CROSS-SECTIONS OF NUCLEAR ISOMERS IN THE INTERACTION OF PROTONS ON THIN THORIUM TARGET

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^{238}U and ^{232}Th as an alternative for ^{235}U

Neutron cross-section for isotopes

Изотоп	$\sigma_{эф}$, барн
^{232}Th	0,006
^{233}U	2,784
^{235}U	1,972
^{238}U	0,025
^{239}Pu	1,781

Natural Uranium:

^{238}U - 99,2745 %

^{235}U - 0,72 %

^{234}U - 0,0055 %

Advantages:

- Much more in nature
- It is easier to obtain

Disadvantages:

- For fission, we need fast neutrons

The problem of recycling

- Burial in continental geological formations
- Burial to the bottom of the ocean
- Burial in the glacial zone
- Removing beyond Earth
- **Transmutation**

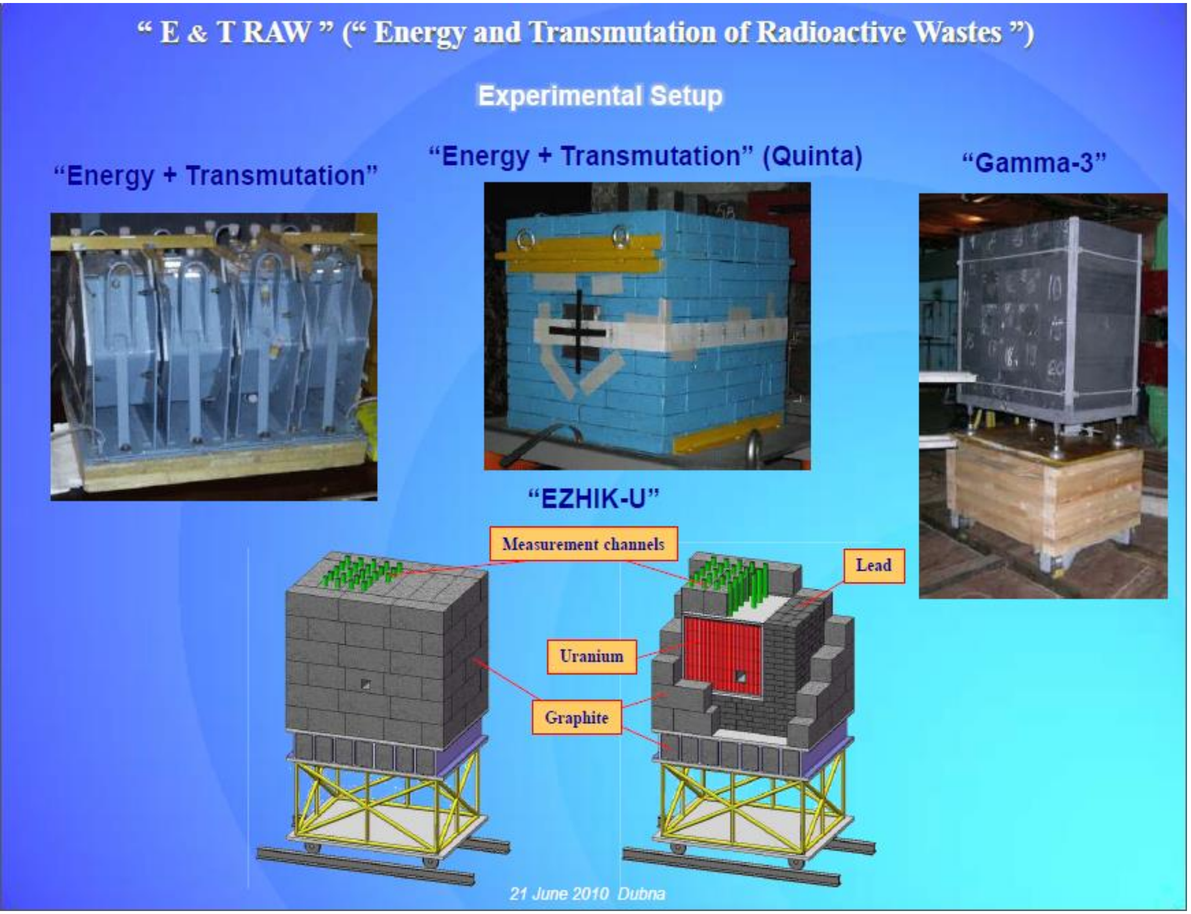
Transmutation

- This is the transformation of an isotope of one element into an isotope of another element by one or more nuclear reactions.

Creation of uranium-thorium-type nuclear power plants controlled by accelerators of high-energy particles (Accelerator Driven Systems - electronuclear systems controlled by a subcritical system accelerator, ADS).

Energy + Transmutation project

In the mid 90's in the Joint Institute for Nuclear Research (Dubna, Russia) was designed and created the installation "Enehrgy + transmutation" (E + T).

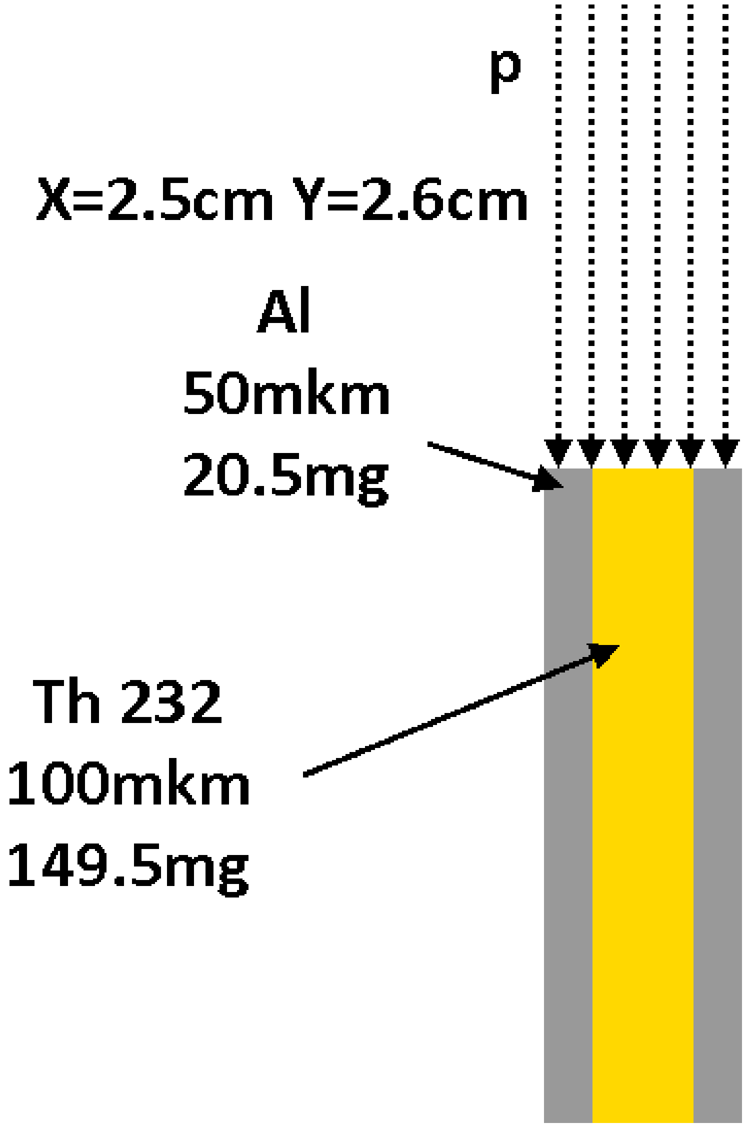


In this project, the study of the generation of neutrons and energy in the lead target and the uranium target on relativistic nuclei is carried out, as well as the transmutation of radioactive waste from nuclear power.

Goal:

Investigation of space-energy distribution of neutrons in a system of "lead target + target from natural uranium".

The experiment of irradiation Th232



- The energy of protons is - 100 and 600 MeV
- The current is 0.3 μA.
- Thickness of foil
  Th - 100 microns.
- Weight - 149.5mg.
- Area - 1.5 cm2.
- To determine the integral flux of protons used reaction
  $^{27}Al + p \rightarrow {}^{24}Na + \alpha$
- Thickness 27Al - 50 μm
- Weight - 20.5, 21 mg.

The irradiation of the 232Th sample was processed on the internal bundle of protons of the LNP on the JINR Phasotron (Dubna).

The spectra of the γ-radiation of the 232Th and 27Al foil were measured using a CANBERRA HPGe detector with an efficiency of 18% and a resolution of 1.9 keV on a line of 1332 keV 60Co.

Processing of gamma spectra

- Deimos
- A set of scripts
- Comparison of the results obtained with data from the Los Alamos National Laboratory (MCNP6)

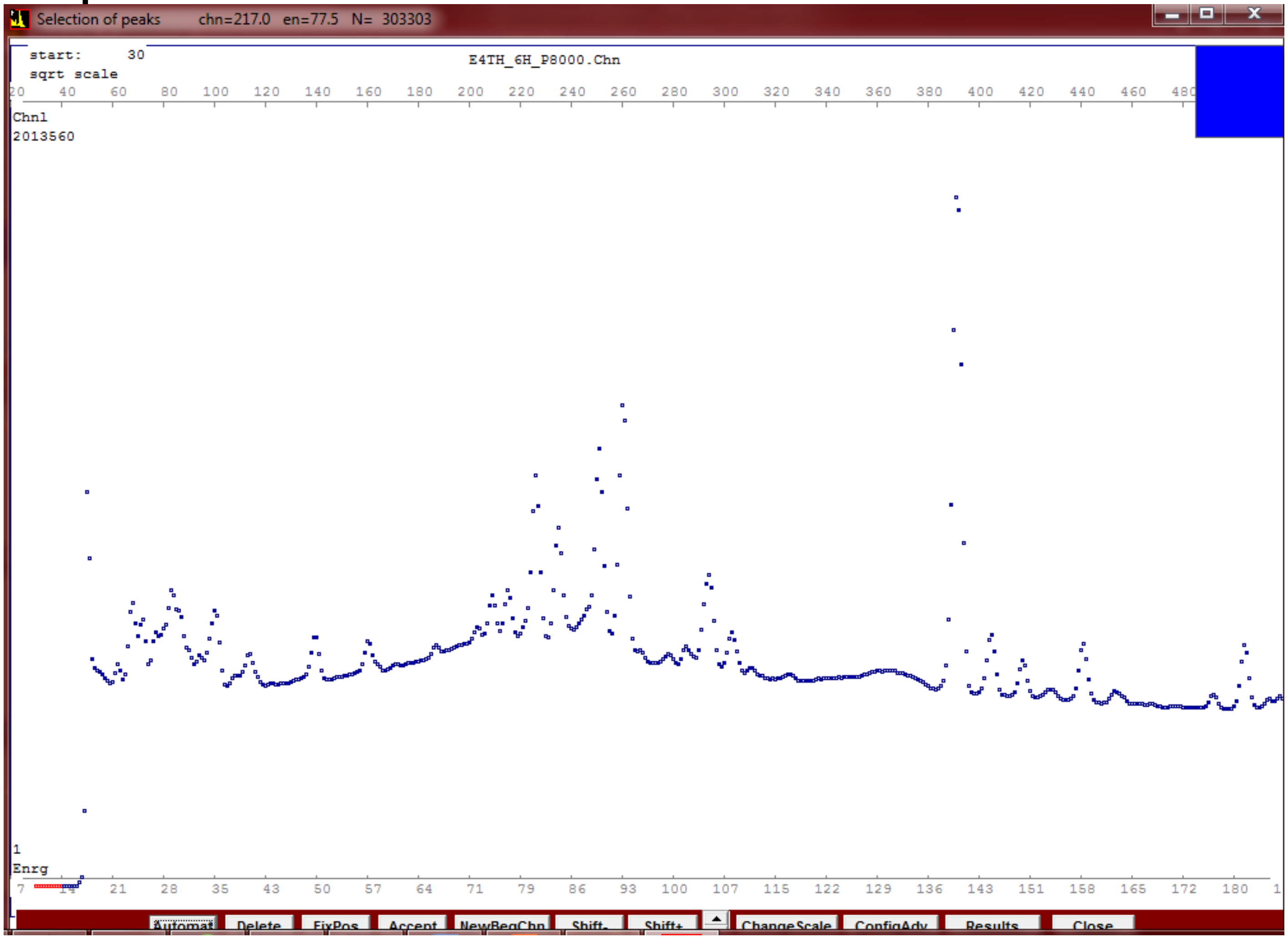
 MCNP is a family of programs for modeling ionizing radiation in material systems using the Monte Carlo method. It can simulate the interaction of particles with the substance of the system (scattering, capture, as well as the division of nuclei).

Software

- The software for processing γ-spectra is a set of programs written in the object-oriented programming language Ruby and the program Deimos32.

Deimos

Allows to find peaks in the gamma spectra and determine their position and area.



Programs

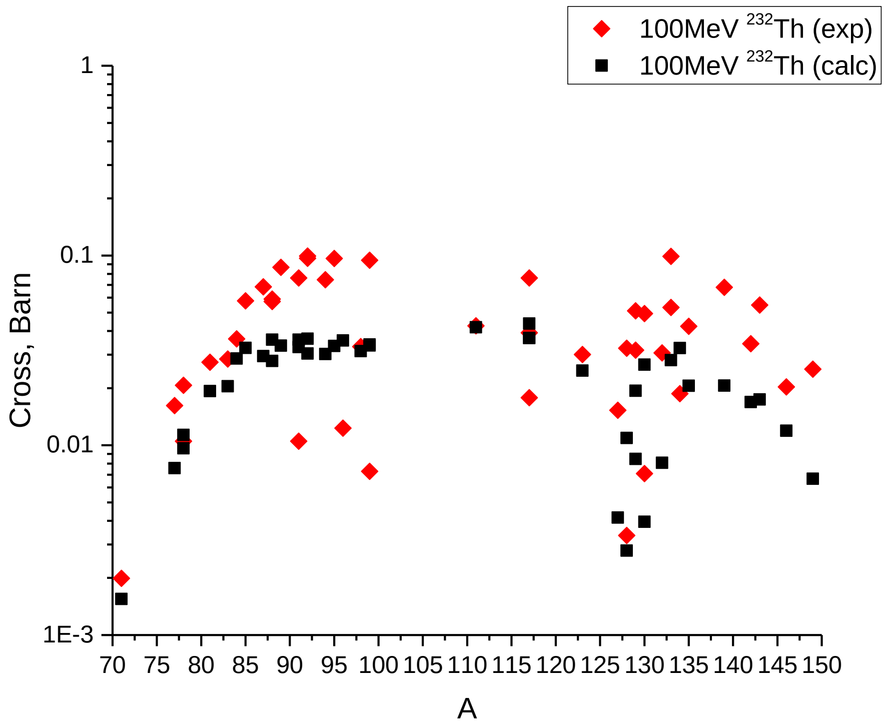
1. **Timeconst** - creates an input file that is used as a list of important spectrum data
2. **Nonlin64** - correction for non-linearity of the equipment.
3. **Puregam** - filters out the background radioactivity.
4. **SepDepe** – filters out annihilation peaks.
5. **Effcor** - used for the full energy peak efficiency correction.
6. **Attcor -** determines the self-absorption correction coefficient.

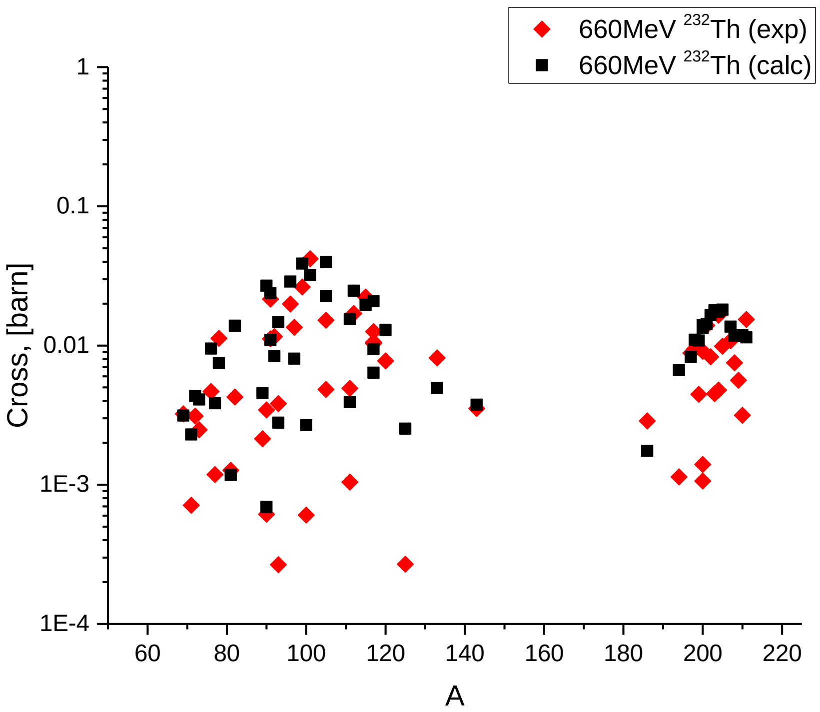
7. **MidLit7** - The program reads necessary data for each isotope -gamma line energy, gamma line intensity, isotope's half-life and identifies the isitope.
8. **TransCs9** - determine the amount initially formed nuclei, reaction rate and cross-section for each detected isotope.

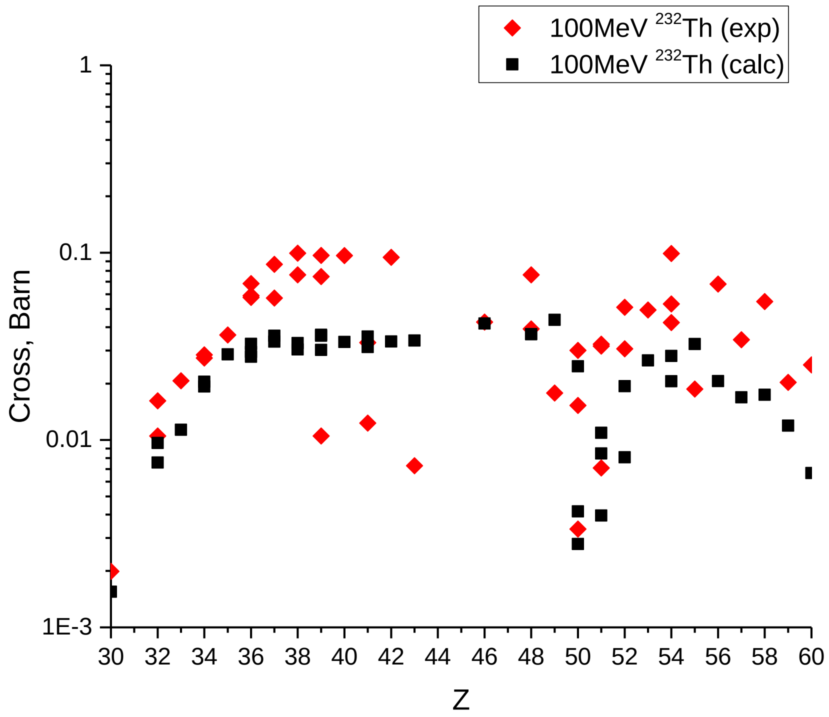
$$R_R = B\frac{A}{N_A}$$

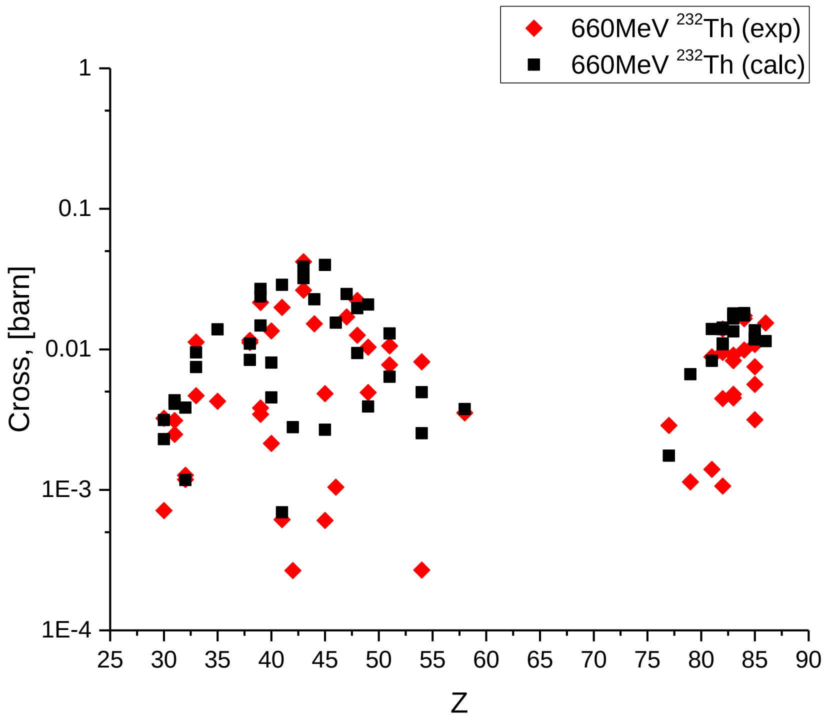
$$\sigma_a\left(E_\gamma(j)\right) = \frac{S_i\left(E_\gamma(j)\right)\lambda_a * (\frac{t_{r,i}}{t_{l,i}})}{N_p N_{targ}\,\varepsilon_\gamma I_\gamma\left(E_\gamma(j)\right)(1-e^{-\lambda_a t_1})1-e^{-\lambda_a t_{2,i}}(1-e^{-\lambda_a t_{r,i}})}$$

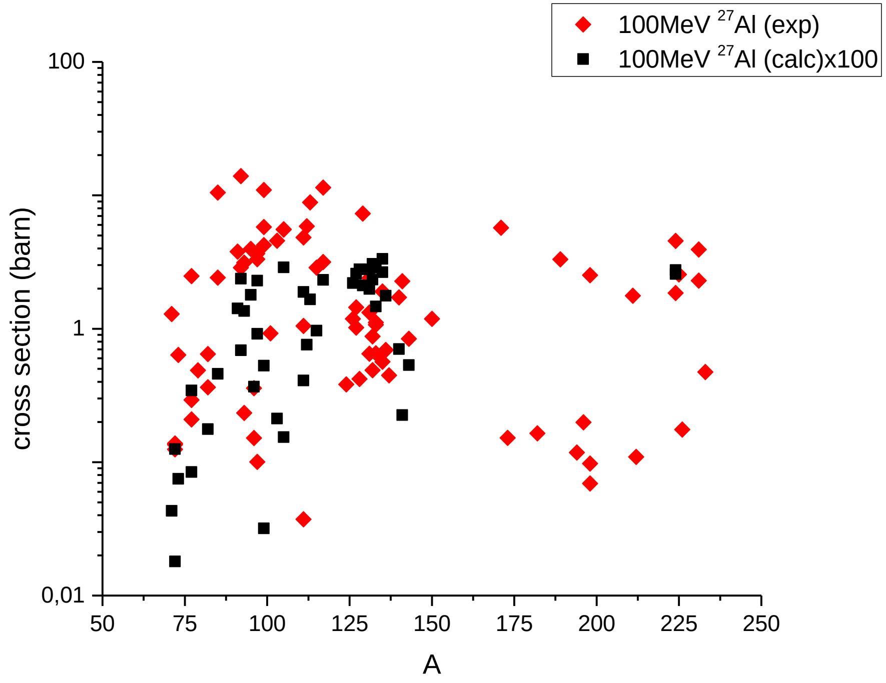
9. **SigmaJ7 -** sorting all data into a table.

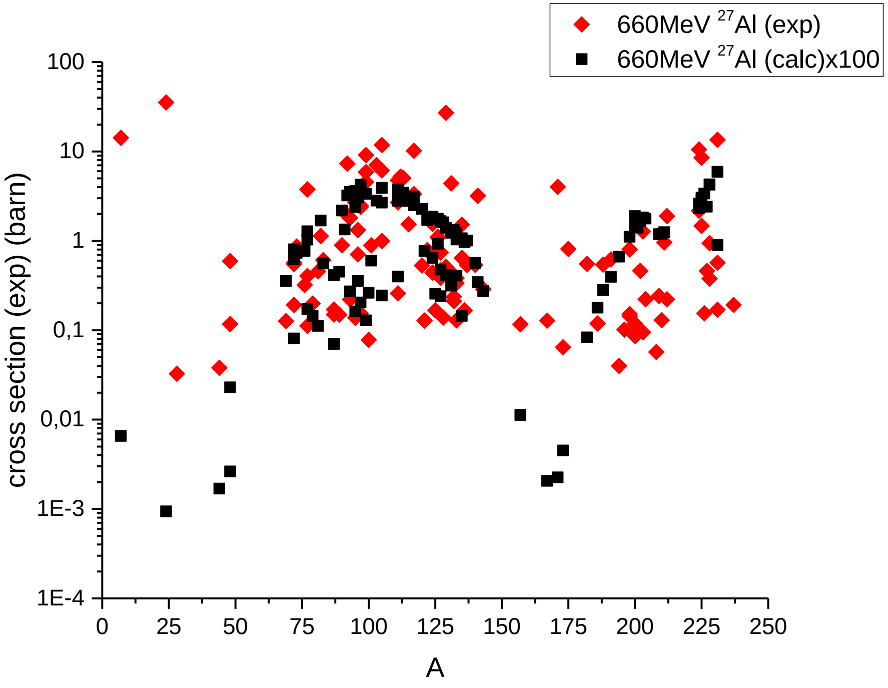

100MeV 232Th (exp)
100MeV 232Th (calc)
Cross, Barn
A
1
0.1
0.01
1E-3
70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150


660MeV 232Th (exp)
660MeV 232Th (calc)
Cross, [barn]
A
1
0.1
0.01
1E-3
1E-4
60 80 100 120 140 160 180 200 220


100MeV 232Th (exp)
100MeV 232Th (calc)
Cross, Barn
1
0.1
0.01
1E-3
30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60
Z


660MeV 232Th (exp)
660MeV 232Th (calc)
Cross, [barn]
1
0.1
0.01
1E-3
1E-4
25 30 35 40 45 50 55 60 65 70 75 80 85 90
Z





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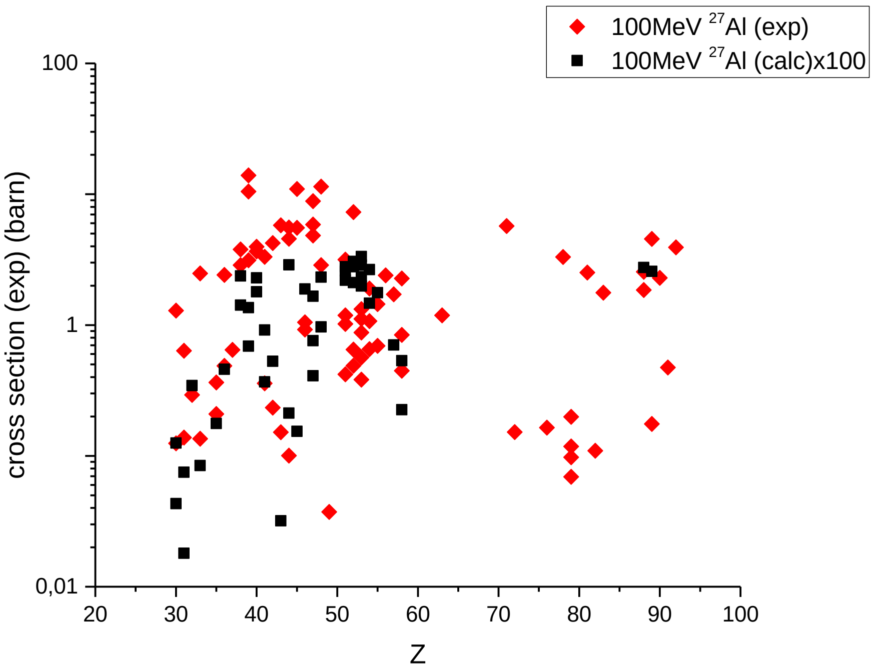
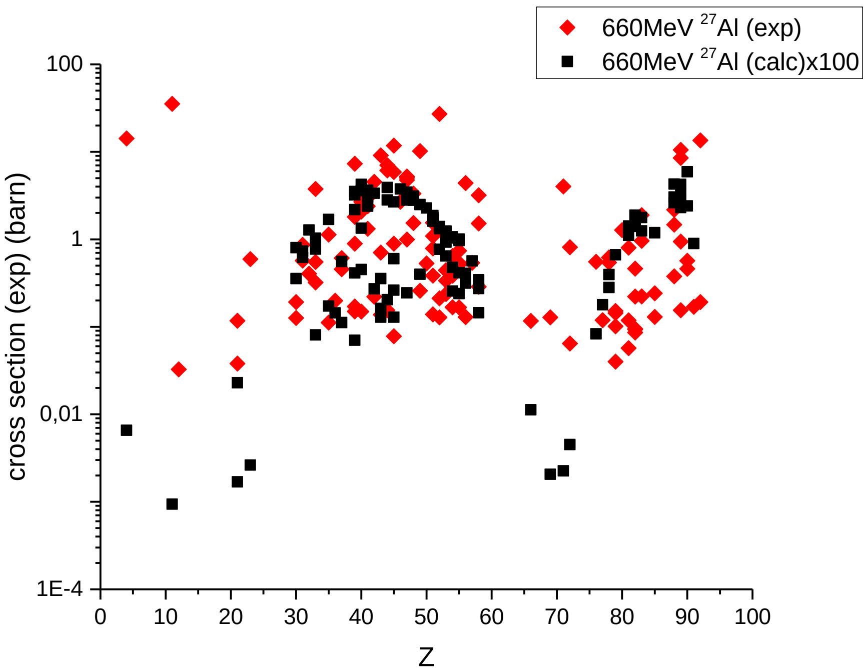


100MeV 27Al (exp)
100MeV 27Al (calc)x100
cross section (exp) (barn)
100
1
0,01
20 30 40 50 60 70 80 90 100
Z



660MeV 27Al (exp)
660MeV 27Al (calc)x100
cross section (exp) (barn)
100
1
0,01
1E-4
0 10 20 30 40 50 60 70 80 90 100
Z

Conclusions

- The processing of experimental data on the fragmentation of the ^{232}Th nucleus under the influence of protons in the energy of 100 and 600 MeV has been processed.
- The cross-sections of fragmentation of the 232Th nucleus have been obtained, depending on the charge and mass number of the reaction fragments .
- For 100 MeV proton beam there were identified for 258 gamma lines that belong to 45 nuclides and identified 222 gamma lines that belong to 55 nuclides in the case of 600 MeV proton beam.
- For the Al collector 238 gamma lines belonging to 81 nuclides in the case of 100 MeV protons and 330 lines for 119 nuclides in the case of 600 MeV.
- The incommensurability of the number of lines for the target and the collector can be explained by the different distribution of fragments by kinetic energy. In the mass and charge spectra there are clearly separated fission and spallation reactions.

Thank you for attention