Beta delayed neutron measurements by means of Modular Total Absorption Spectrometer

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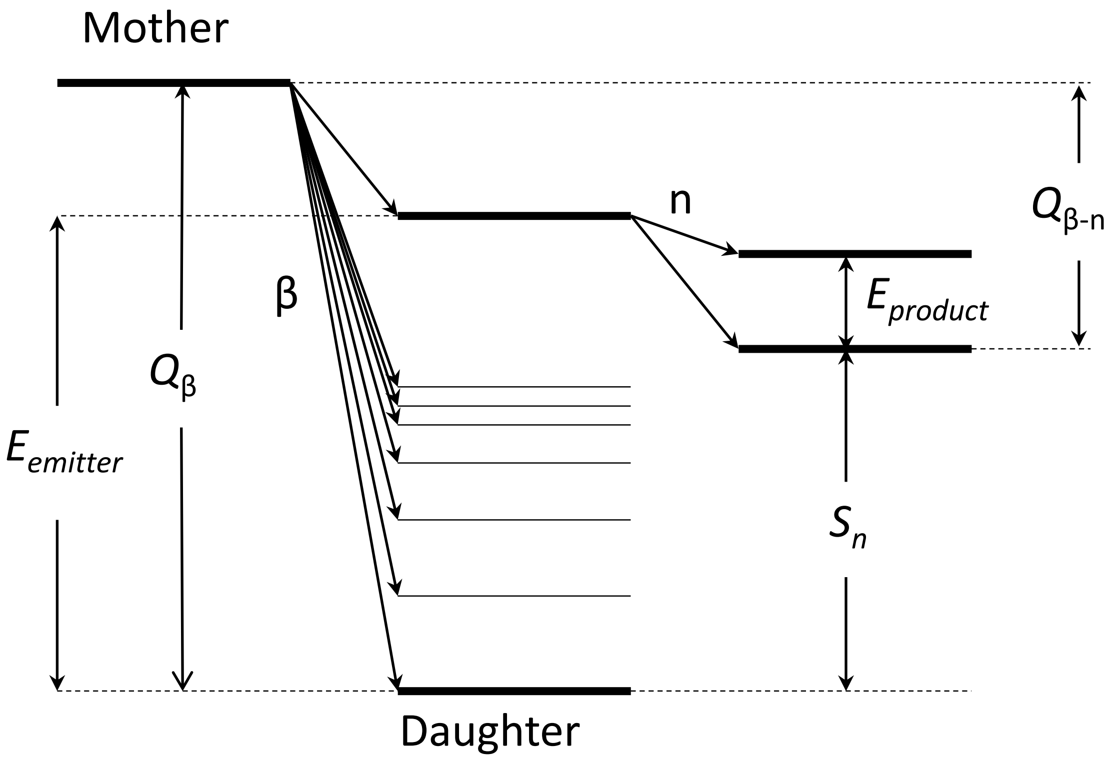
Beta minus decay

$$n \rightarrow p + e^{-} + \bar{\nu}_e$$



Importance of the delayed neutrons:

- Nuclear reactors
  - Decay heat,
  - reactor control,
  - accurate simulations.
- r-proces
  - Creation of heavy elements,
  - neutron fluxes during universe creation.

Delayed neutron measurements

Neutrons do not directly ionize matter.

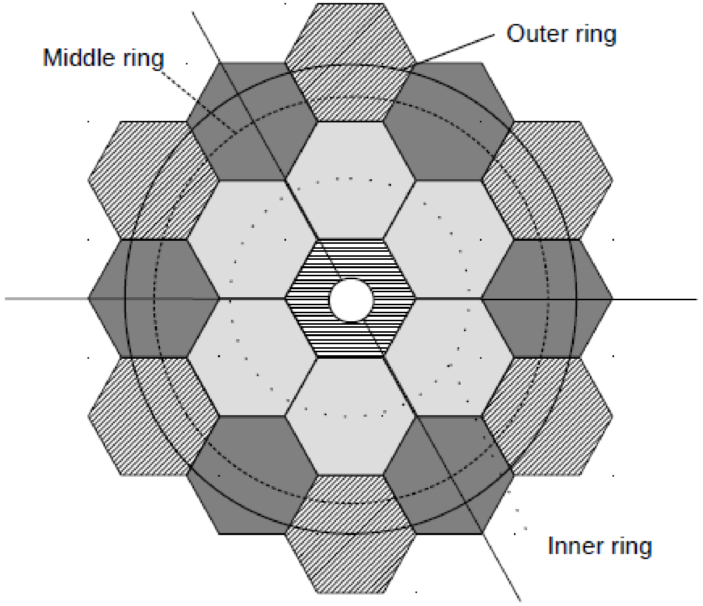
Ways to measure neutrons using:

- reactions (^{10}B, ^{6}Li, ^{3}He),
- fission,
- proportional counters,
- plastic and liquid scintillators,
- ionisation chambers,
- time of flight technique.

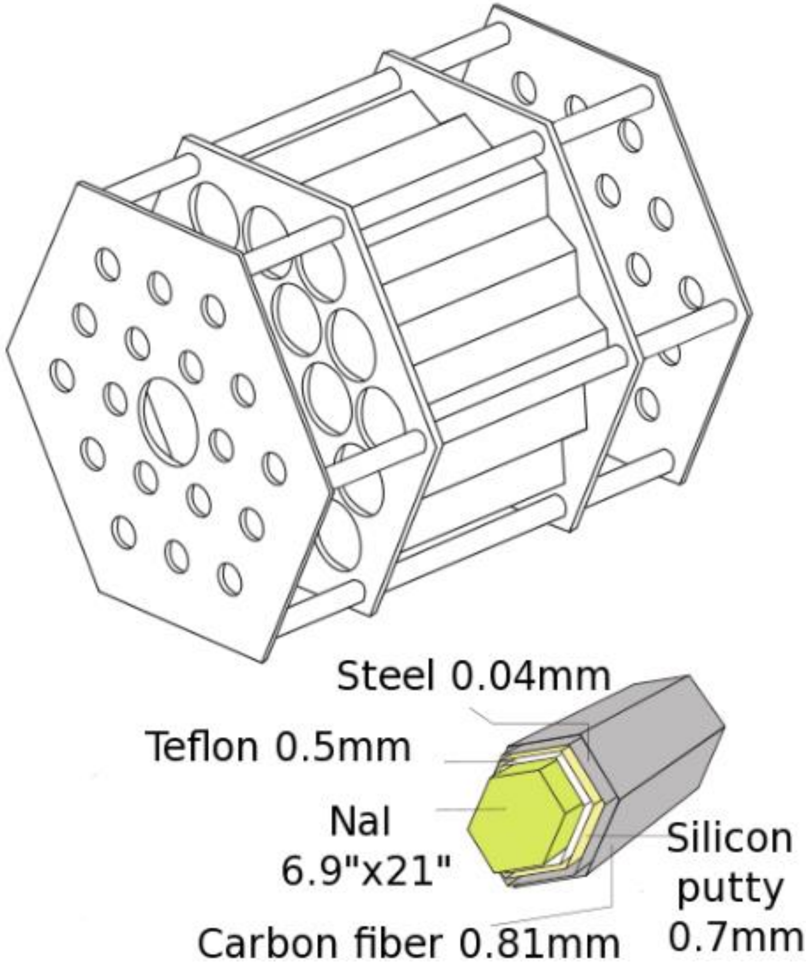
Is it possible to measure neutrons with **total absorption spectrometry**?
Yes, if detector is BIG enough!

MTAS (Modular Total Absorption Spectrometer)

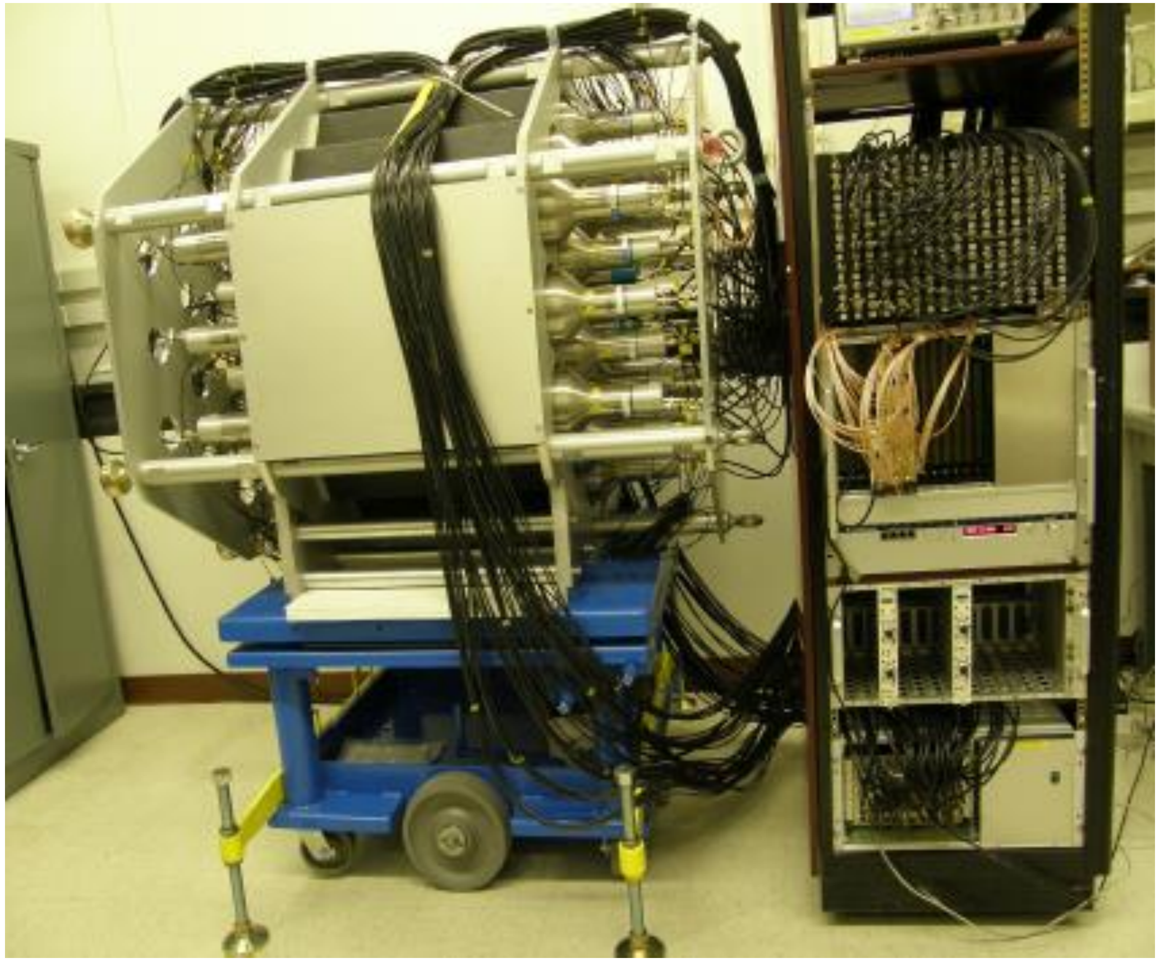
The largest total absorption spectrometer.
19 hexagonal modules 21" long and 6.93" wide, placed side-to-side in a honeycomb like structure.
Over 1 ton of NaI(Tl)!
Over 5 tons of lead shielding + neutron shielding.



Karny, M. et al. NIM A 836 (2016): 83-90



MTAS (Modular Total Absorption Spectrometer)



~ 53 cm

Neutrons interaction with MTAS matter

Scattering ->

-> ionization -> energy deposit in detector

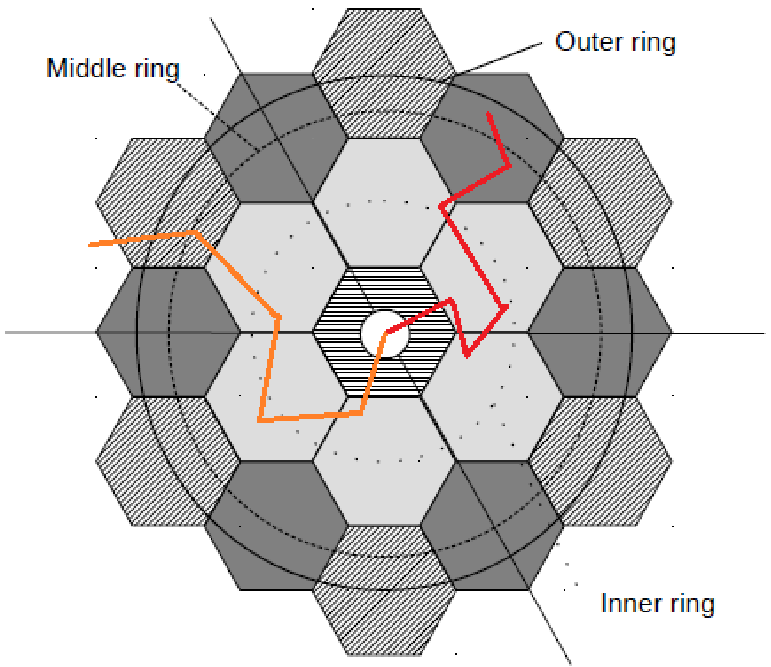
$E_{max} \simeq E_{kin}$

Neutron capture ($^{23}Na^{127}I$) **->**

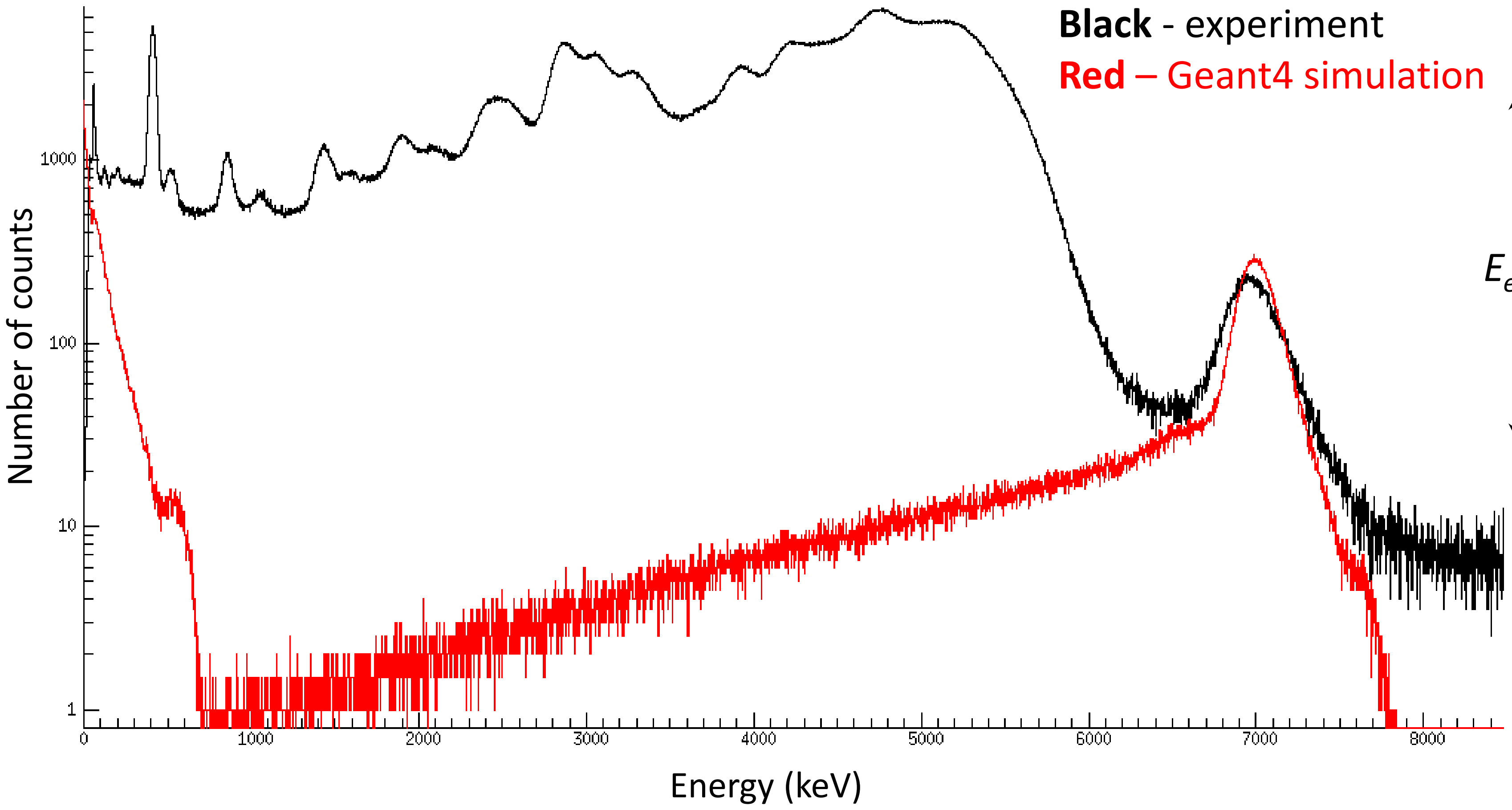
-> gammas emmited -> ionization -> energy deposit in detector

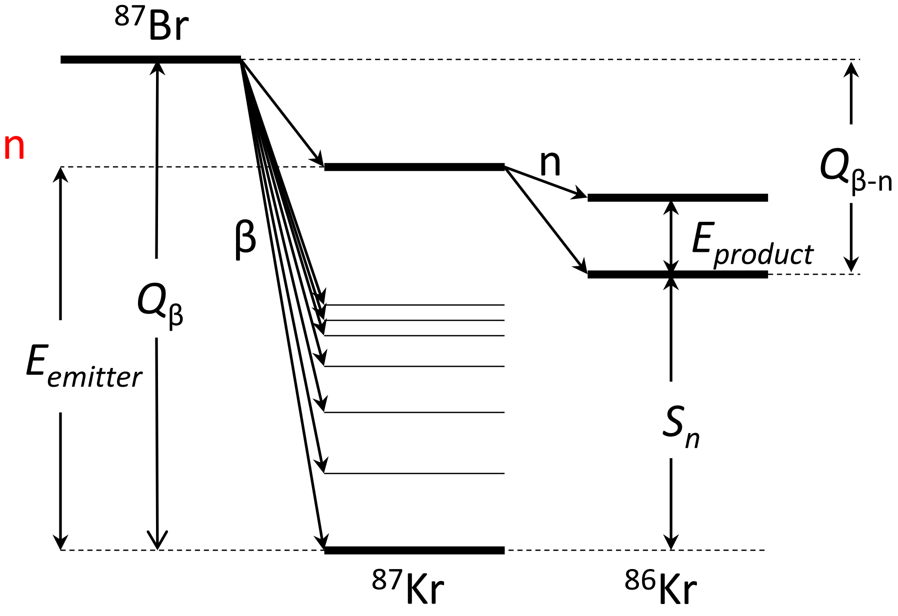
$E_{max} = E_{kin} + S_n$

^{128}I: S_n= 6826.13 keV
^{24}Na: S_n= 6959.42 keV



^{87}Br decay spectrum

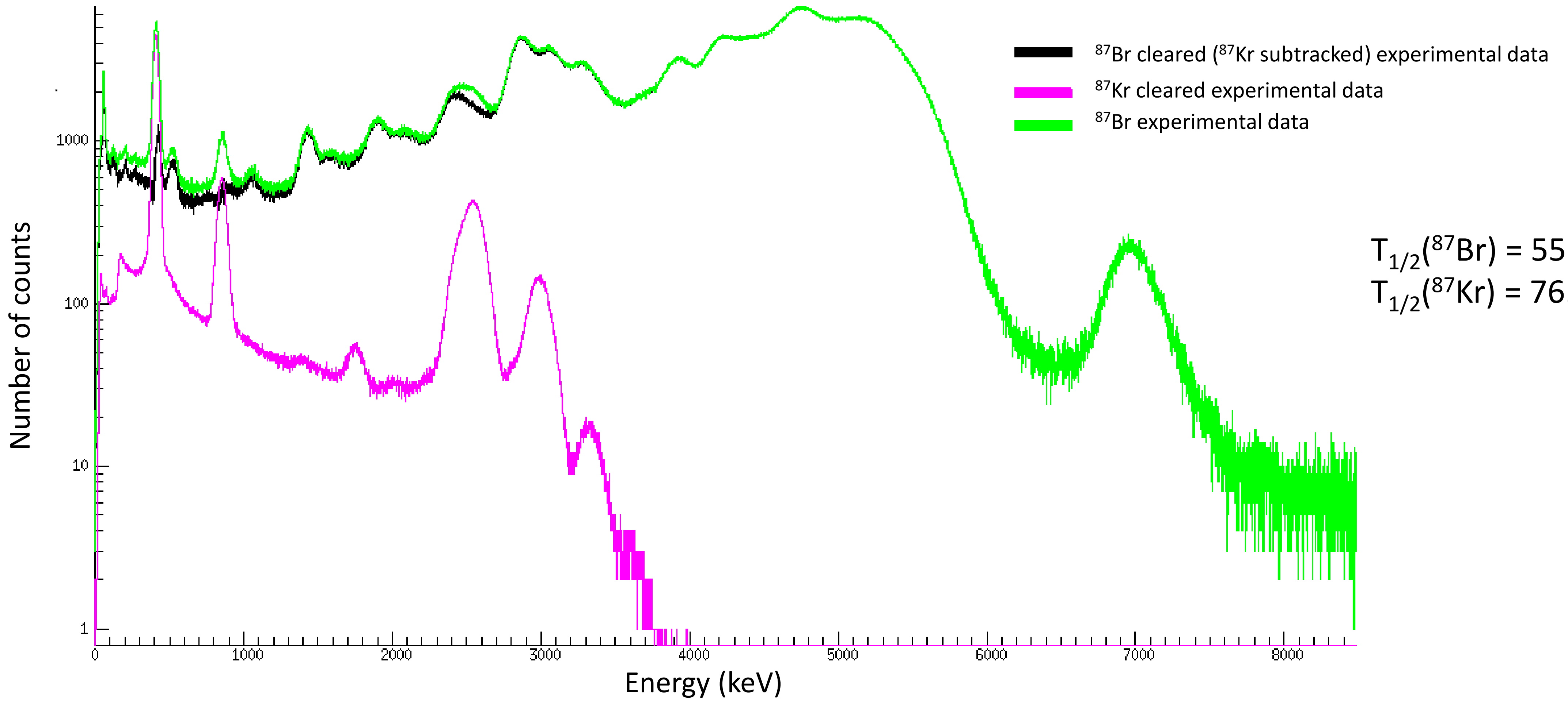




β-n = 2.6%
Q_{β} = 6818 keV
S_n = 5515 keV
$Q_{\beta\text{-n}}$ = 1303 keV

Simulation data: *ENSDF Evaluated Nuclear Structure Data File, NNDC, Brookhaven National Laboratory*

^{87}Br decay spectrum – analysis preparations



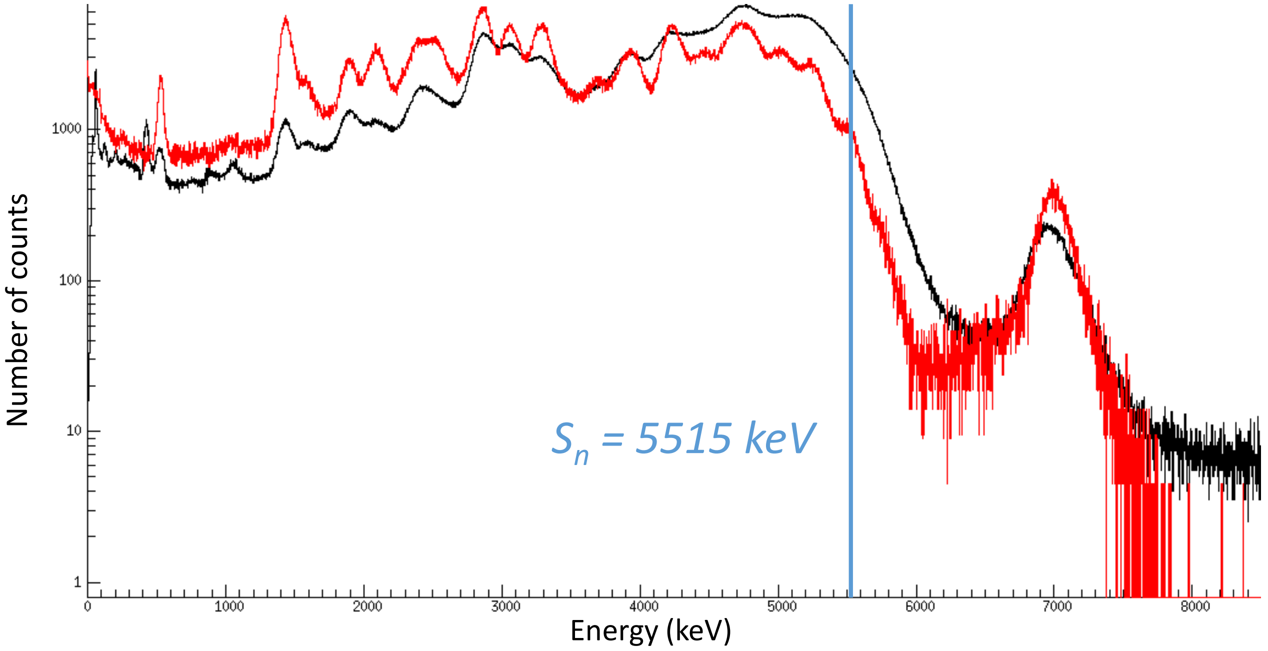
$T_{1/2}(^{87}Br)$ = 55.65 s
$T_{1/2}(^{87}Kr)$ = 76.3 min

^{87}Br decay spectrum – analysis

Black - experiment
Red – Geant4 simulation

Before

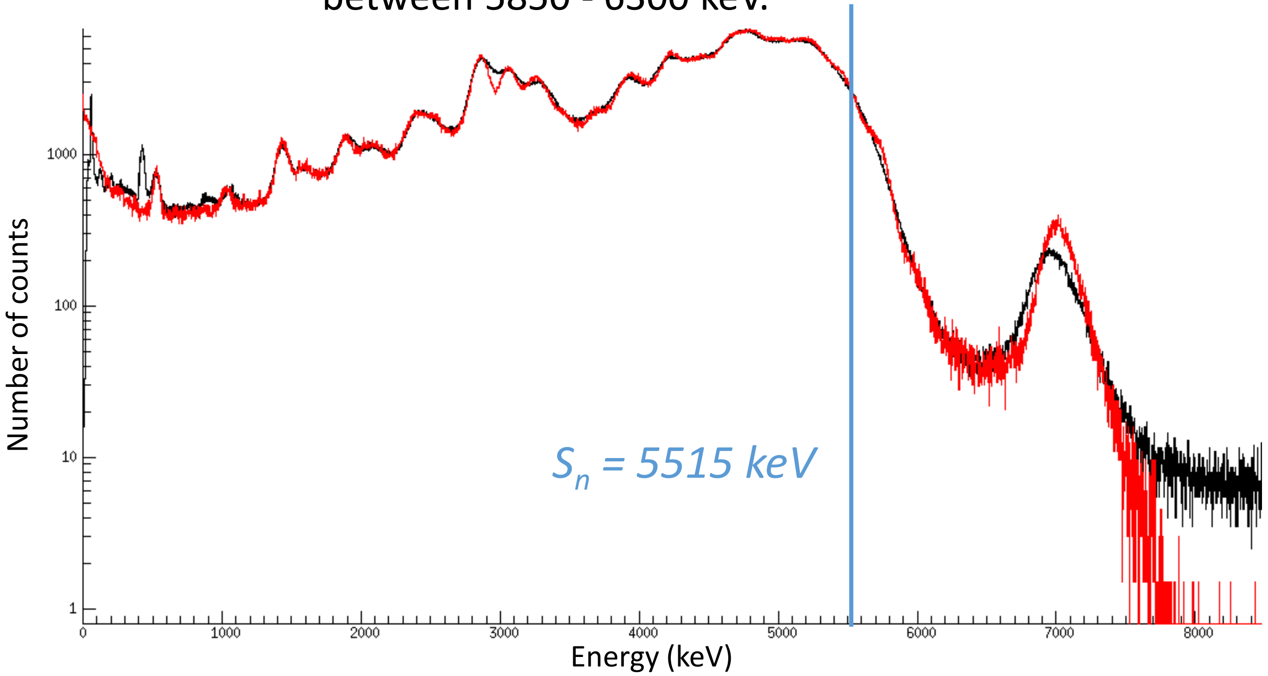
Not modified ENSDF data.



After

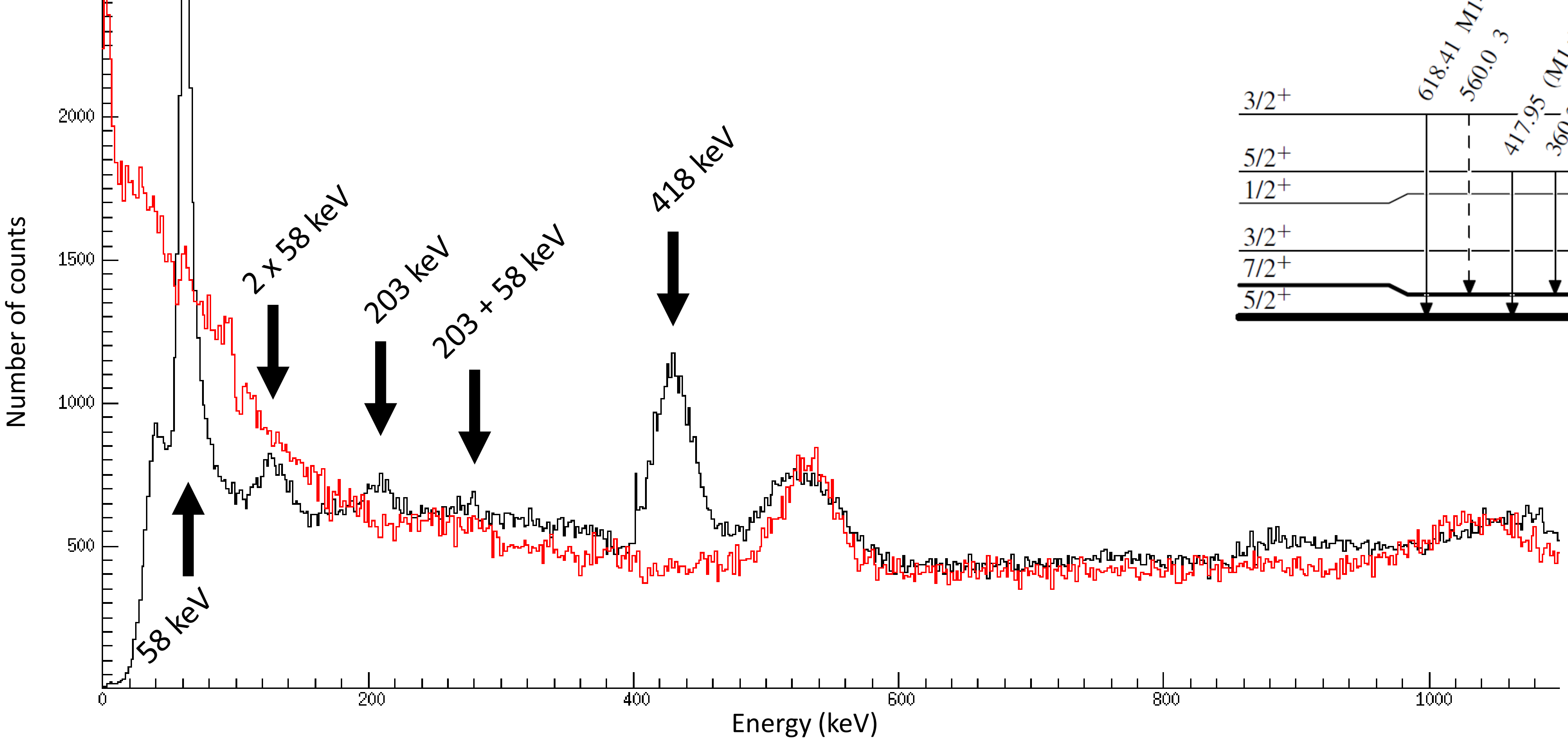
Adjusted ENSDF data:

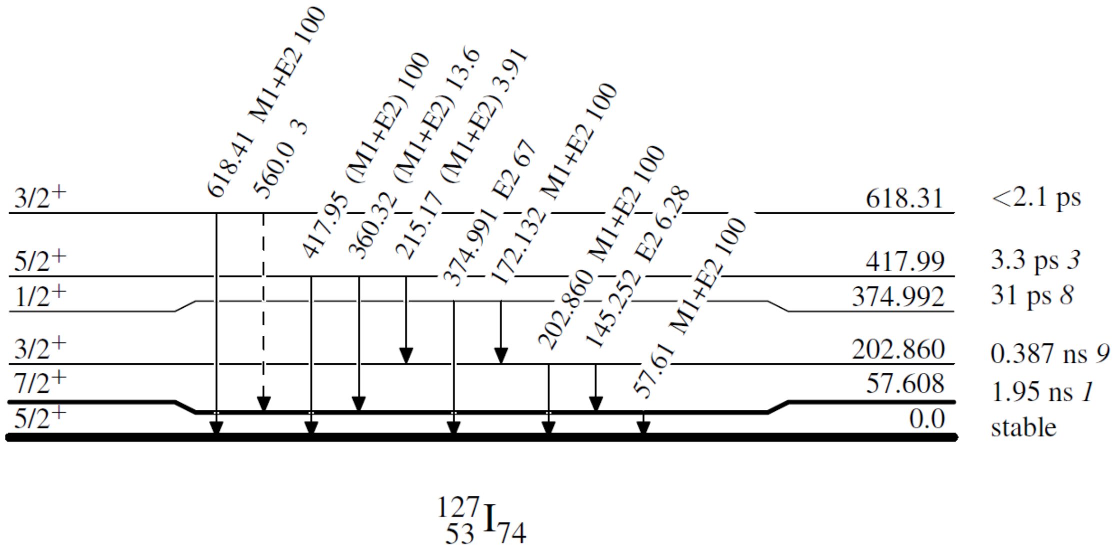
- adjusted existing branching ratios and transitions intensities;
- added so-called pseudo-levels for gamma between 5850 - 6300 keV.



^{87}Br decay spectrum – low energies analysis

Inelastic scattering seen on experimental spectrum but not in simulation.



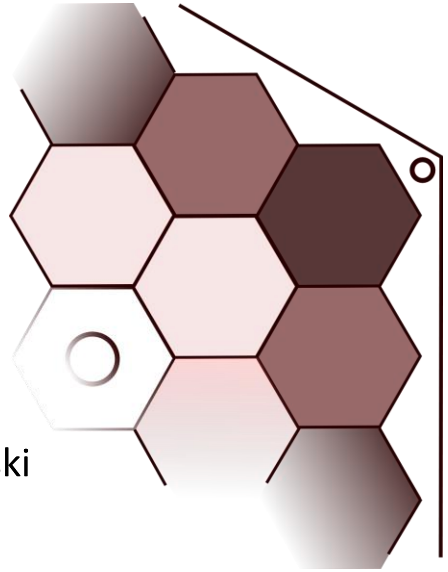


Plans and problems

1. More precise calibration needed.
2. Neutrons intensity and simulated spectra shape (low energies and peak) – to investigate.
3. Inelastic scattering on ^{127}I – to investigate.
4. Automated analysis – fitting simulated response functions to experimental spectra.

It is possible to measure whole beta minus decay by means of Modular Total Absorption Spectrometer, including delayed neutrons.

Thank you for your attention



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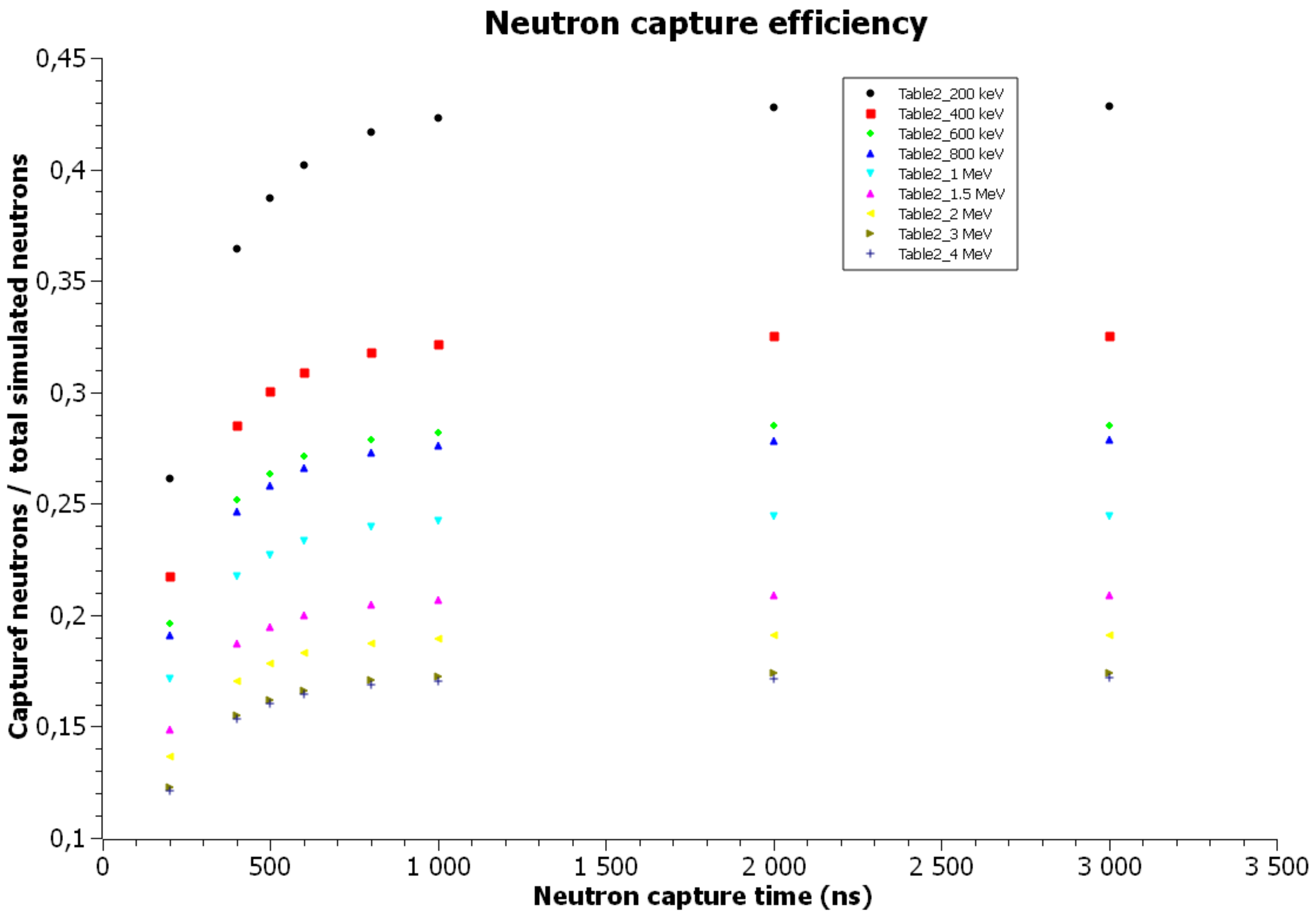
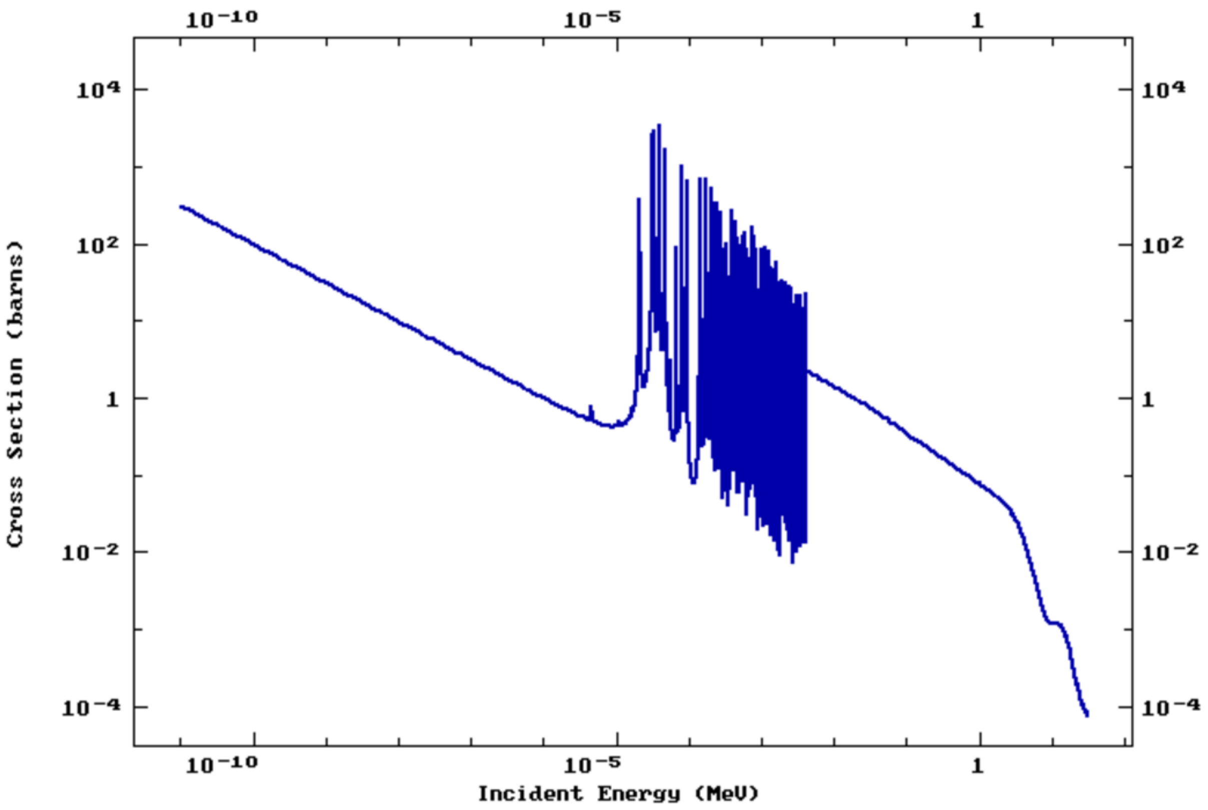
Additional materials

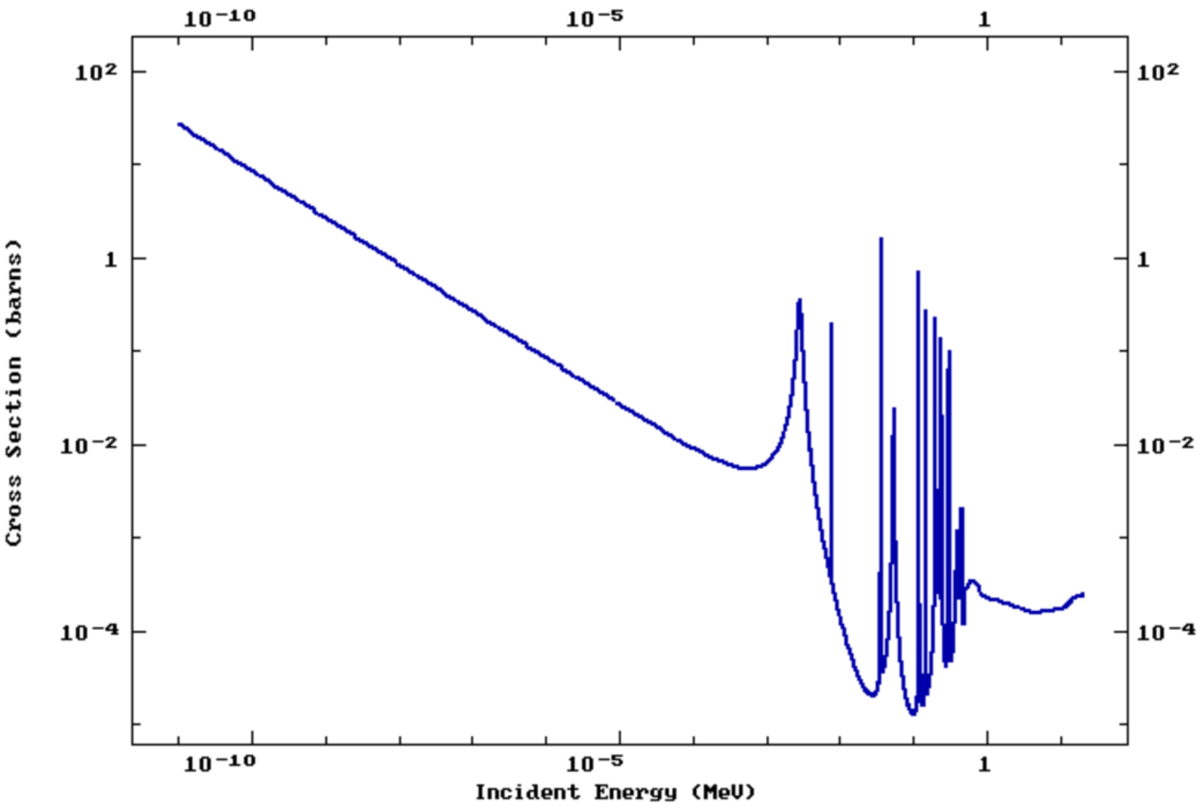
MTAS neutron capture effciency



Neutron capture cross section



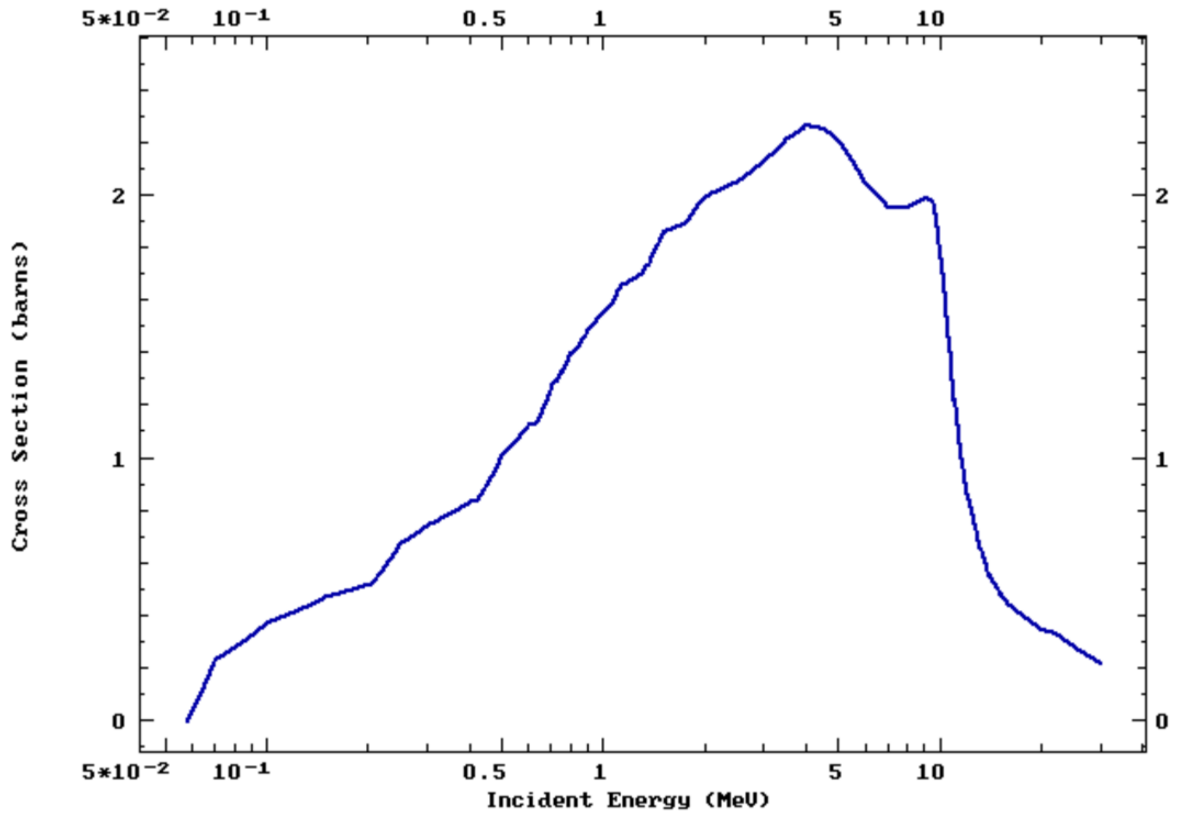
^{127}I



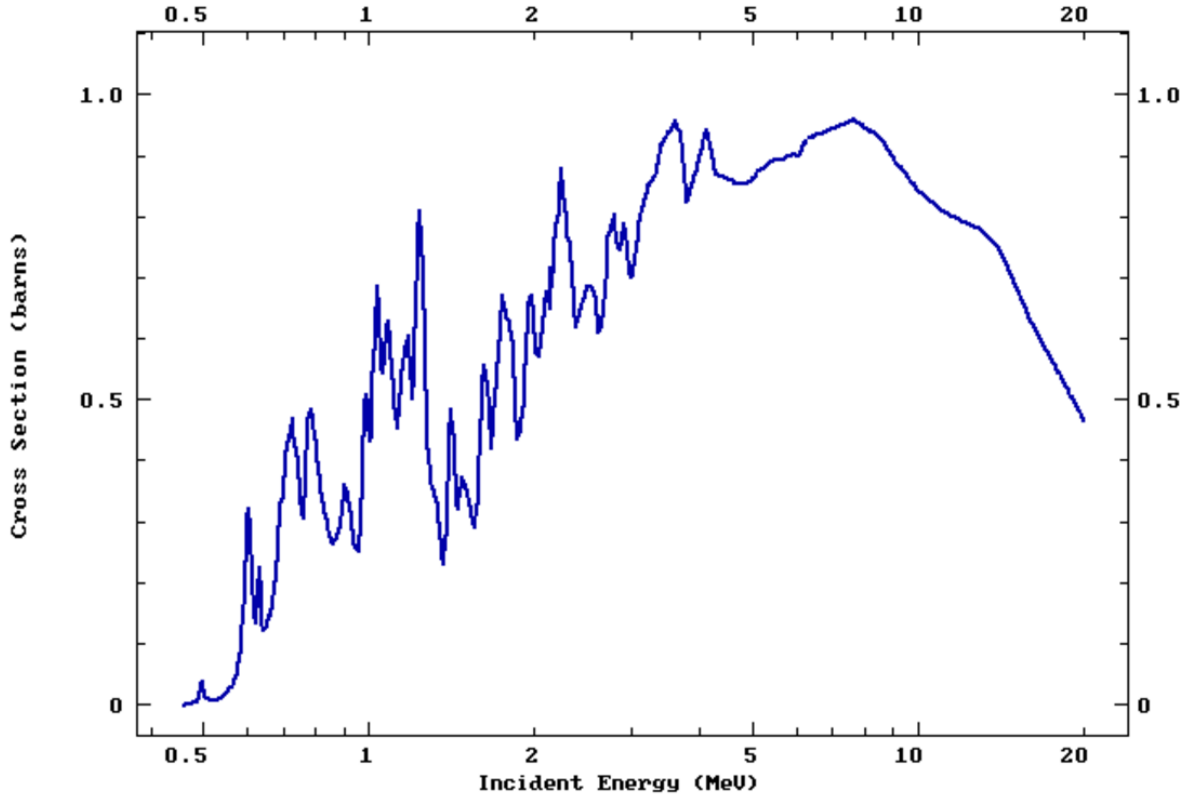
^{23}Na

Evaluated Nuclear Data File (ENDF), NNDC, Brookhaven National Laboratory

Inelastic scattering cross section



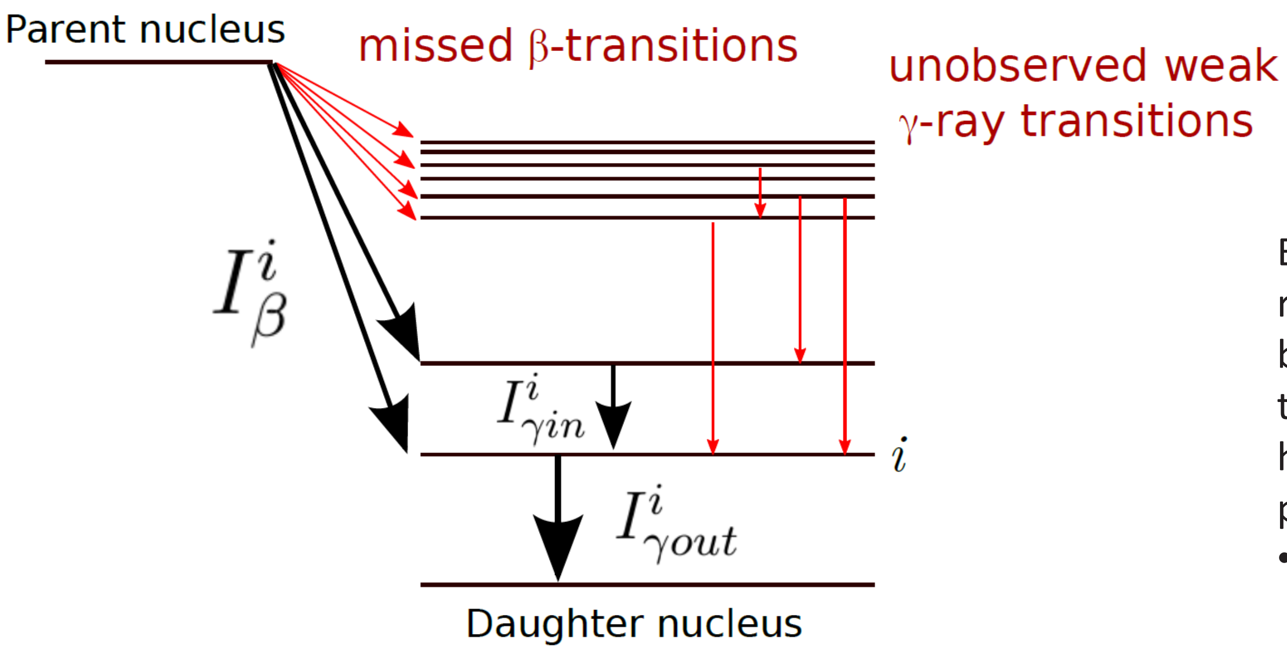
^{127}I



^{23}Na

Evaluated Nuclear Data File (ENDF), NNDC, Brookhaven National Laboratory

Total absorption spectrometry



Courtesy: A. Fijałkowska

$\overline{E\gamma}$ ↑ & $\overline{E\beta}$ ↓ & $\overline{E\nu}$ ↓

Experimental decay schemes based on high-resolution but low-efficiency measurements are burdened with systematic error due to the inability to detect numerous weak β transitions feeding highly excited states in the daughter nucleus (the pandemonium effect). This leads to:

- underestimation of the longer range γ-ray flux and overestimation of energy carried by electrons,
- incorrect or incomplete β-decay schemes of fission products, usually based on low-efficiency measurements.

The solution is to measure the β decay of fission products using high-efficiency systems like **total absorption spectrometers (TASs).**

Nuclear reactor control – simple example

How much times neutron number will be multiplied during 1s?

$$n = n_0 e^{\frac{k-1}{\tau}t}$$

Lets say: k=1,005
Average lifetime of one prompt neutron generation: $\tau=10^{-3}$s

$$n = n_0 \; e^{\frac{0{,}005}{0{,}001s}*1s} = 148{,}4\, n_0$$

When delayed neutrons are present: τ=0,1s

$$n = n_0 \; e^{\frac{0{,}005}{0{,}1s}*1s} = 1{,}05\, n_0$$