NUCLEI PRODUCED FROM ^{238}U IRRADIATED BY SECONDARY NEUTRON FIELD INITIATED BY PROTON BEAM (E = 660 MeV)

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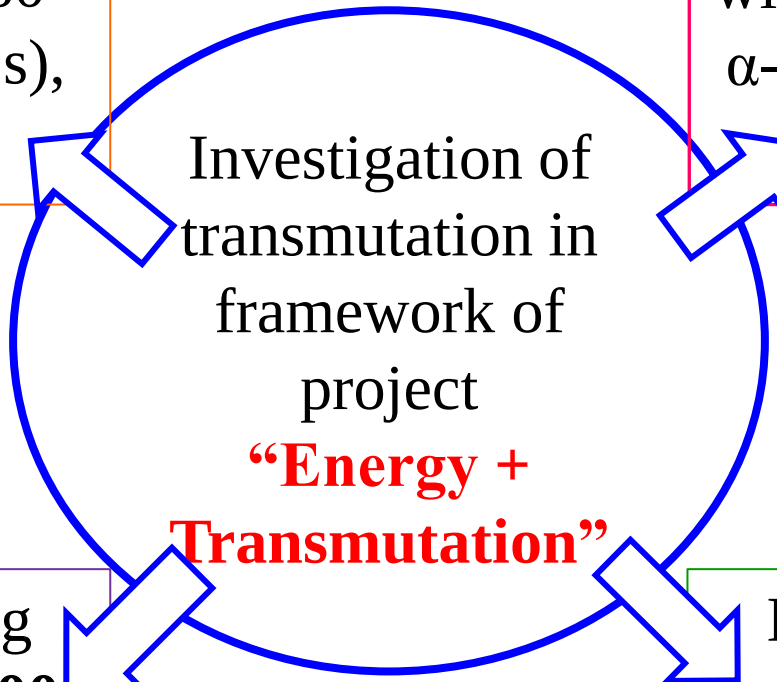
Collaboration "Energy + Transmutation"

Experimental methodological base

In neutron field at **Phasotron** (**protons** with energies - 660 MeV, 10^{13} **p**/(cm^2.s), current ~ 1μA

In neutron field at **Nuclotron** (**Deuteron** with energies 1-8 GeV, α-particles, Li^{6+}, C^{12+}, etc)



In bremsstrahlung field at **LINAC-200** (**electrons** with energy 20-200 MeV)

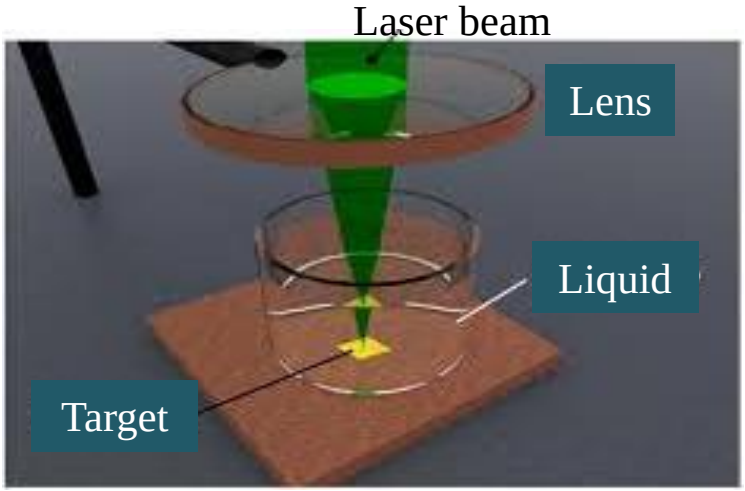
In electromagnetic radiation field at **Nd-laser** (Impulse 1064 nm, 700 mJ)

Research facilities

Proton accelerator PHAZOTRON at LNP

Accelerator NUCLOTRON at LHEP

Linear accelerator LINAC-200 at LNP



Nd-laser at IOFAN (Moscow)

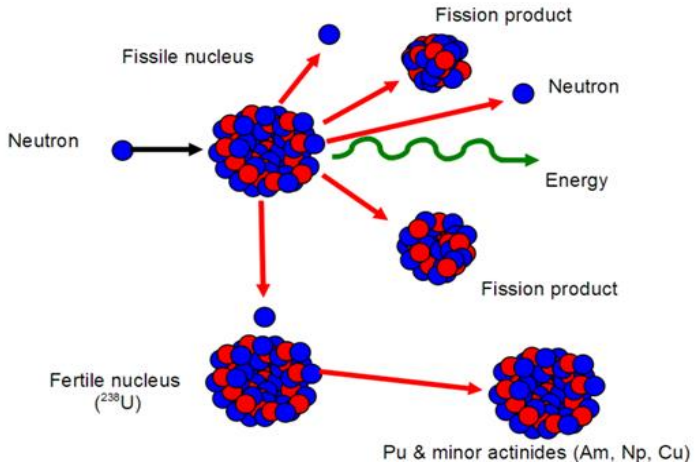
Introduction

- The experiment has been performed in the proton accelerator Phasotron of the Dzhelepov Laboratory of Nuclear Problems, JINR at the 660 MeV proton beam with the current of 1 μA.
- The goal of the work is to determine nuclear-physics characteristics of the nucleus, the fission – capture ratio, and the production of residual nuclei in the sample of ^{238}U in a neutron field, which placed in surfaces a Lead brick irradiated with 660-MeV protons.
- Gamma spectra of the irradiated sample was measured using an HP-Ge PLANAR detector.

^{238}U sample

- ^{238}U: The most common isotopes in natural uranium (over 99%), as one of the components of a reactor fuel. It is non-fissile, however, it is fissionable by fast neutron and is fertile, meaning it can be transmuted to fissile plutonium-239.The reactions of neutrons with this material need special attention.
- There are two channels of neutron interaction with 238U: fission and capture lead to production of isotopes.
- ^{239}Np (58 h) resulting from a chain of beta decays.

$$^{238}U(n,\gamma)^{239}U\ (23{,}54\ m)\ \beta^- \rightarrow {}^{239}Np\ (2{,}36\ d)\ \beta^- \rightarrow {}^{239}Pu\ (24110\ y)$$



Accelerator Driven Systems (ADS)
"Energy + Transmutation"

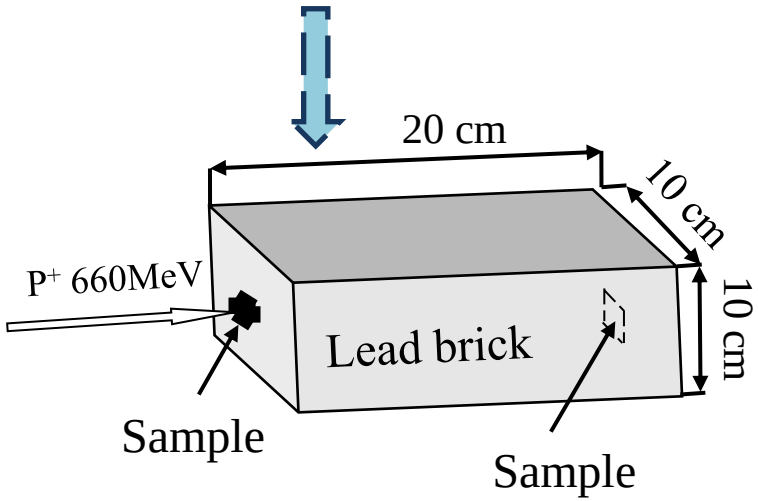
Accelerator → Proton or ion beam → Subcritical target → Neutrons for Energy and Transmutation

The main goals of ADS:

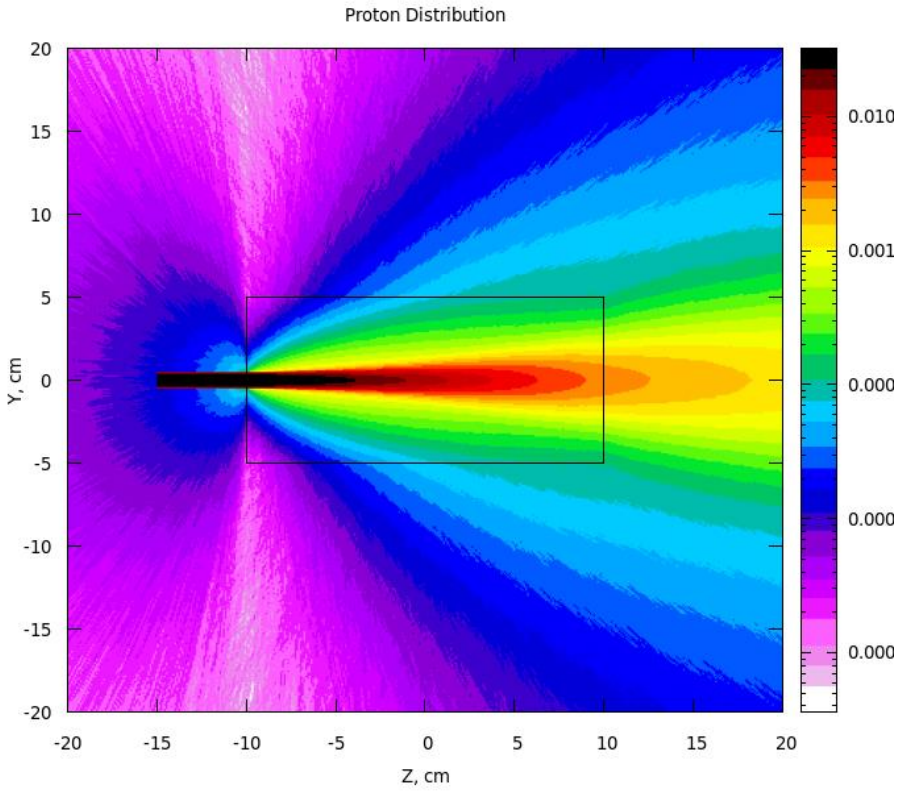
- Safe reactor.
- Cheaper "fuel".
- Utilization of the worked – off nuclear fuel (WNF).

Example of WNF irradiated by neutrons

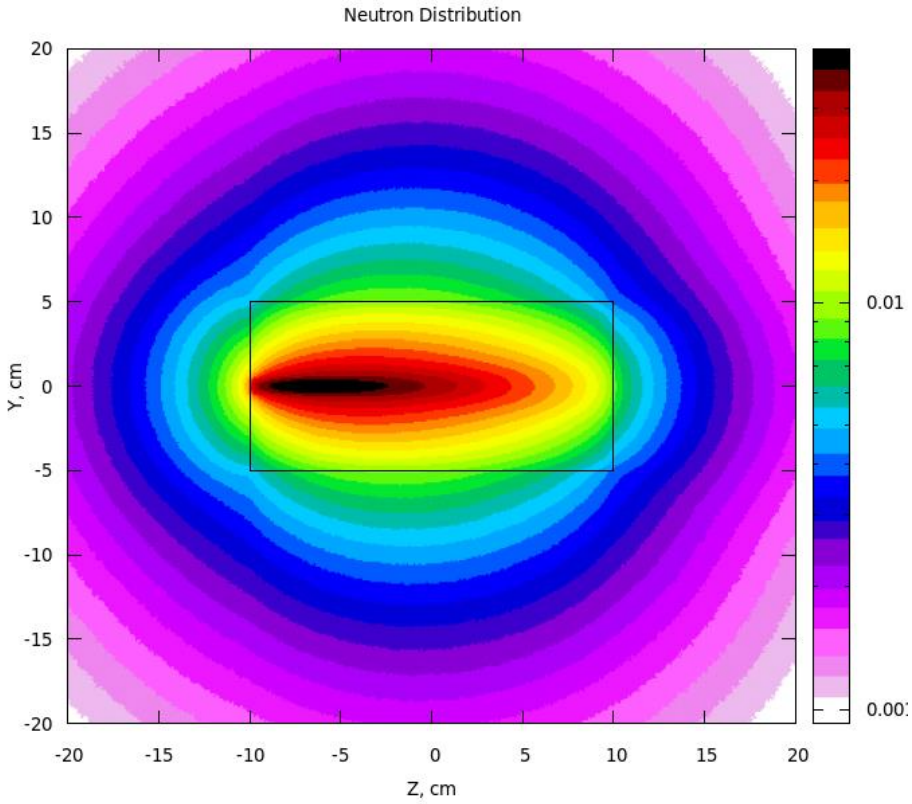
$$n^{o} + {}^{238}U$$



The Lead target irradiated by the 660 MeV proton beam



a)



b)

Fig. 1. Distribution of protons (a) and neutrons (b) in space, neutron/cm^2 , FLUKA

Neutron Flux inside the Pb target

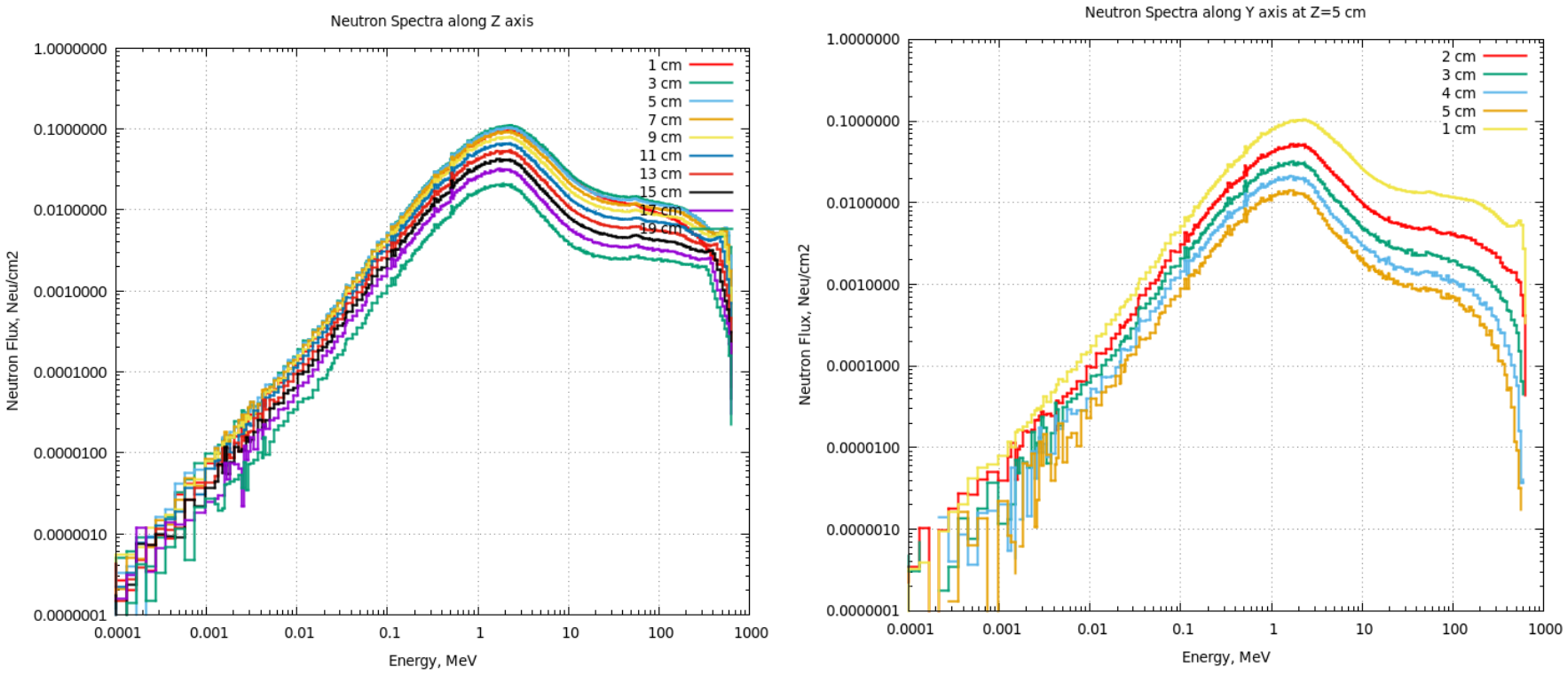


Fig. 2. Neutron fluxes along the beam direction (left) and in a perpendicular direction at z = 5 cm (right), FLUKA

Measurements

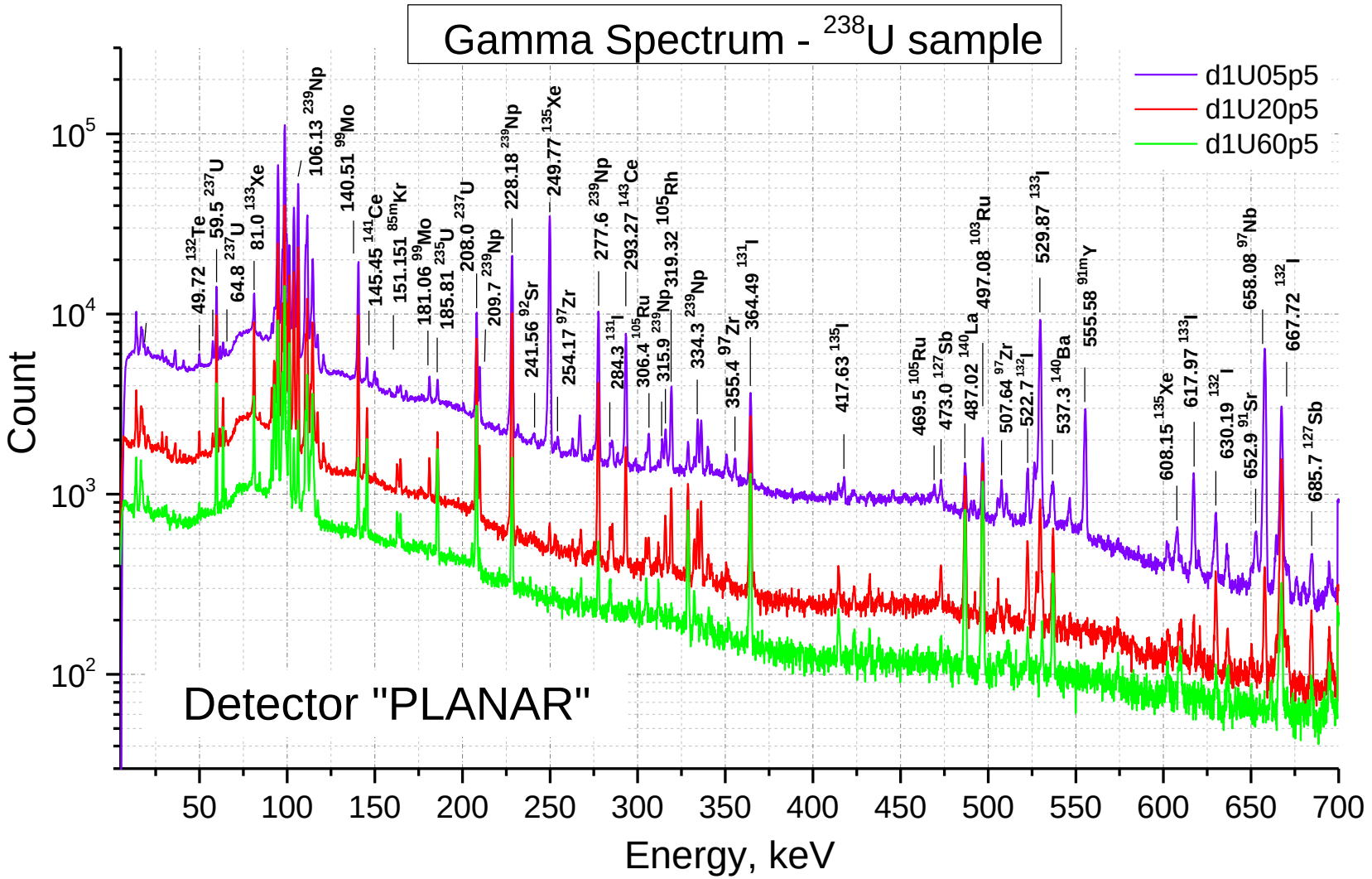
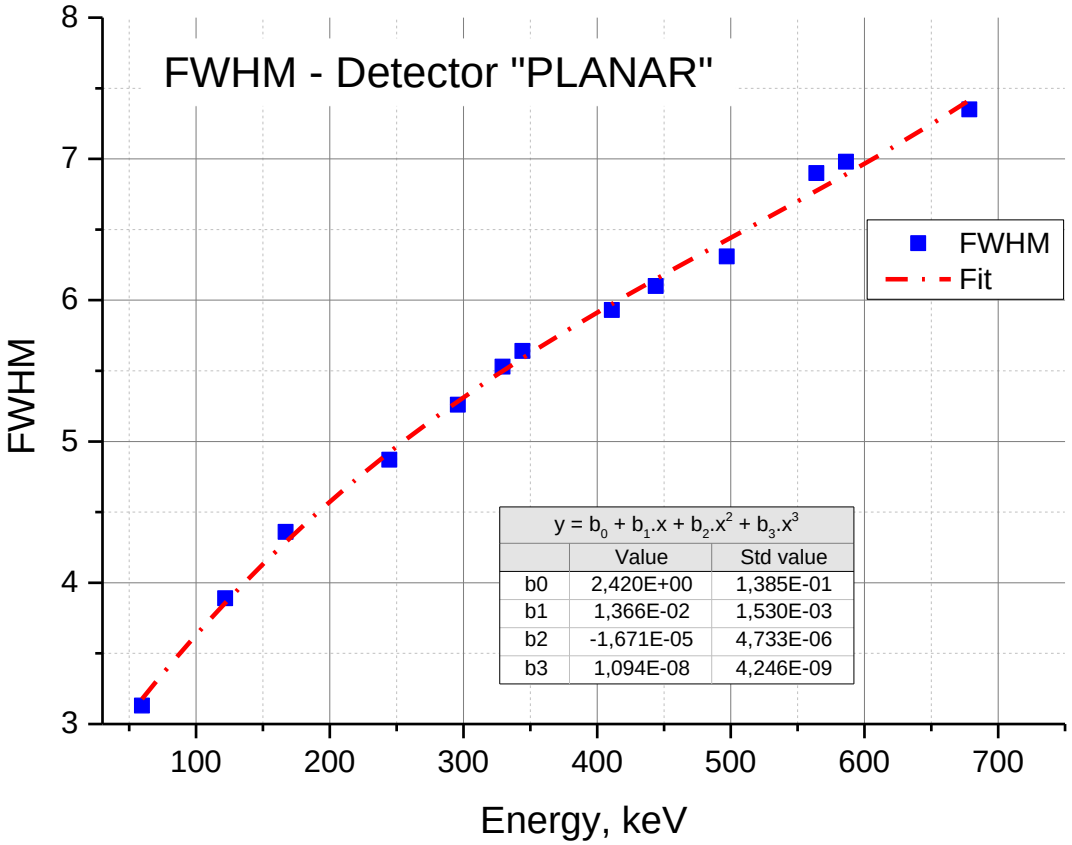
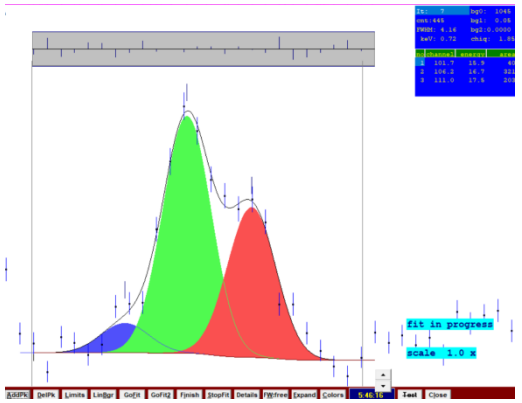


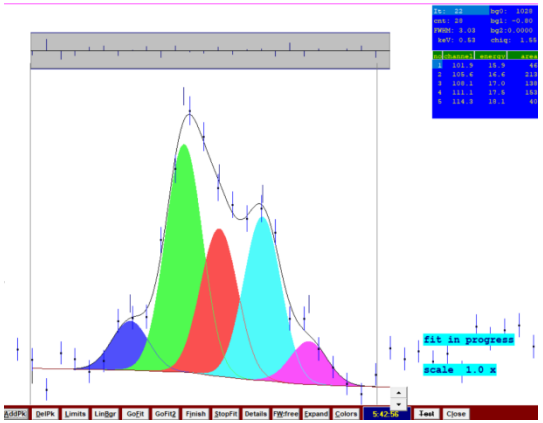
Fig. 3. Gamma spectra of the 238U sample measured using HP-Ge PLANAR detector

Analysis and processing





Before corrections



After corrections

Fig. 4. The full width at half maximum and process overlapping peak

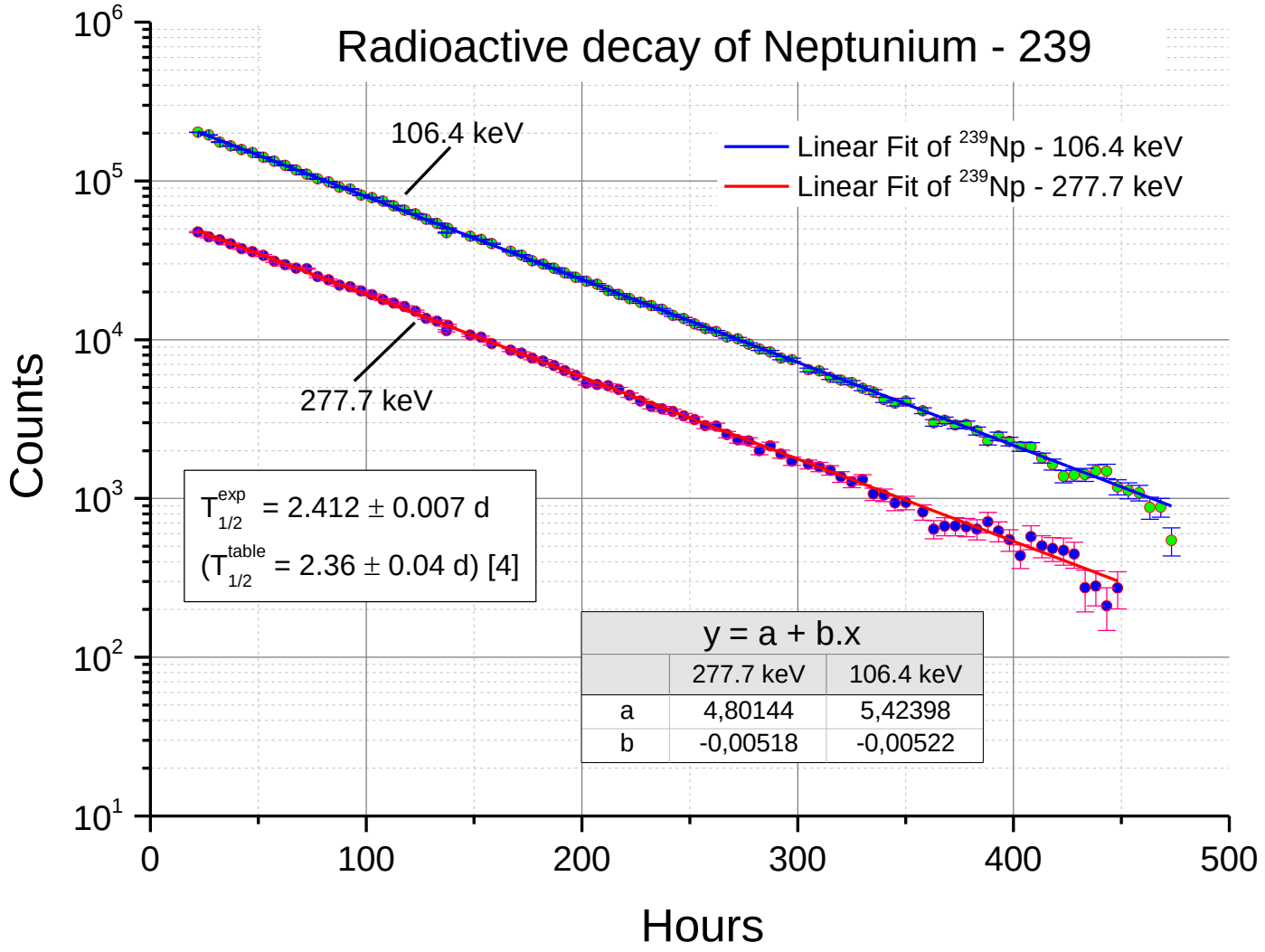


Fig. 4. ^{239}Np radioactive decay

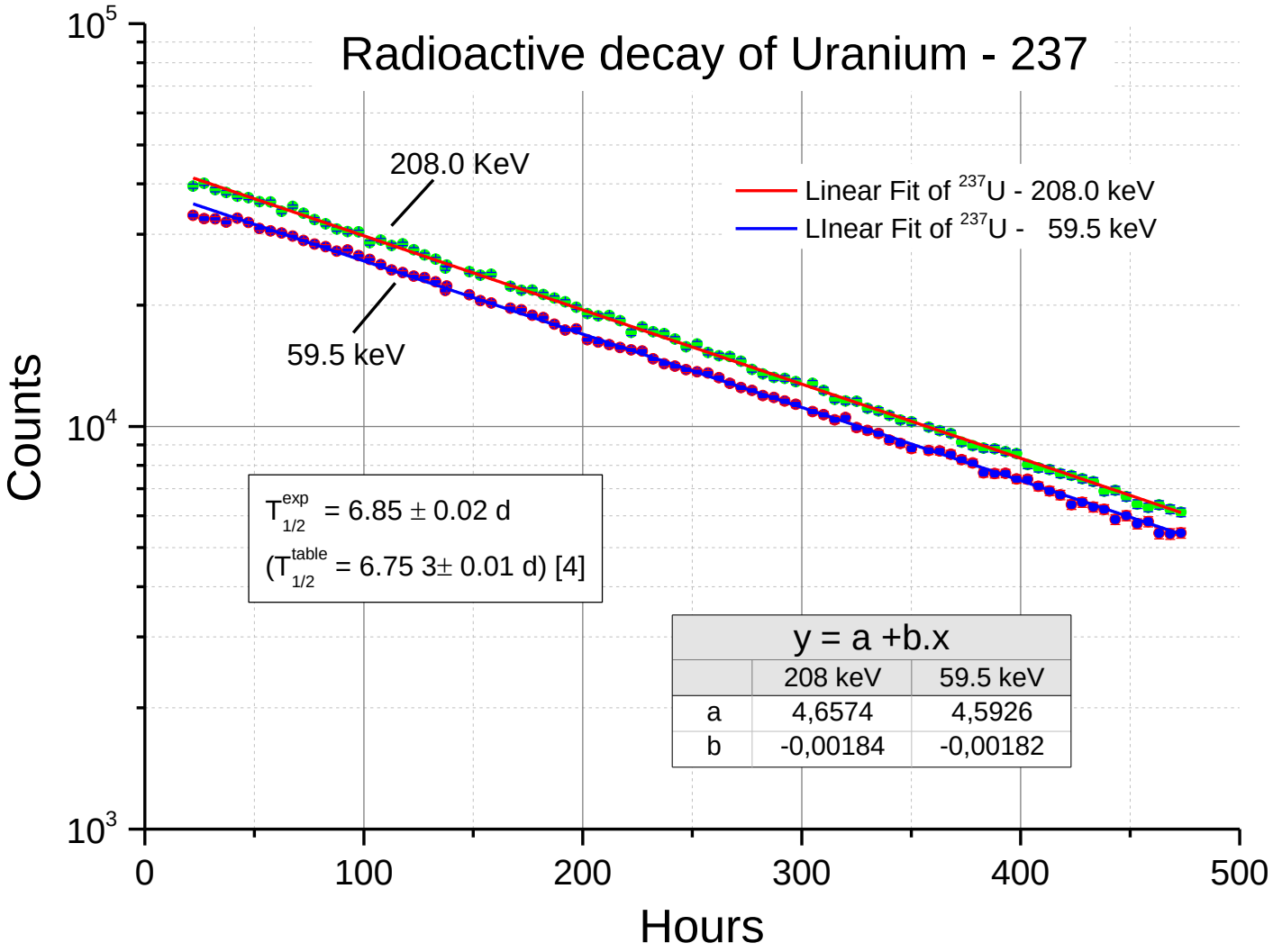


Fig. 5. ^{237}U radioactive decay

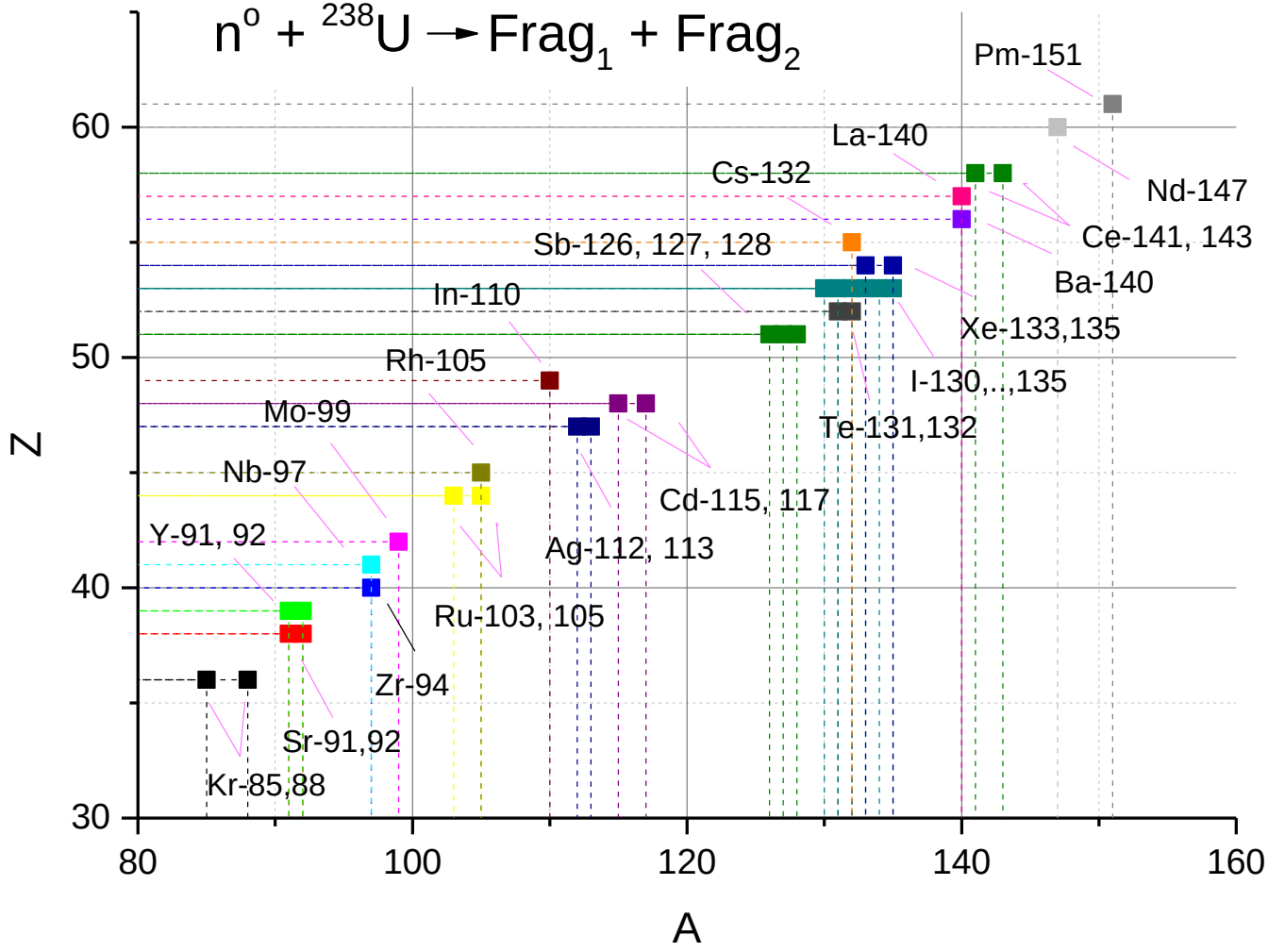


Fig. 7. Diagram of the fission products in reaction of neutron with ^{238}U sample

Detection Efficiency

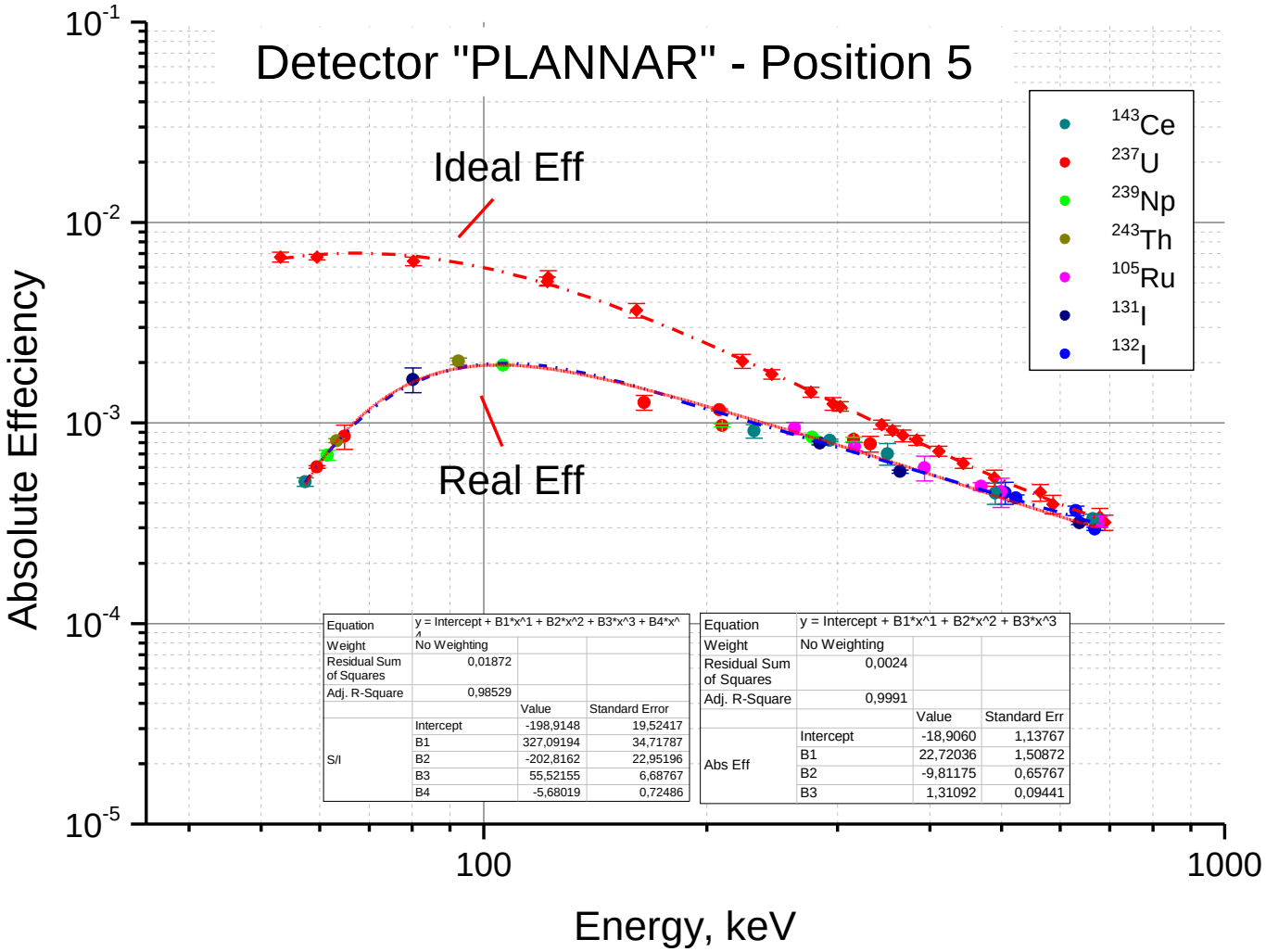
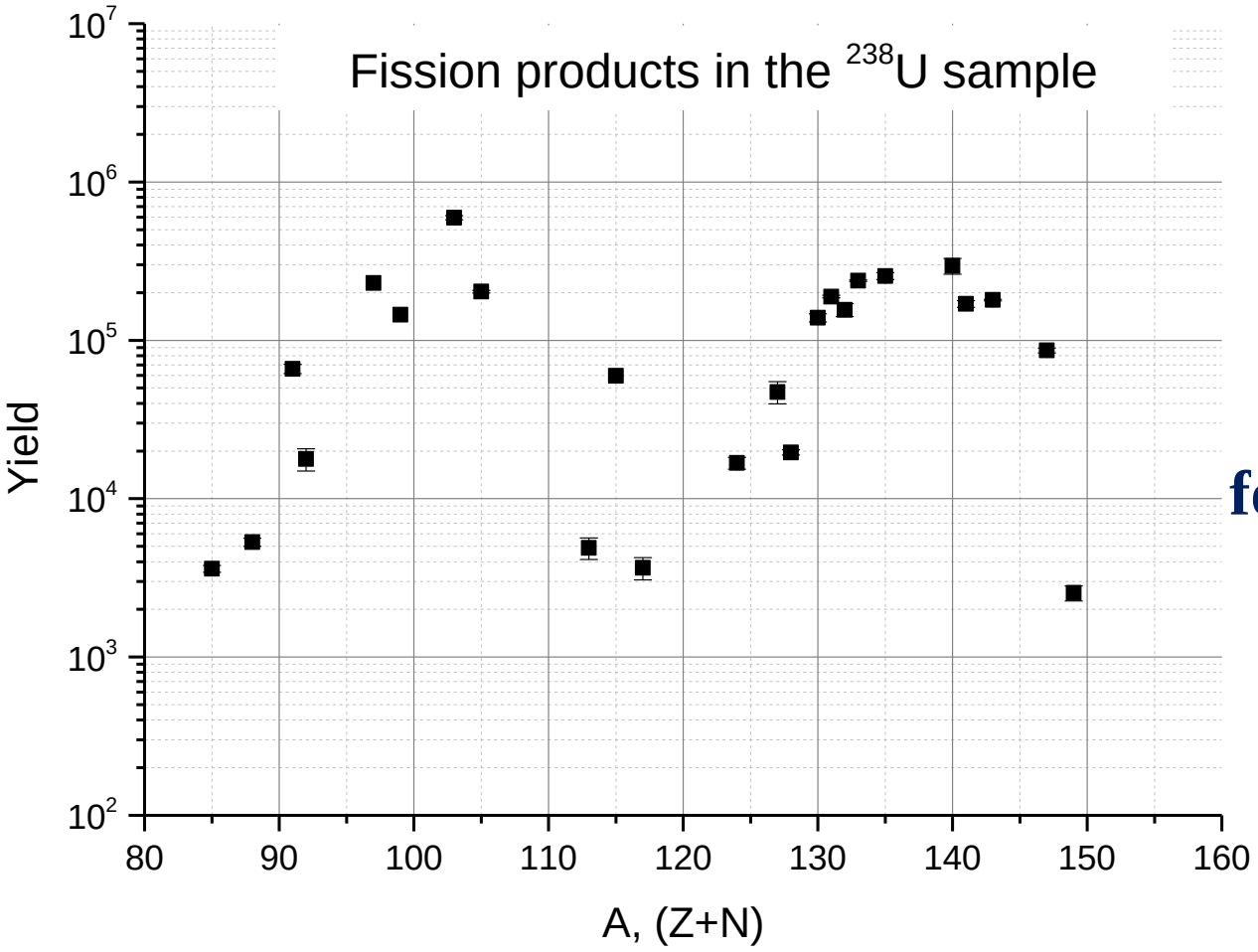


Fig. 8. The efficiency affected by the self-absorption effect in the sample

Activation formula

$$R_{f\gamma} = \frac{S_\gamma}{m \cdot \phi \cdot \gamma_f \cdot \varepsilon_p \cdot I_\gamma} \cdot \frac{\lambda \cdot t_{irr}}{\left(1 - e^{-\lambda \cdot t_{irr}}\right)} \cdot \frac{e^{\lambda \cdot t_+}}{\left(1 - e^{-\lambda \cdot t_{real}}\right)} \cdot \frac{\lambda_{real}}{\lambda_{live}}$$

- $R_{f\gamma}$ – fission rate, per beam particle and per gram;
- γ – gamma line index;
- f – reaction index (f = fission);
- S_γ – gamma peak area;
- γ_f – isotope production yield [%];
- m – activation sample mass [g];
- ε_p – gamma spectrometer efficiency;
- I_γ – gamma line intensity [%];
- ϕ – (deuteron/proton/C6+) integral number;
- λ – isotope decay constant;
- t_+ – cooling time;
- t_{irr} – irradiation time;
- t_{real} – real time of measurement;
- t_{live} – live time of measurement;
- C_{IH} – correction for irradiation history.



Ratio of fission to capture for the experiment.

K = F/C ~ 3.7

Fig. 9. Fission products of the 238U sample in the neutron field

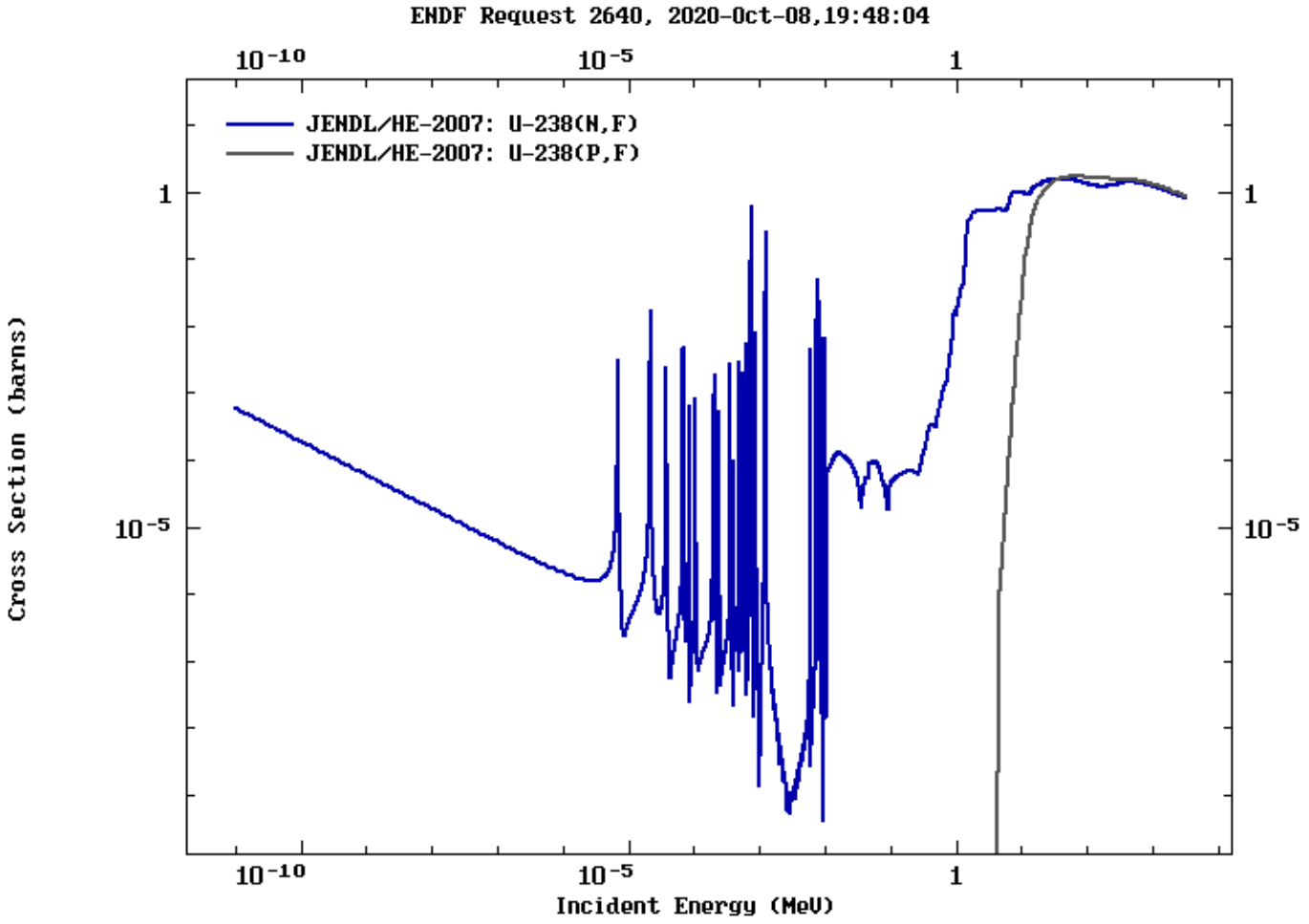
Number	Isotope	E_exp (keV)	E_table (keV)	T1/2_exp	T1/2_table
1	Nd-147	91	91,187	12,574 ± 0,854 d	10,98 d
2	Ce-143	293,358	293,266	32,614 ± 0,328 h	33,039 h
		350,425	350,619	35,167 ± 0,76 h	
3	Ce141	145	145,445	30,6 ± 2,9 d	32,501 d
4	Xe135/I132	249,164/250,8	249,77/250,8	10,146 ± 0,281 h	9,14 h/2,259 h
5	I-133	529,991	529,872	1,02 ± 0,844 d	0,867 d
		617,595	617,974	0,895 ± 0,782 d	
6	Xe-133	81,094	80,9971	5,675 ± 0,00804 d	5,243 d
7	Te-132	228,379	228,16	3,015 ± 0,00225 d	3,204 d
8	I-132	522,784	522,7	3,089 ± 0,07 d	2,259 h
		630,29	630,19	3,327 ± 0,062 d	
		667,379	667,718	3,474 ± 0,117 d	
9	I-131	284,506	284,305	7,511 ± 0,609 d	8,0207 d
		364,568	364,489	8,362 ± 0,07 d	
10	Mo99	140,056	140,511	2,819 ± 0,0285 d	2,748 d
		181,144	181,063	2,931 ± 0,1 d	
11	Sr-91	653,076	652,9	9,761 ± 0,693 h	9,63 h
12	Y-91m	555	555,58	9,695 ± 0,0075 h	49,71 m

Table of isotopes as results of (n, f)^{238}U reactions

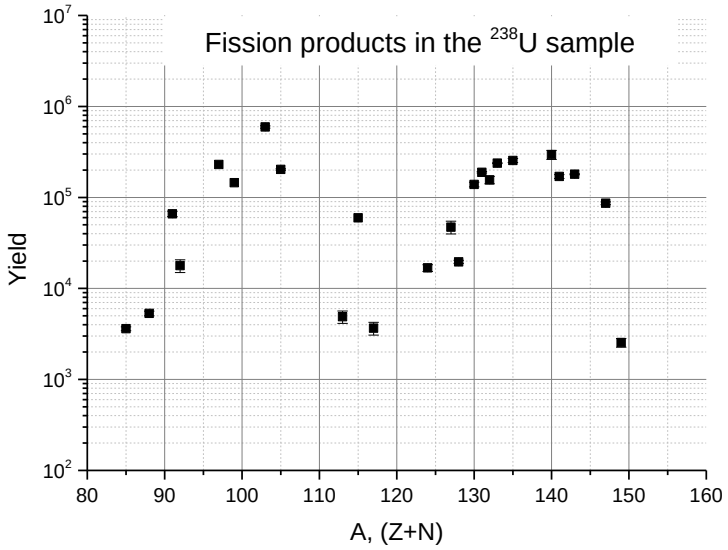
Discussion

- Sample ^{238}U in the neutron field generated by irradiation of the 660 MeV proton beam in Lead target.
- Distributions of neutrons and protons in this experiment has been studied.
- Gamma rays of isotopes were analyzed and processed by spectrometric methods.
- The products of neutron fissions and captures of ^{238}U sample were achieved.
- The ratio of the nuclear fission reactions to the rates of neutron capture reactions for ^{238}U was estimated.

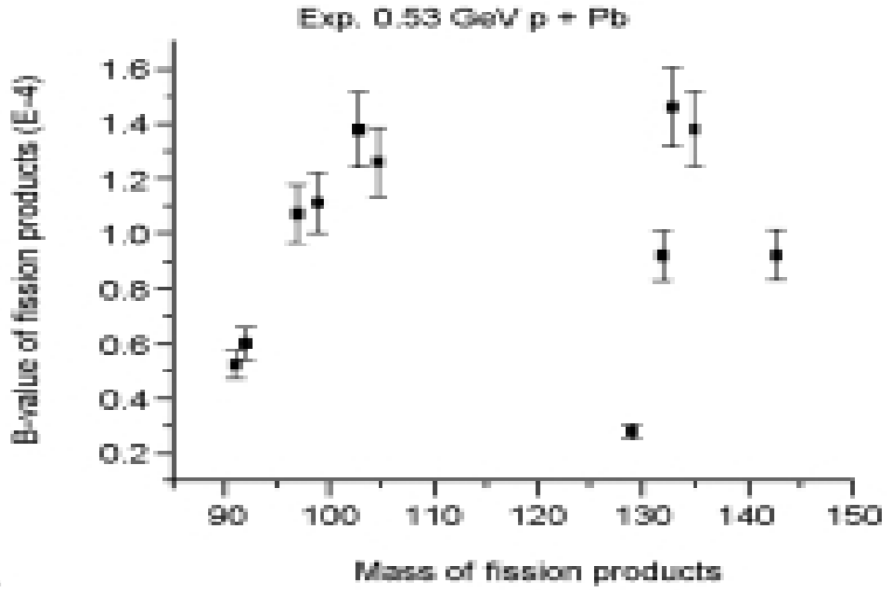

Thank You
For Your Attention



The fission cross-section of neutron and proton with ^{238}U



Our work



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- [1] J.-S. Wan et al. Transmutation of ^{239}Pu with spallation neutrons Journal of Radioanalytical and Nuclear Chemistry, Vol. 247, No. 1 (2001) 151157