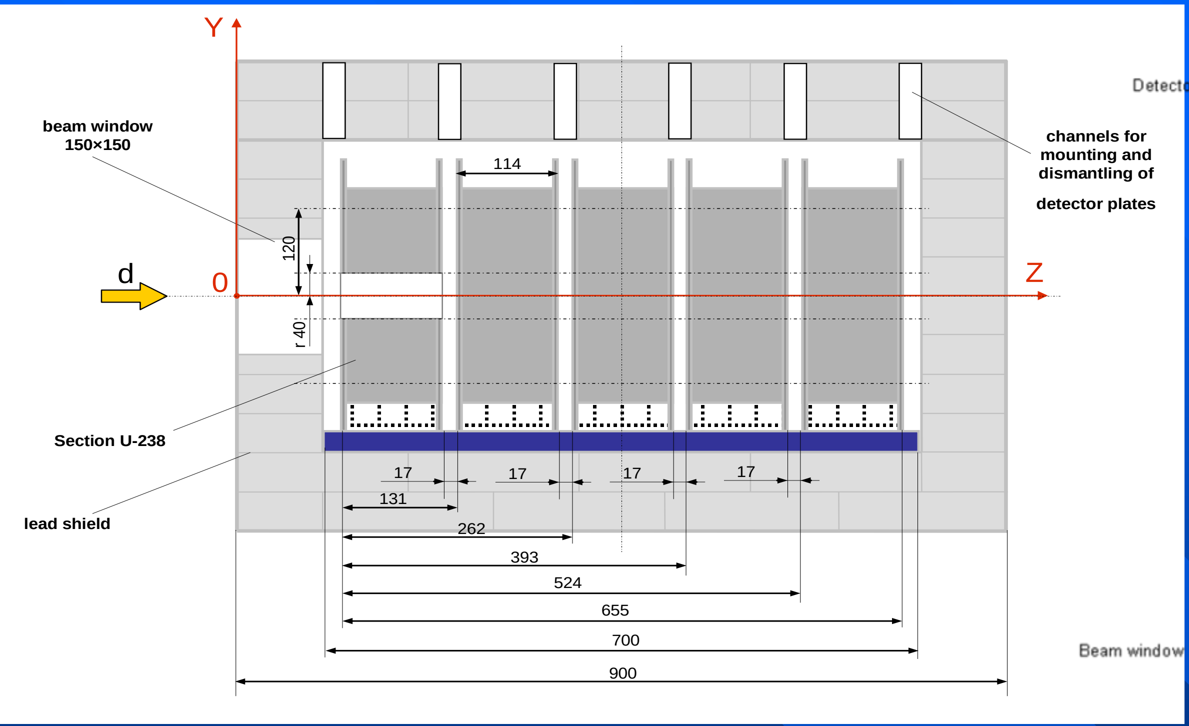
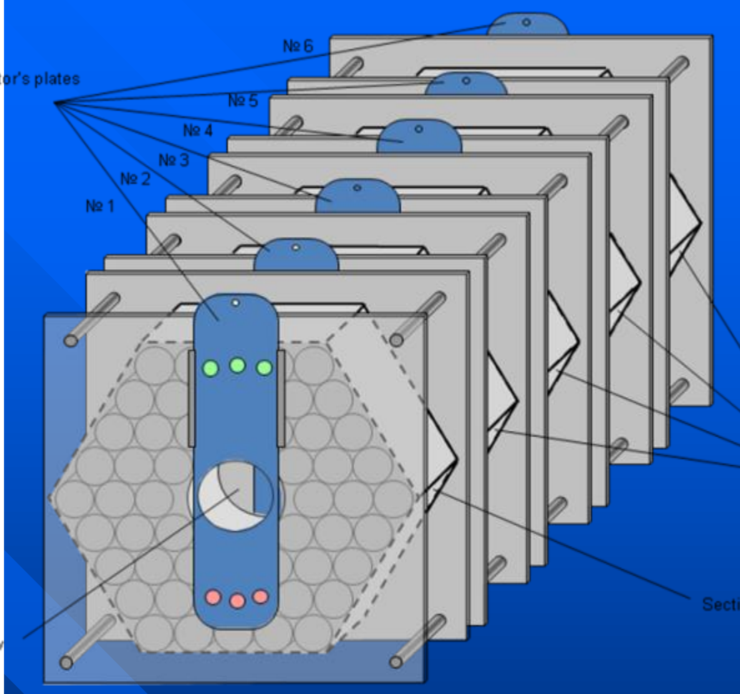
1. QUINTA experiments with two types of beams

QUINTA assembly – longitudinal view



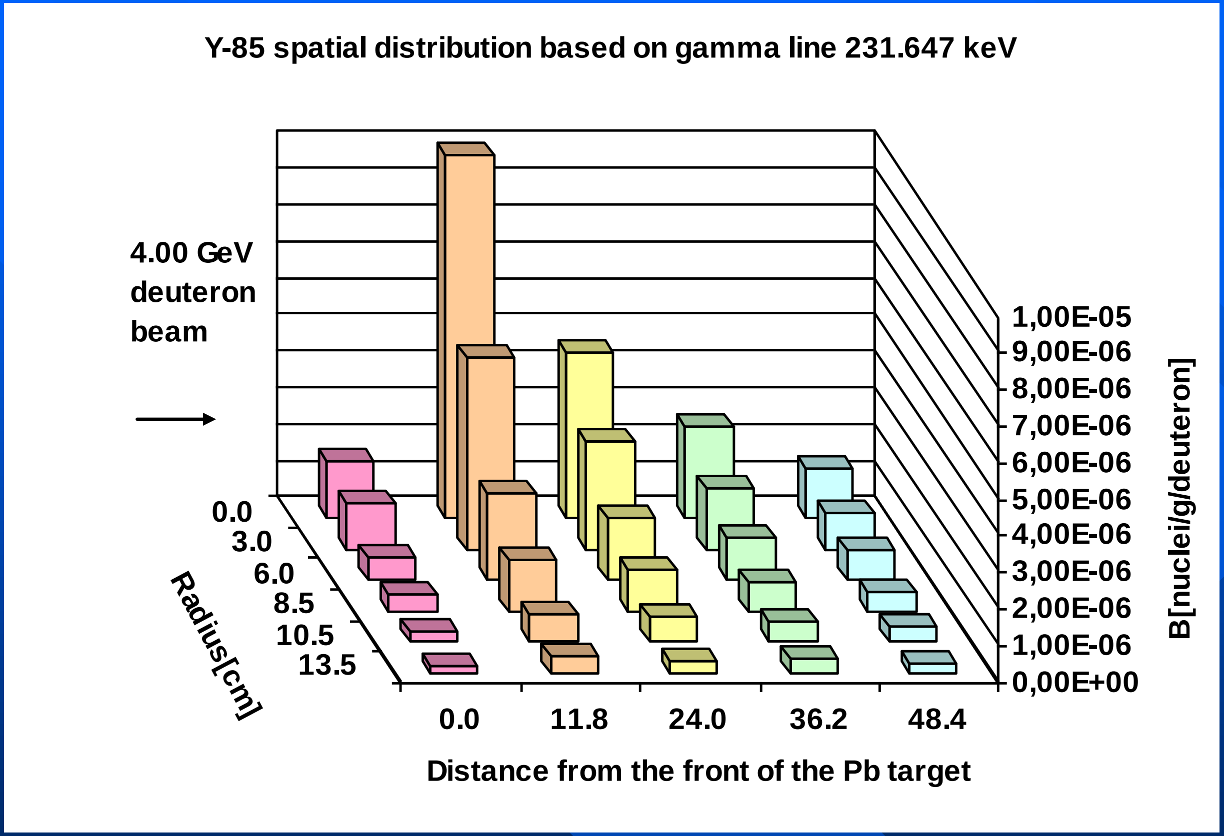


The Quinta assembly, consists of a total of 512 kg of natural uranium. It is composed of five sections, 114 mm long and separated by a 17 mm air gap. The uranium cylindrical rods, 36 mm in diameter, 104 mm in length and 1.72 kg in mass. The first section contains only 54 rods and the removal of the central 7 rods is to create a beam window next sections have 61 uranium roads. This beam window is 80 mm in diameter and serves to reduce the loss of backward emitted/scattered neutrons. The front and back of each section are bounded by aluminum plates 350 x 350 x 5 mm.

1. Some applied activation detectors

Material:	Co-59	Bi-209	Au-197	Y-89
(n,2n) MeV	13,3	7,3	8,1	11,5
	78,82 d	368000 y	6,183 d	106,65 d
(n,3n) MeV	24,6	13,9	14,8 !!!	20,8
	271,79 d	31,55 y	186,1 d	79,8 h
(n,4n) MeV	41,7	22,6	23,2	32,7
	77,27 d	6,243 d	38,02 h	14,74 h
(n,5n) MeV	56,2	29,6	30,2 !!!	42,1
	17,53 h	15,31 d	17,65 h	2,68 h
(n,6n) MeV		38,1	38,9	54,4
		11,22 h	4,94 h	39,5 m
(n,7n) MeV		45,2	45,7	
		11,76 h	3,18 h	
		to (n,9n)		

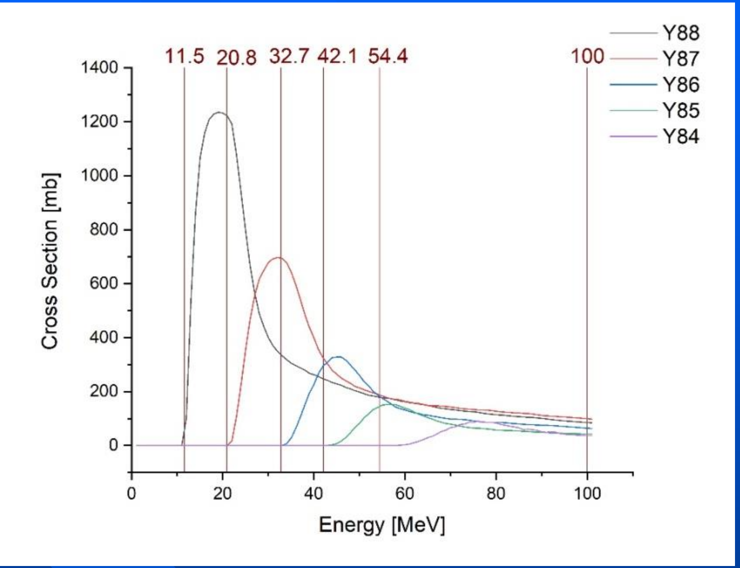
2. High Energy Cross-Section problem



Spatial distribution (radial & axial) of Y85 production. The deuteron beam 4 GeV.

2. Neutron flux calculation

Y-89 (n,2n) Y-88 E_{th}=11,5 MeV
Y-89 (n,3n) Y-87 E_{th}= 20,8 MeV
Y-89 (n,4n) Y-86 E_{th}= 32,7 MeV
Y-89 (n,5n) Y-85 E_{th}= 42,1 MeV
Y-89 (n,6n) Y-84 E_{th}= 54,4 MeV

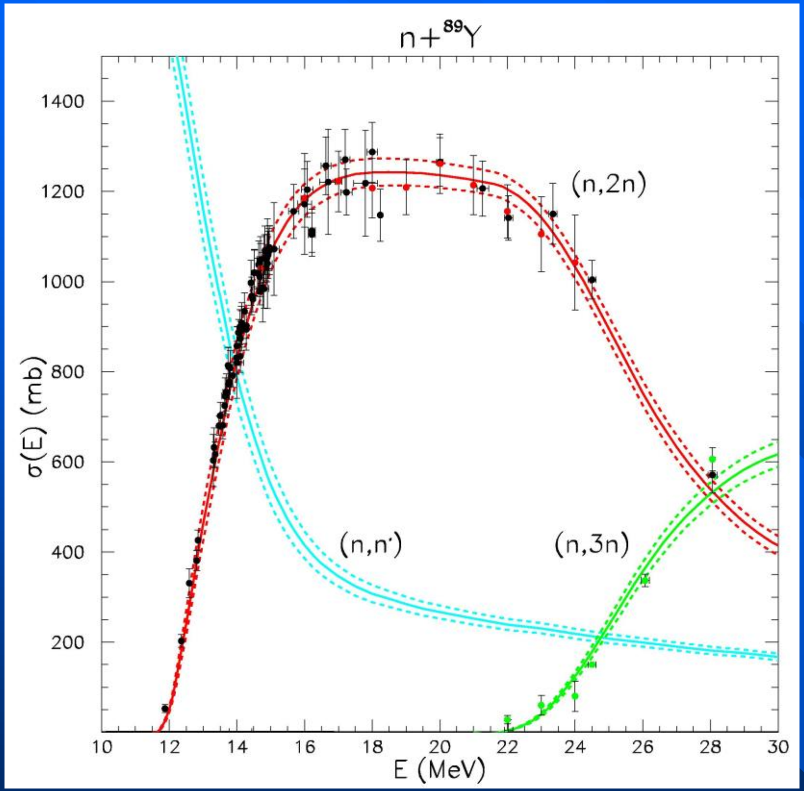


- Solution of the system of five algebraic equations let us evaluate the average neutron fluxes in the five energy ranges expressed in [n/cm2·s]:

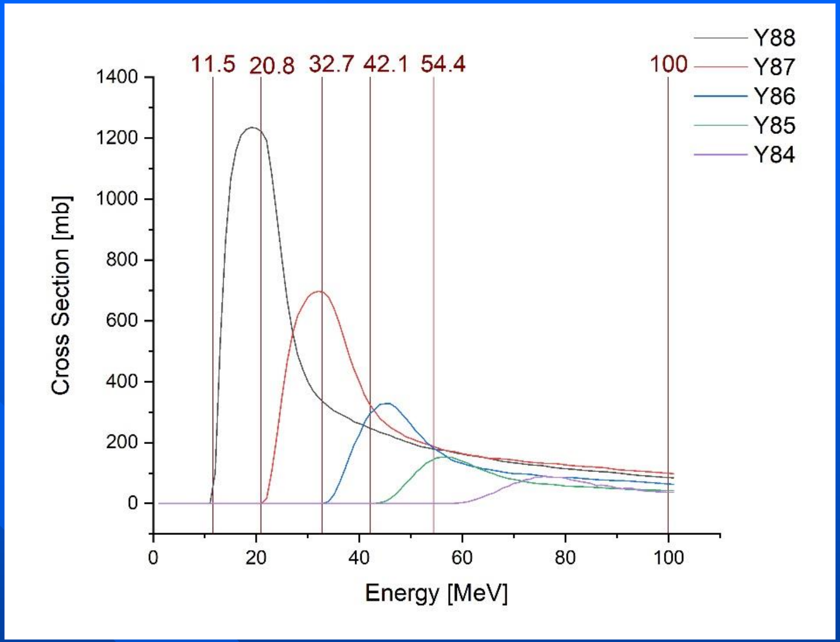
$$\begin{cases} B^{88}C = \overline{\phi_1}\overline{\sigma_{11}}+\overline{\phi_2}\overline{\sigma_{12}}+\overline{\phi_3}\overline{\sigma_{13}}+\overline{\phi_4}\overline{\sigma_{14}}+\overline{\phi_5}\overline{\sigma_{15}} \\ B^{87}C = 0+\overline{\phi_2}\overline{\sigma_{22}}+\overline{\phi_3}\overline{\sigma_{23}}+\overline{\phi_4}\overline{\sigma_{24}}+\overline{\phi_5}\overline{\sigma_{25}} \\ B^{86}C = 0+0+\overline{\phi_3}\overline{\sigma_{33}}+\overline{\phi_4}\overline{\sigma_{34}}+\overline{\phi_5}\overline{\sigma_{35}} \\ B^{85}C = 0+0+0+\overline{\phi_4}\overline{\sigma_{44}}+\overline{\phi_5}\overline{\sigma_{45}} \\ B^{84}C = 0+0+0+0+\overline{\phi_5}\overline{\sigma_{55}} \end{cases}$$

$$C = \frac{S\,G^{89}}{A\,t}$$

2. High Energy Cross-Section problem

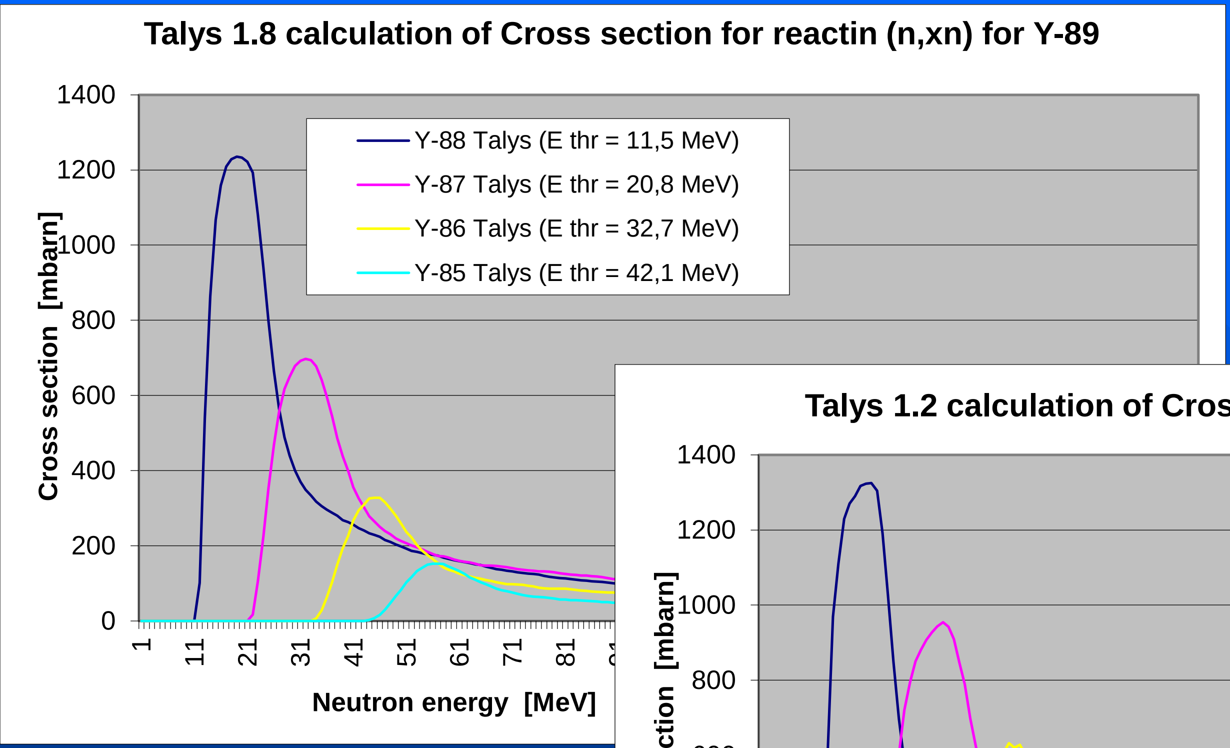


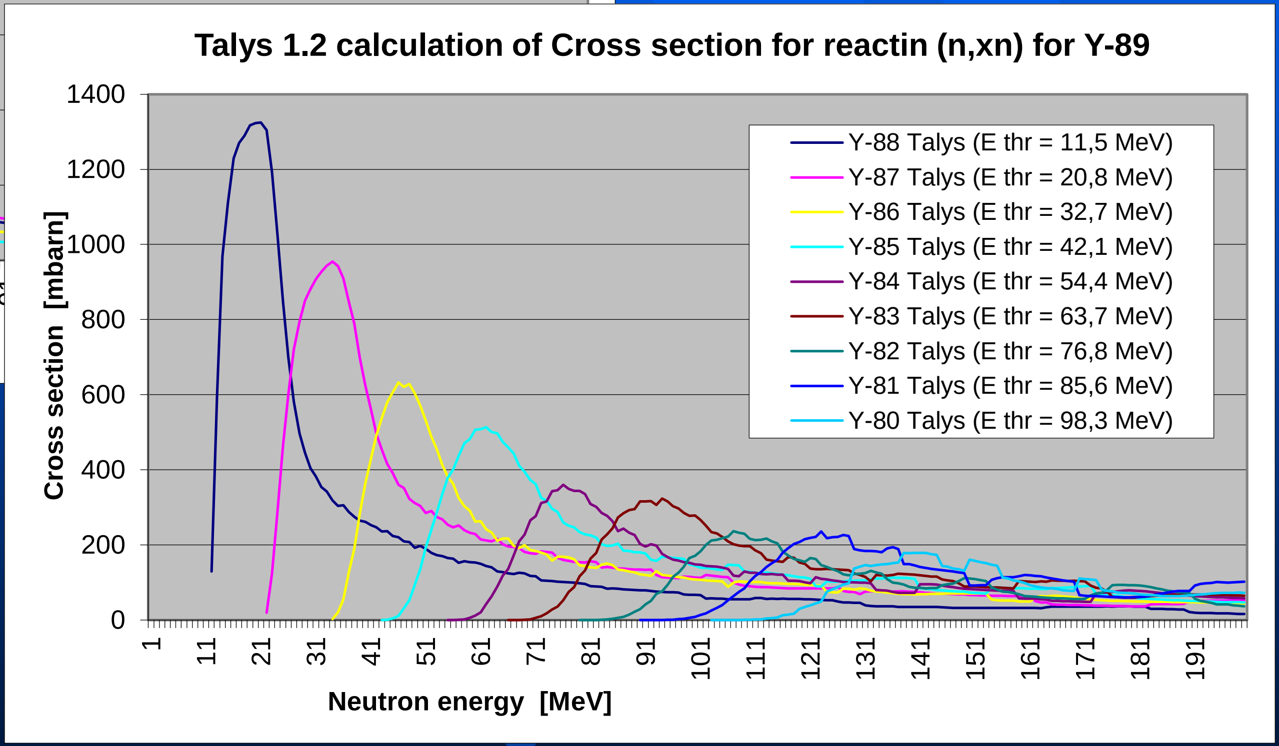
Experimental data from older EXFOR data base



Cross section for yttrium (n,xn) reactions from TALYS programme

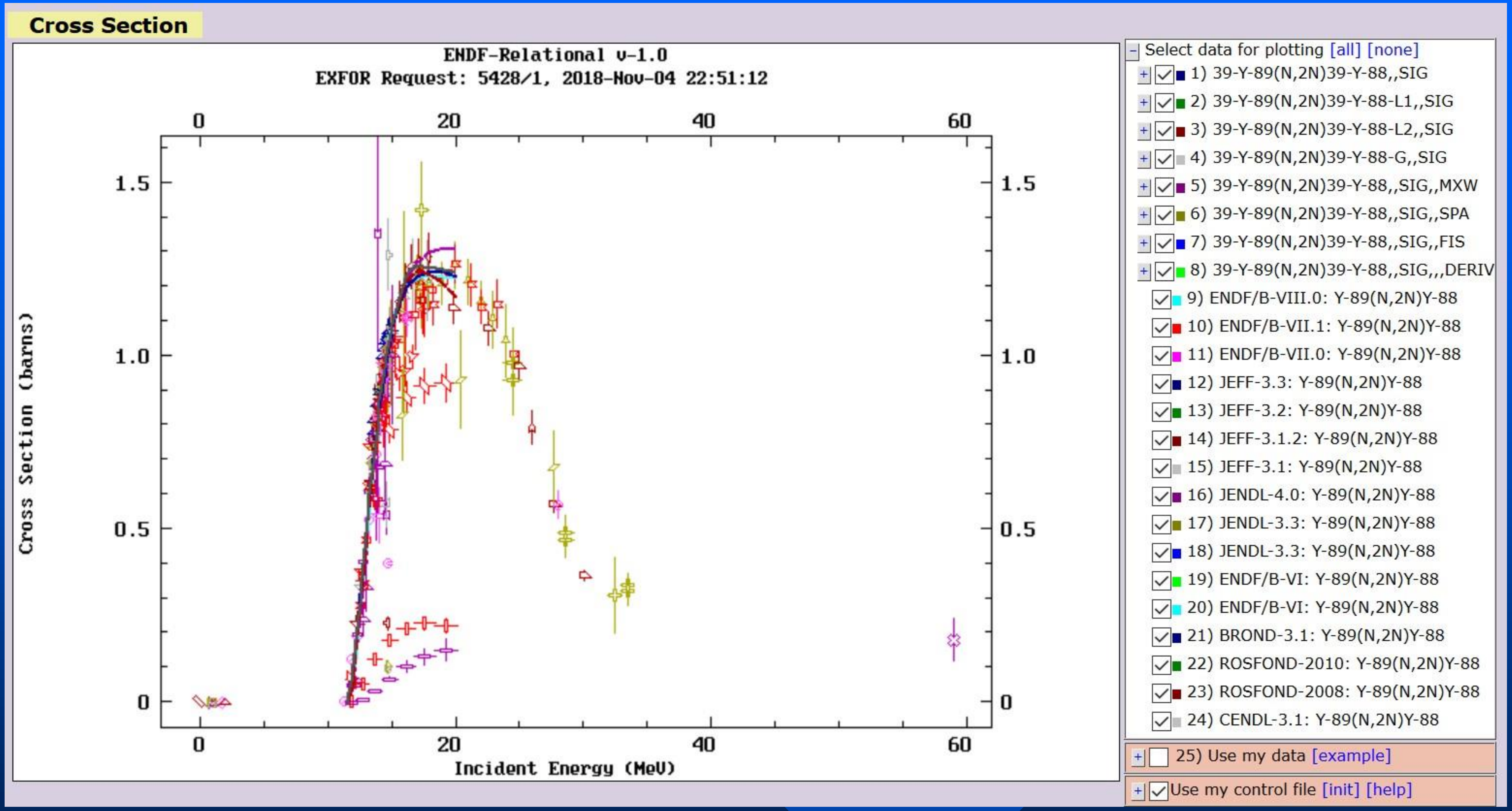
2. High Energy Cross-Section problem





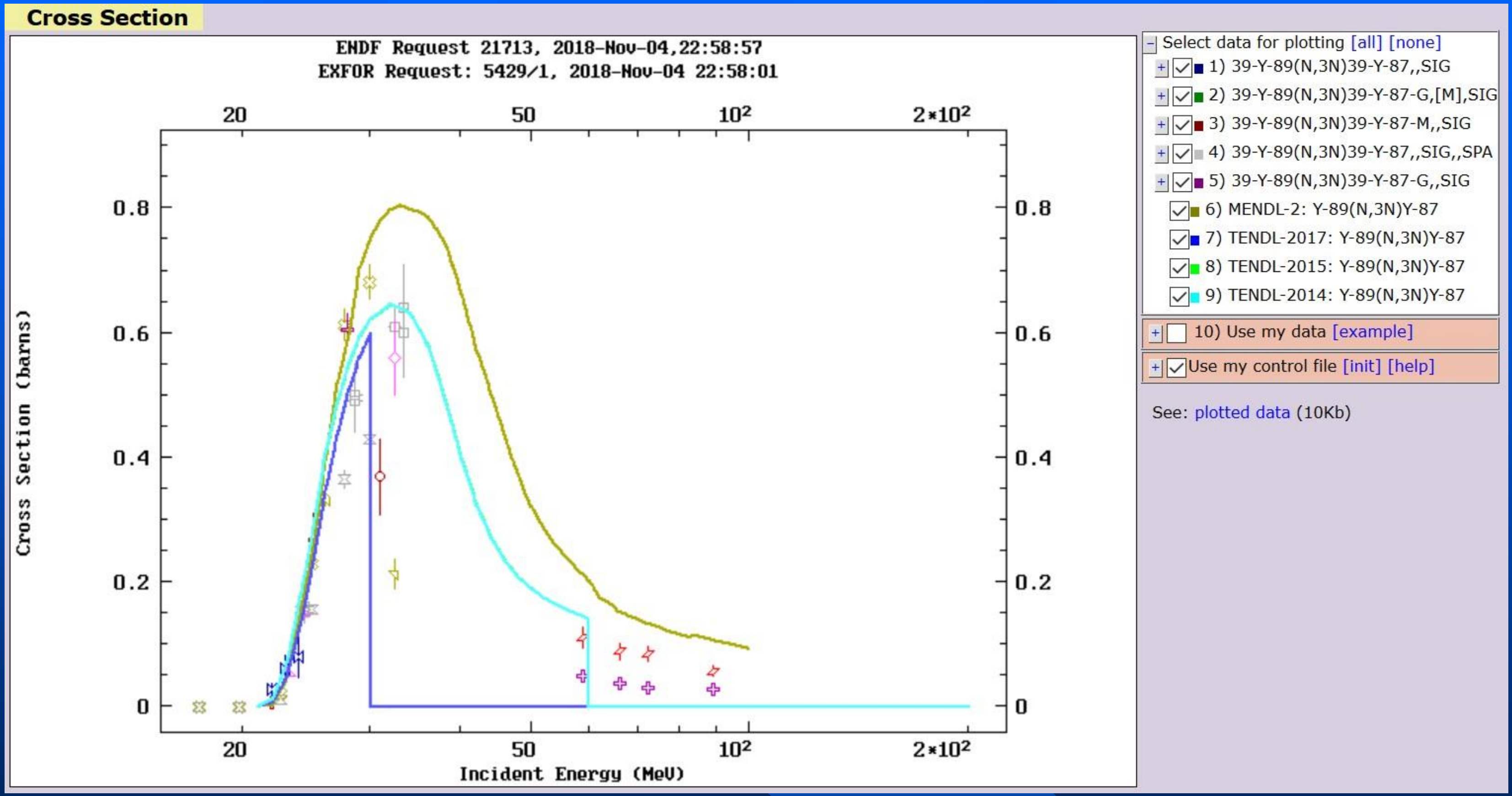
TALYS Microscopic cross sections for several $^{89}Y(n, xn)$ reactions.

2. High Energy Cross-Section problem



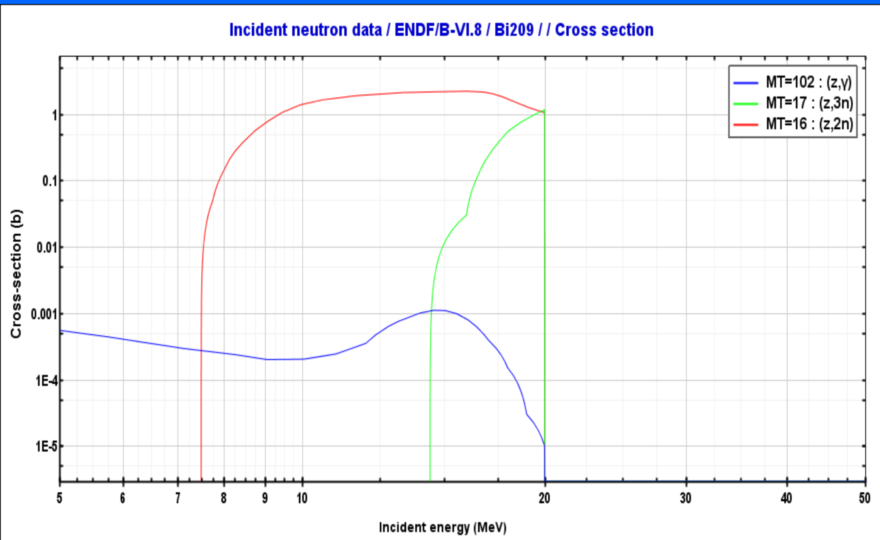
Cross Section for Y89 (n,2n) Y88 reaction

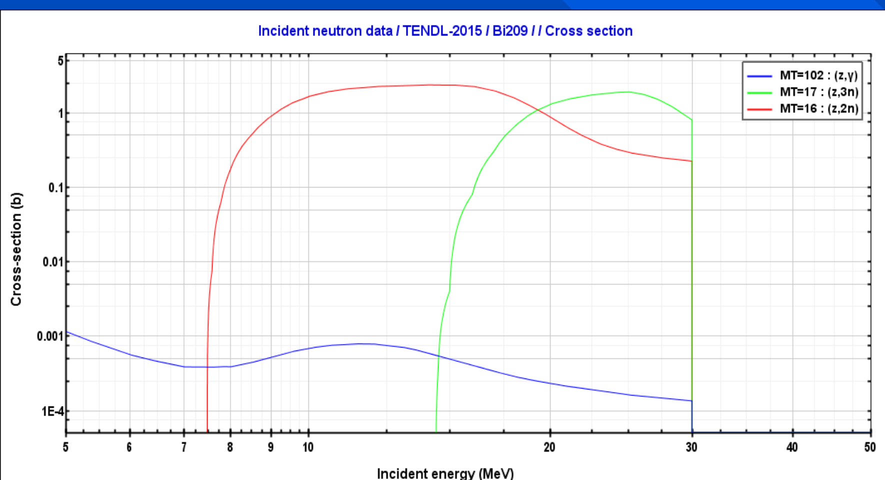
2. High Energy Cross-Section problem



Cross Section for Y89 (n,3n) Y87 reaction

2. High Energy Cross-Section problem



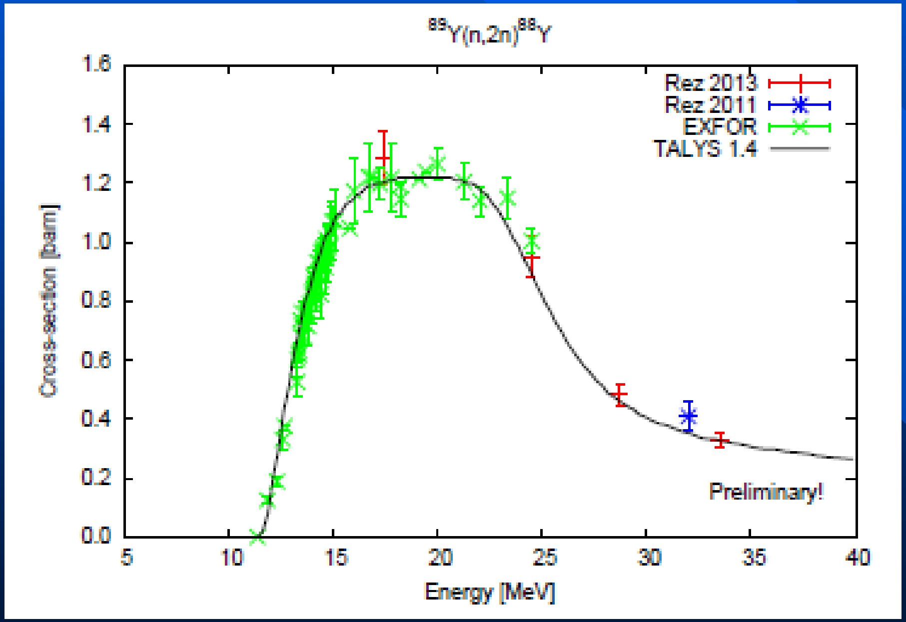


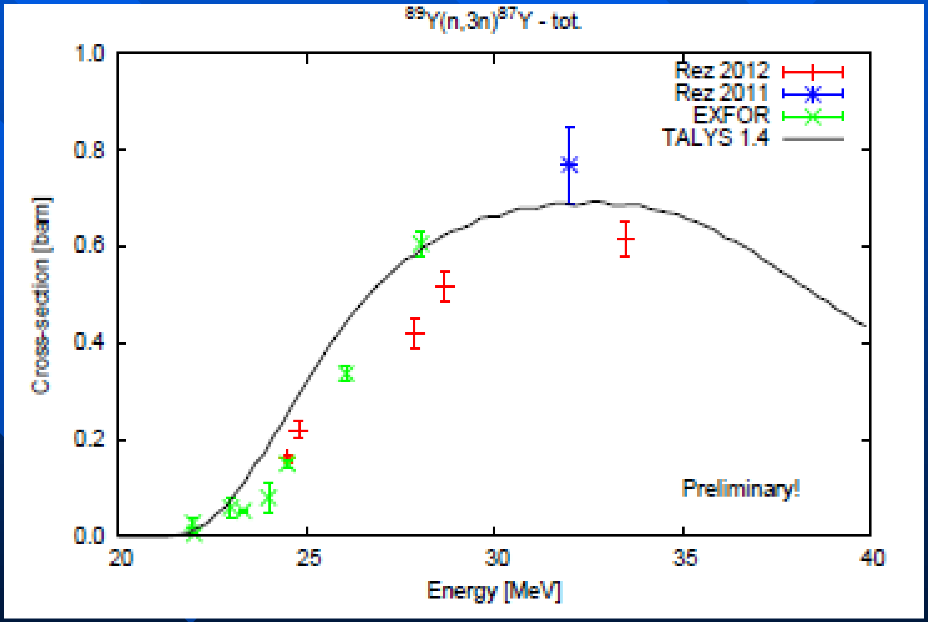
Emax [MeV]	30	150	20	150	200
	ENDL92	ENDF70	ENDF60	LA150	TENDL12-14
(n,2n)	5.1	4.5	4.34	4.7	5.1
(n,3n)	1.35	0.3	0.3	0.3	1.7-1.9
(n,4n)	---------	---------	------------	---------	0.28 - 0.33
(n,γ)	66	52	57	52	58-63
$N_{spall.}$	8.5	1.6	11.1	1.7	3.5
N_{total}	86	94	112	94	103

Neutrons induced reactions in ^{209}Bi, libraries and restrictions

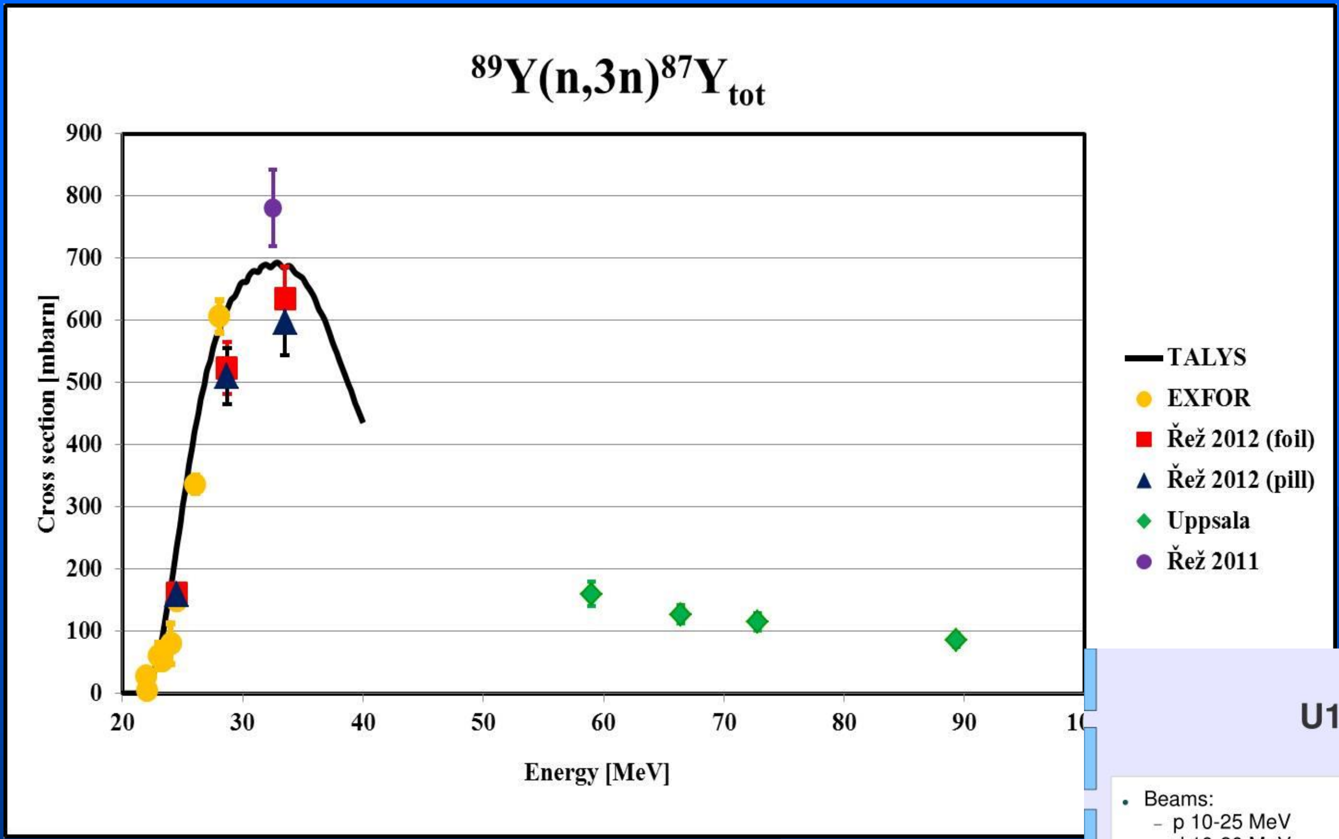
3. Results of previous experiments

We have performed measurement of neutron reaction cross-sections for selected energies of these reactions by means of quasi mono-energetic neutron sources at Nuclear Physics Institute (NPI) in Řež, Czech Republic (2011 and 2012) (EU - ERINDA program) and at
The Svedberg Laboratory (TSL) in Uppsala, Sweden (2011 and 2015) (EU - CHANDA program)





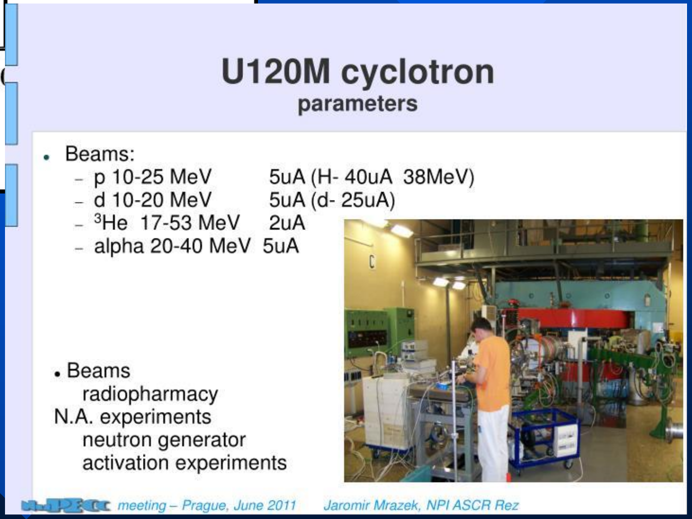
3. Results of previous experiments



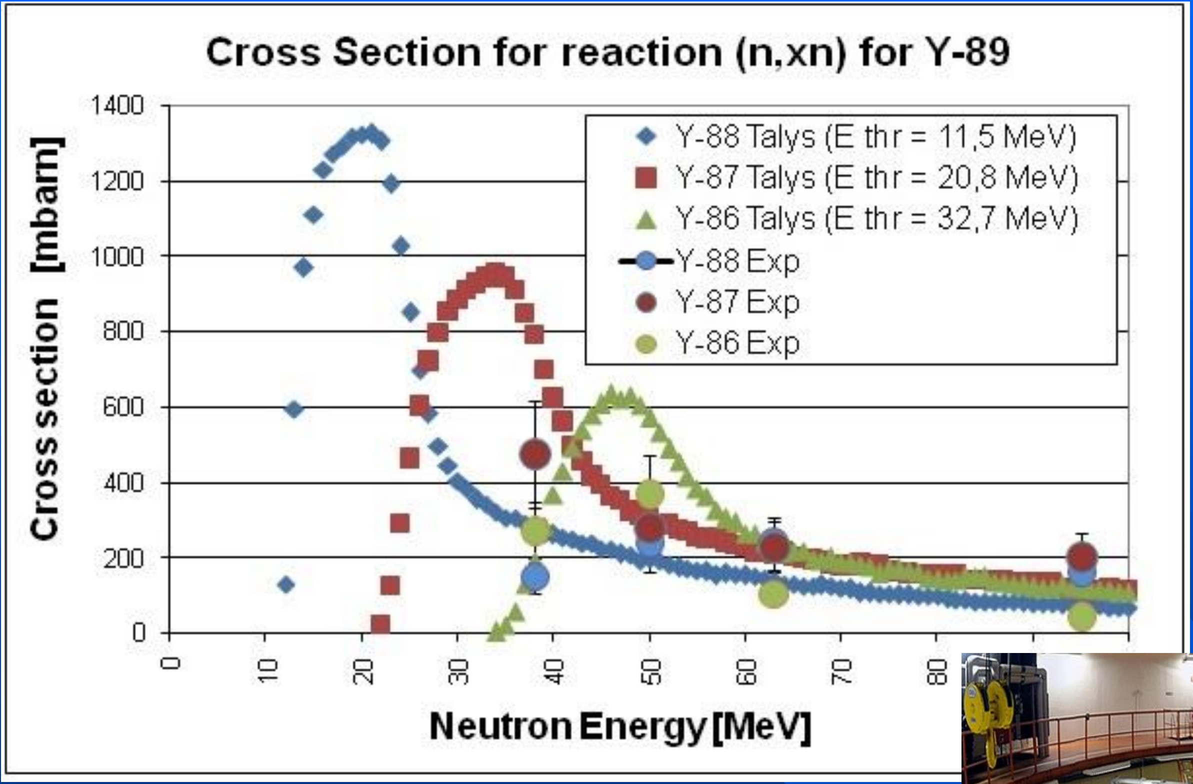
NPI ASCR Řež:
Energy range
18 -37 MeV,
Neutron intensity
~ 10^8 neutron cm^{-2} s^{-1}

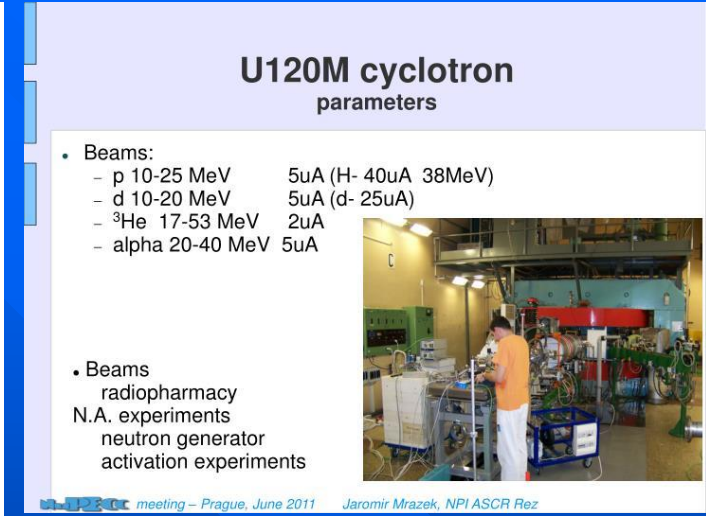
TSL Uppsala:
Energy range
25 – 180 MeV
Neutron intensity
~ 10^5 neutron cm^{-2} s^{-1}

Total cross section of ^{87}Y production



3. Results of previous experiments





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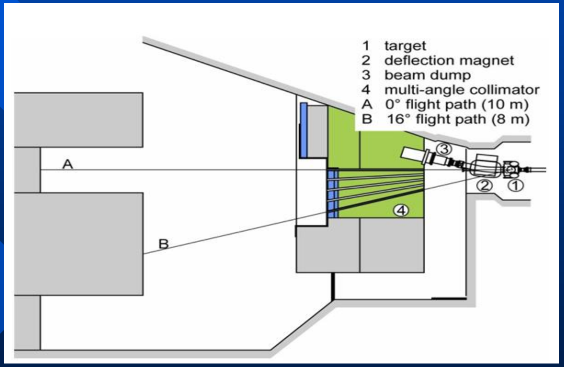
After application of the corrections we obtained four cross-sections for the following four neutron energies 38, 50, 63 and 95 MeV.

4. Beam Time proposal and future plans

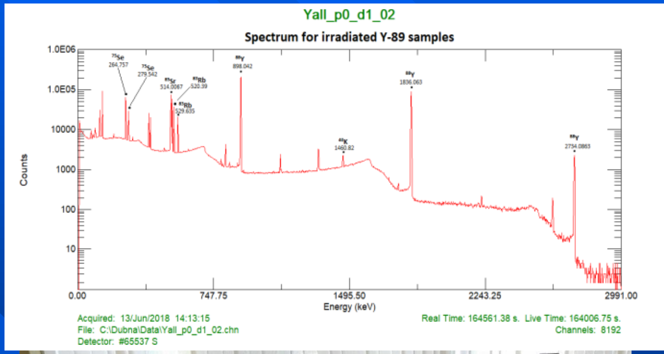
The aim of the project is to measure (n,xn) reaction cross sections for the for the Y, Bi, Co and other targets using quasi mono-energetic neutron beams of 56 MeV, 66 MeV, 100 MeV and 180 MeV.
Additionally we will use the gold target for results comparison, and copper and aluminum foils for beam monitoring.
Each material now we have in state of solid cylinders and the thin foils – every are high purity (>=99.9%) material. In every experiment we will be irradiate the same set of the foils in the both (A and B) positions.

iThemba LABS, Cyclotron, and D-line (neutron source)



4. Beam Time proposal and future plans - Calibration formulas

$$N_{nucl} = N_1 \cdot \frac{\Delta S(G) \cdot \Delta D(E)}{\frac{N_{abs}}{100} \cdot \varepsilon_p(E) \cdot COI(E,G)} \cdot \frac{(\lambda \cdot t_{ira})}{[1-\exp(-\lambda \cdot t_{ira})]} \cdot \exp(\lambda \cdot t_+) \cdot \frac{\frac{t_{real}}{t_{live}}}{[1-\exp(-\lambda \cdot t_{real})]}$$



where:

- N_{nucl} number produced nuclei

- N_1 peak (line) area
- N_{abs} the absolute intensity of given line in percent [%]
- $\varepsilon_p(E)$ detector efficiency function of energy (polynomial)
- $COI(E,G)$ cascade effect coefficient
- $\Delta S(G), \Delta D(E)$ calibrations function for thickness and shape of detectors
- λ decay constant ($\lambda=\ln(2)/t_{1/2}$)
- $t_{1/2}$ half life time [s]
- t_{ira} elapsed time of irradiation [s]
- t_+ time from the end of irradi.and the start of measur. [s]
- t_{real} time of the measurement [s]
- m mass of the sample (target) [g]

It was assumed that the main contribution to value B error came from statistical error, ΔN_1 and I number error .

4. Beam Time proposal and future plans – Cross Section calculation

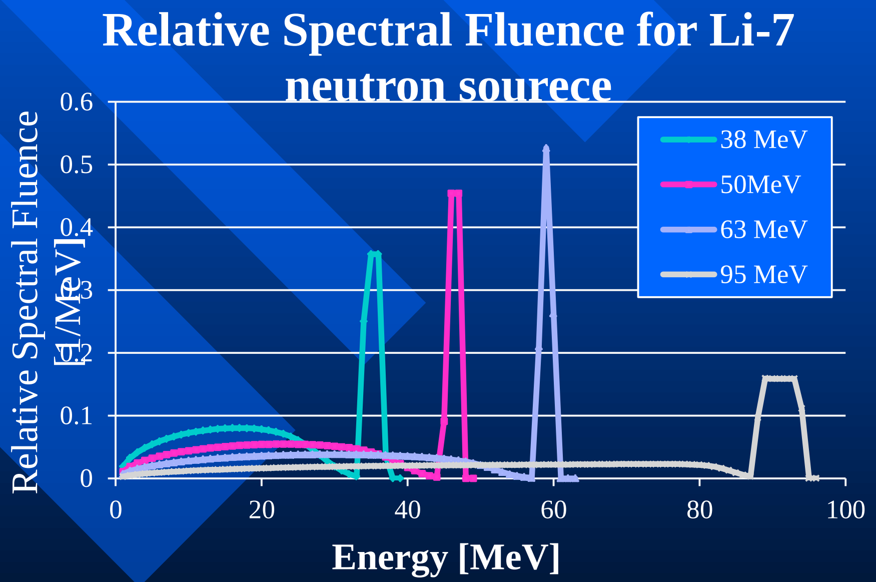
The procedure (Background subtraction method) is based on the ratio between folding of the cross-section (E) and the neutron spectrum in the peak energy interval and the same folding only through the whole spectrum.

$$\sigma = N_{nucl} \cdot \frac{S \cdot A \cdot B}{N_n \cdot N_A \cdot m} \cdot \left(\frac{\sum_{i \in Peak} \sigma_i \cdot N_i}{\sum_i \sigma_i \cdot N_i} \right) \cdot 10^{27}$$

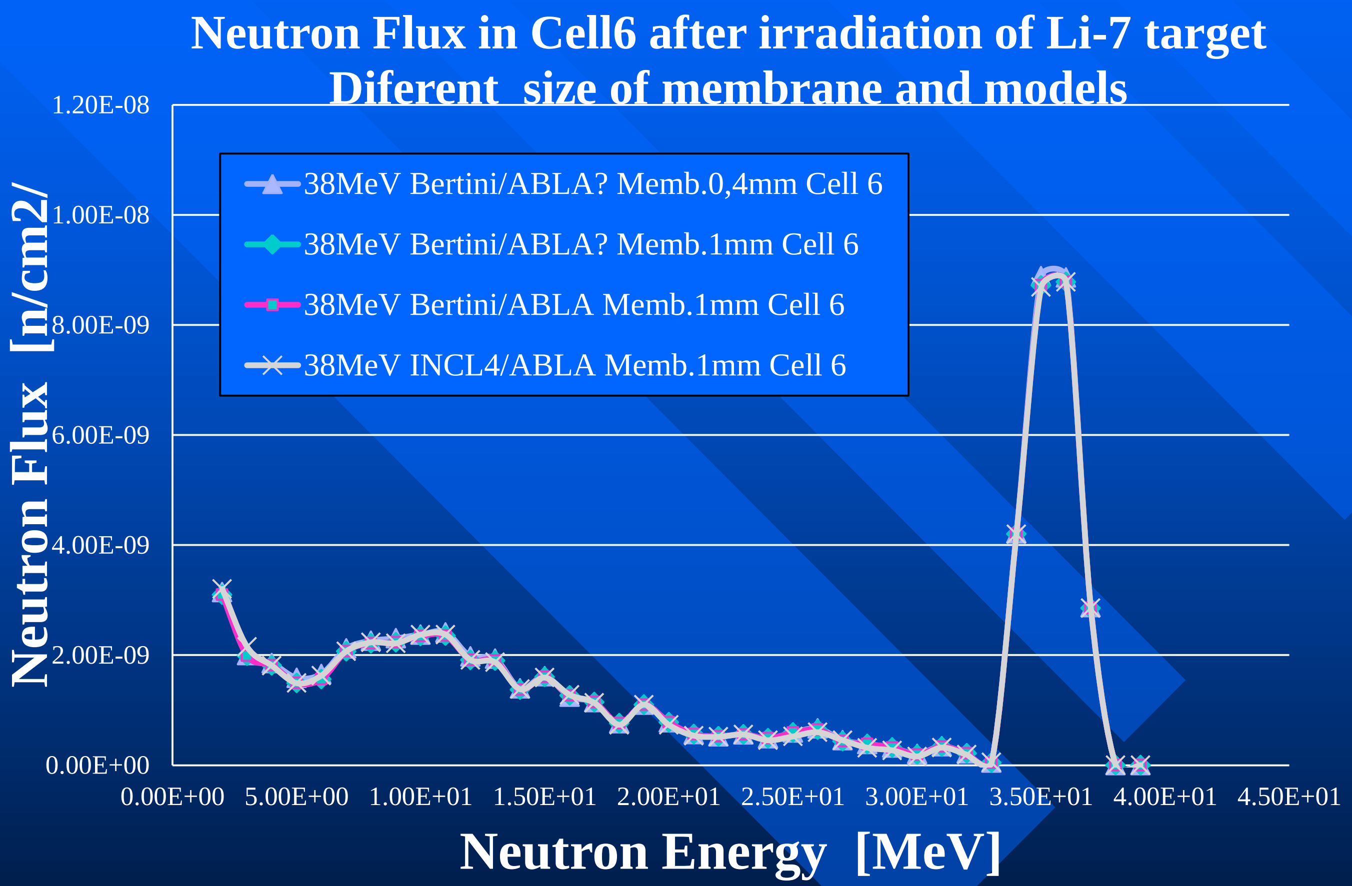
Background subtraction (background correction factor)

Where:

σ - cross section for the studied (n,xn) reaction for the average energy in the high-energy peak (mb),
S - foil (detector) area (cm^2),
A - molar mass of the foil material (g)
B - beam instability correction
N_n – number of neutrons in the high-energy peak
N_A - Avogadro's number
m - foil (detector) mass (g).



4. Beam Time proposal and future plans – MCNPX calculation for validation or recognition problems



4. Future plans

1. A series of measurements for 3-4 energy each year
2. Determining the value and location of the point maximum (cross-section curve).
3. Determination of the high energy wing level on the curve (cross-section curve).
4. In the case of unclear results, the possibility of repeating measurements for the some energy.
5. Correlating measurements for yttrium, bismuth, cobalt and gold, and possibly other materials.
6. To fill in EXFOR data base for a new high energy neutron data

Thank You for Attention ☺