NEUTRON GENERATION BY RELATIVISTIC DEUTERONS IN THE URANIUM TARGET OF ASSEMBLY "QUINTA-M"

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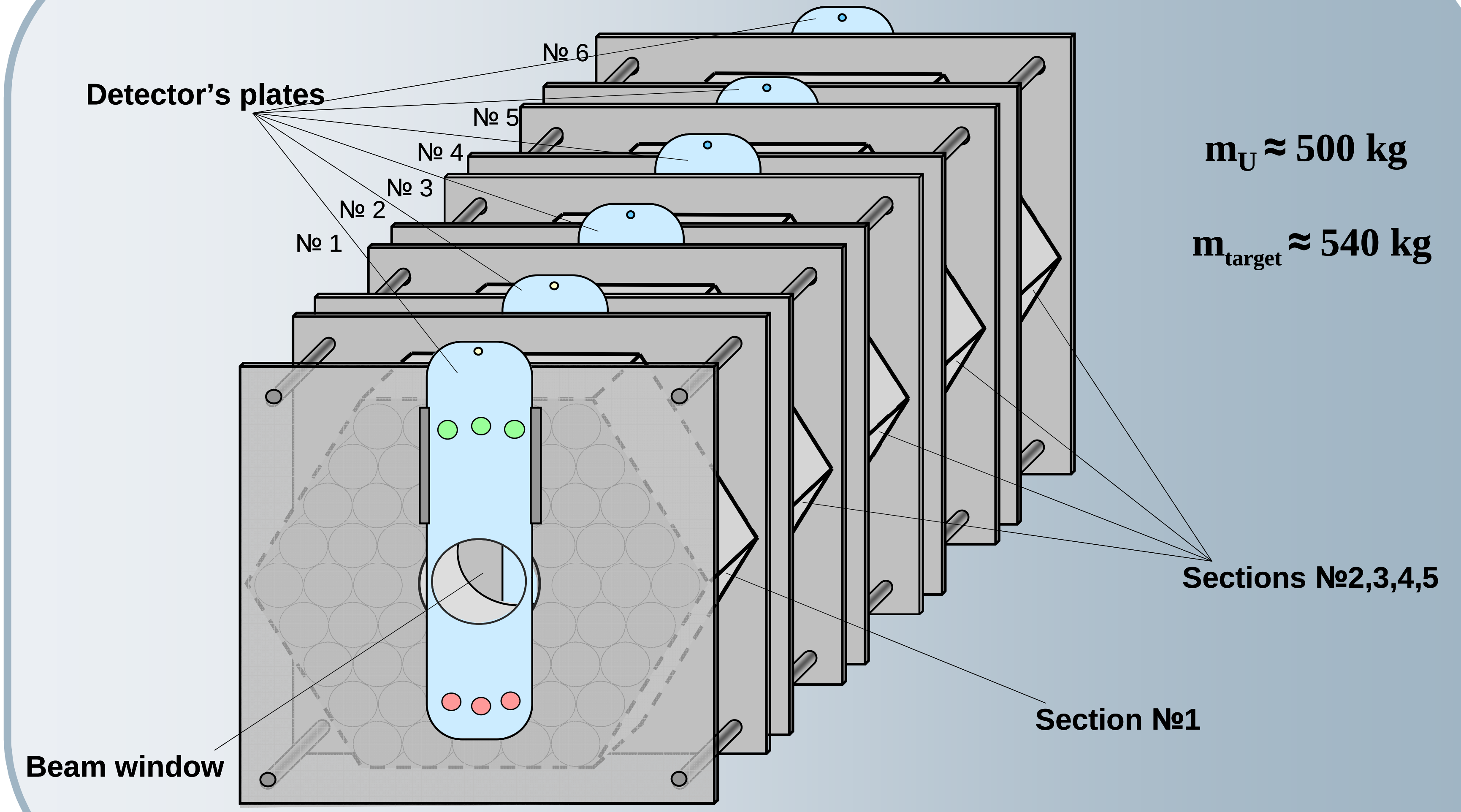
Experimental assembly “QUINTA-M”



$m_U \approx 500$ kg

$m_{target} \approx 540$ kg

Main purposes

- to obtain spatial distributions of density of radiative capture reactions (the number of accumulating ^{239}Pu nuclei) and density of ^{238}U fissions in the volume of uranium target of assembly "QUINTA-M";

- to obtain spatial distribution of spectral indices;

- to determine the total number of ^{238}U fissions and total amount of ^{239}Pu, accumulated at the volume of uranium target of assembly "QUINTA-M";

- to compare of the obtained experimental results in dependence on the energy of the deuteron beam (per unit of beam power).

“QUINTA-M” at the irradiation position

Before the irradiation the target was carefully adjusted to the direction of the Nuclotron beam using polaroid films, i.e. the longitudinal axis of a target was combined with a direction of Nuclotron beam.

Total intensity of deuteron beam

Monitoring of the total intensity of deuteron beam was carried out using standard method of activation of aluminum foil in the reaction **$^{27}Al(d,x)^{24}Na$**

In the subsequent estimates of the deuteron intensity the cross sections were used:
16.8 mb (1 GeV) **15.4 mb (2 GeV)**
14.6 mb (4 GeV) **14.2 mb (6 GeV)**
14.0 mb (8 GeV)

Total intensity of deuteron beam

Run	Energy of deuterons, GeV	Total deuteron intensity
March 2011	2	**$1.69 \cdot 10^{13}$**
	4	**$1.41 \cdot 10^{13}$**
	6	**$1.94 \cdot 10^{13}$**
Dec 2011	1	**$1.47 \cdot 10^{13}$**
	4	**$1.96 \cdot 10^{13}$**
March 2012	1	**$1.9 \cdot 10^{13}$**
	4	**$2.7 \cdot 10^{13}$**
	8	**$3.7 \cdot 10^{12}$**

Determination of the accumulated plutonium

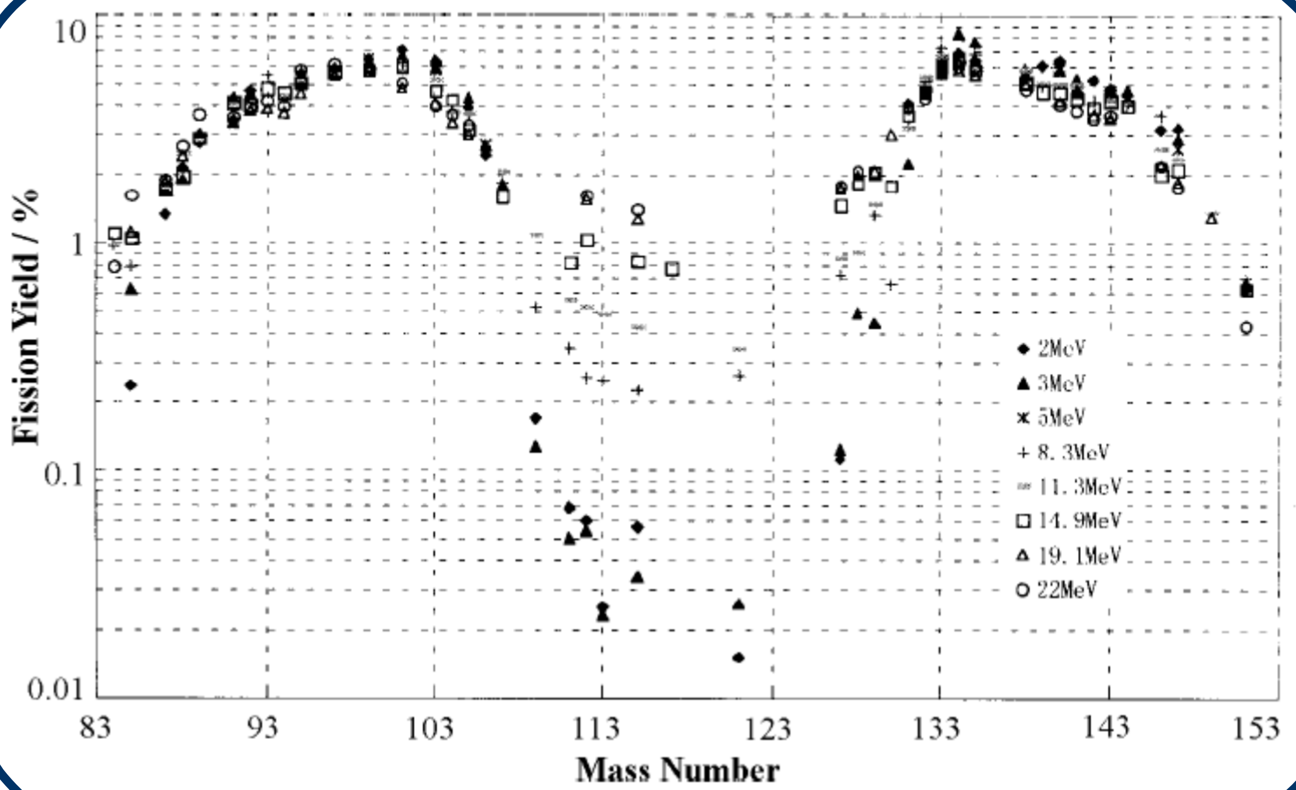
The number of ^{238}U neutron radiative capture reactions corresponds to the number of ^{239}Pu nuclei, which are formed by the chain of ^{239}U β-decay:

$^{238}U(n,\gamma)^{239}U$ β^- (23,54 min) $\rightarrow$ ^{239}Np β^- (2,36 d) $\rightarrow$ ^{239}Pu

After the irradiation of uranium assembly γ-spectra of irradiated uranium foils were measured. Before measurement uranium foils were exposure for more than 4 hours to reach 99.9% of the decays of ^{239}U. The number of neutron capture reactions of uranium-238 was determined by measuring the activity of the ^{239}Np nuclide.

Mass distribution of fission products of ^{nat}U at different neutron energies

The number of nuclear fissions was determined by averaging the results for the following fragments :



^{97}Zr (5.7%)
^{131}I (3.6%)
^{133}I (6.3%)
^{143}Ce(4.3%)

The cumulative yield, averaged over data for neutrons with energy 2-22 MeV is shown in brackets.

Determination of total beam intensity

$$N_{nuc} = \left[\frac{S_p}{\varepsilon_p(E)\cdot I_\gamma} \cdot \frac{e^{\lambda t_c}}{1-e^{-\lambda t_{live}}} \cdot \frac{e^{-\lambda\tau}-1}{\lambda\tau} \cdot K_B \cdot K_{COI} \cdot K_{ABS} \cdot K_G \cdot K_{NP} \right]$$

K_B is factor determining the course of irradiation: $K_B = \sum_i f_i \Big/ \sum_i f_i e^{-\lambda t_{ci}}$

where $\boldsymbol{t_{ci}}$ - time from the end of each beam pulse until the end of irradiation ,
$\boldsymbol{f_i}$ - the intensity of the pulse (according to the values of monitoring of ionization chambers);

K_{ABS} is correction on self-absorption :

$$K_{ABS} = \frac{\mu D_{sum}}{1-\exp(-\mu D_{sum})}$$

K_G is correction on changed detector efficiency due to sample dimensions;

effective center of the bulk sample is closer to the effective center of the detector (R_1) in comparison with a point calibration source (R_2):

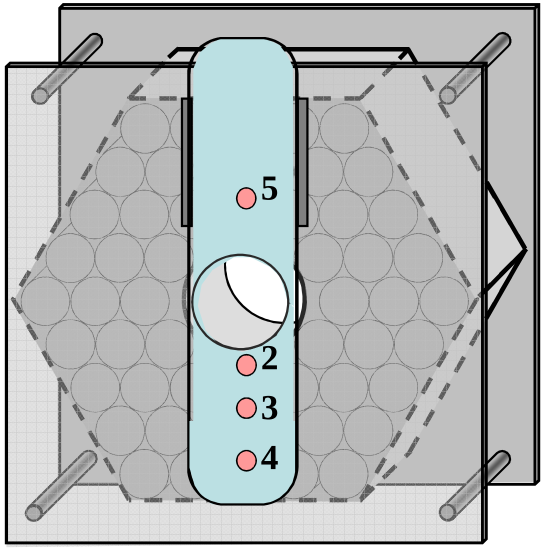
$$K_G \approx (R_1/R_2)^2$$

K_{NP} is correction on non-point like emitters;

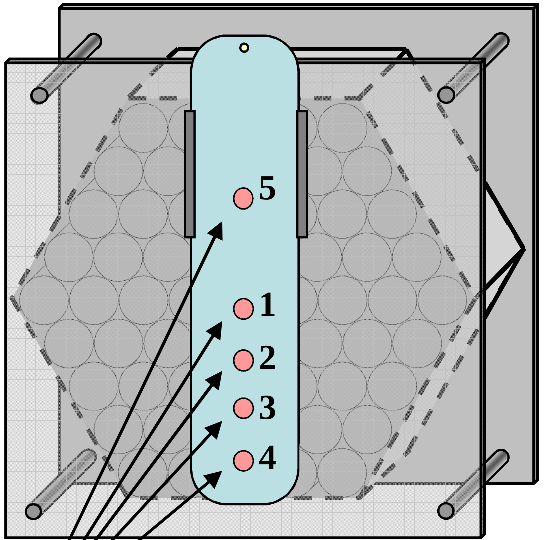
K_{COI} is correction for gamma-lines coincidences

Location of detectors on the plate

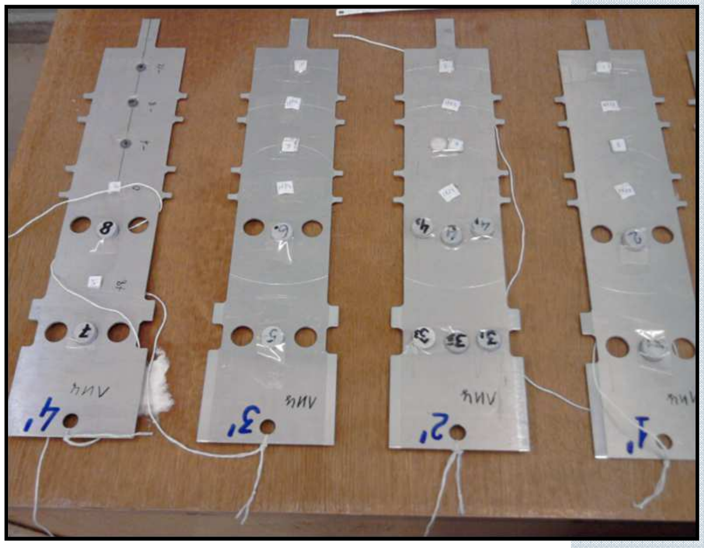
Section № 1



Sections № 2,3,4,5



Detector plates



Location of the detector plate

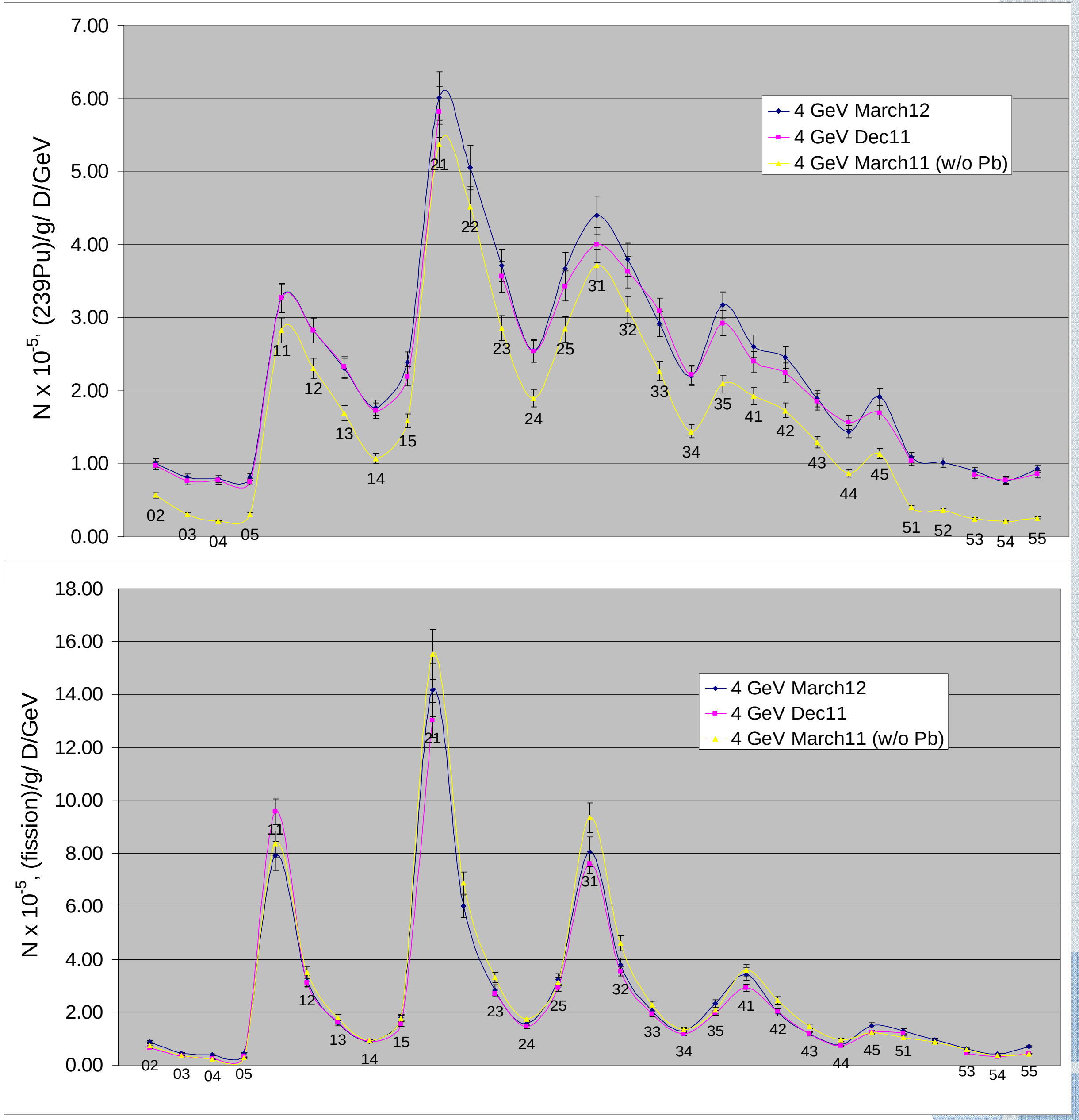
The scheme of ^{nat}U foils location on the detector plate, used in the experiment. Each plate had 5 positions at different distances from the radial symmetry axis of the target

- **5** R = -80 mm
- **1** R = 0
- **2** R = 40 mm
- **3** R = 80 mm
- **4** R = 120 mm

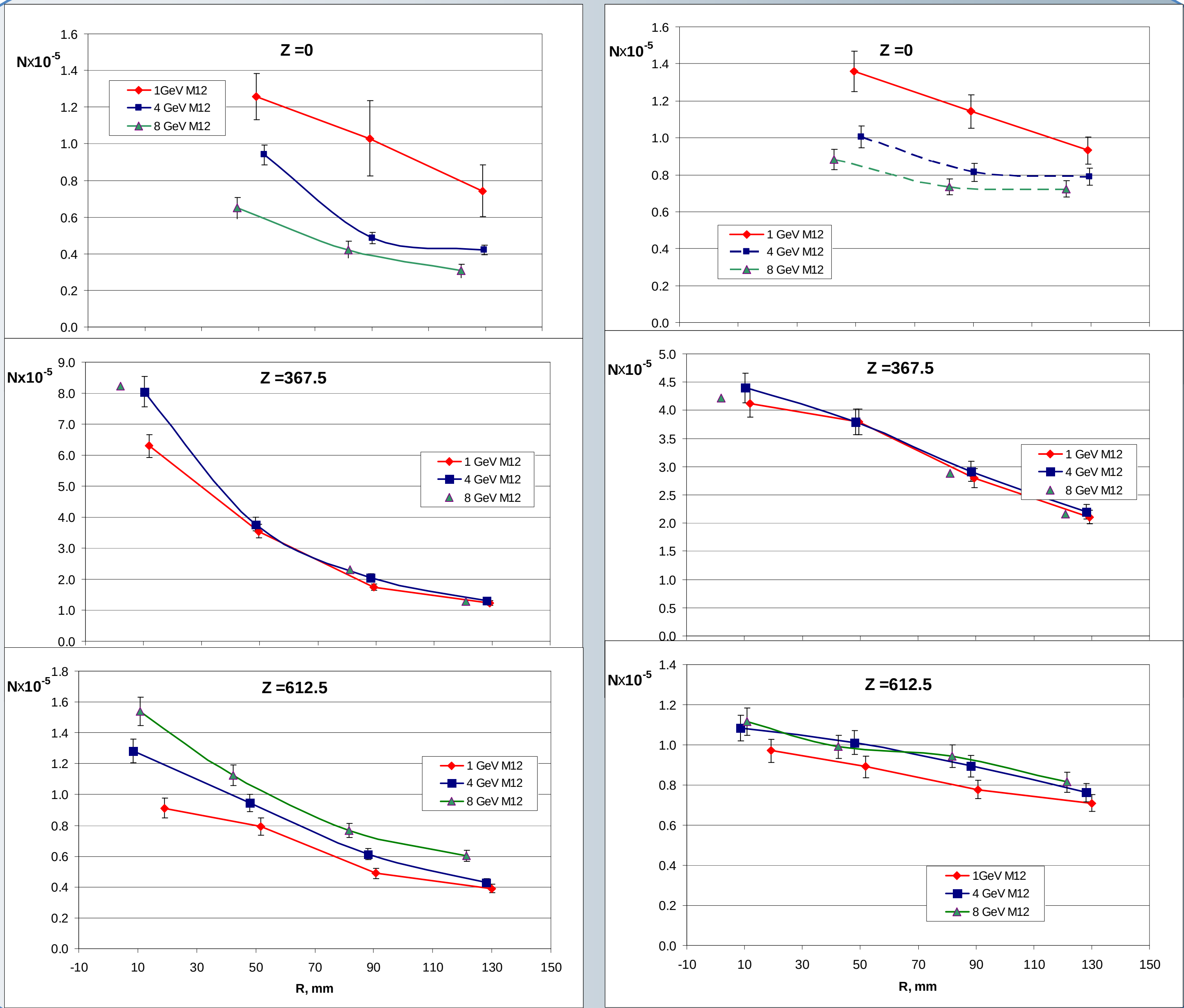
Results

Density distribution of ^{239}Pu production and ^{238}U fissions in assembly "QUINTA-M"

Comparison of results of "QUINTA-M" (March 2011) and "QUINTA-M + Pb" (December 2011 and March 2012)

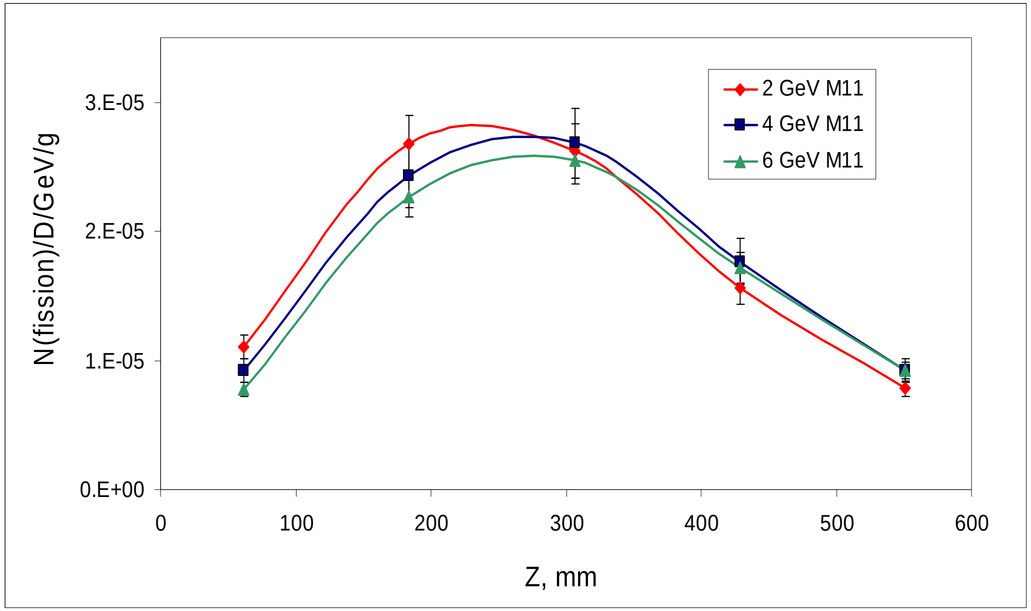


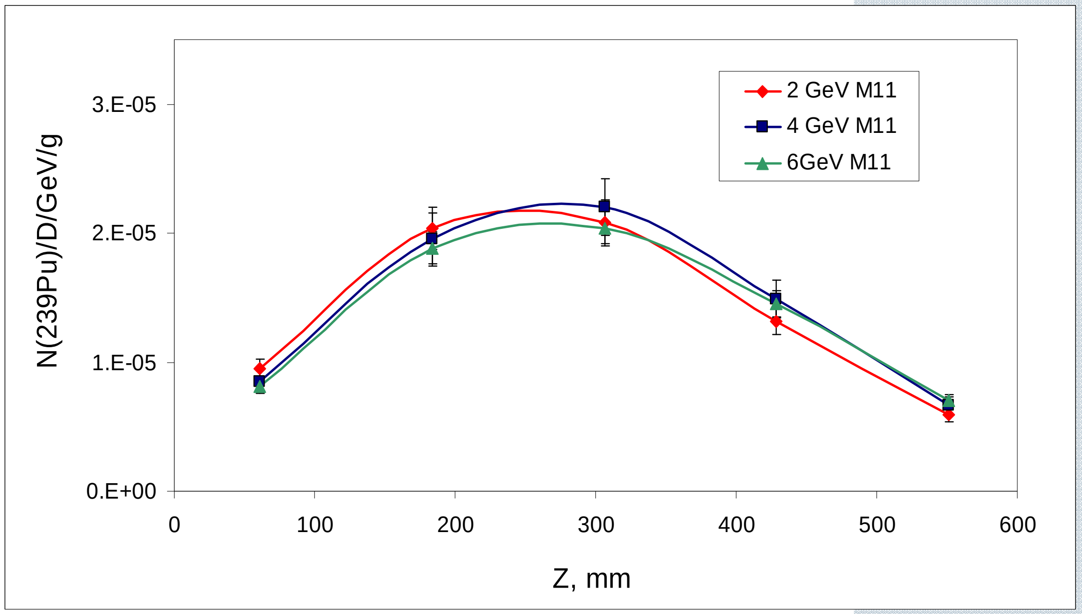
Comparison of results at the different deuteron energies



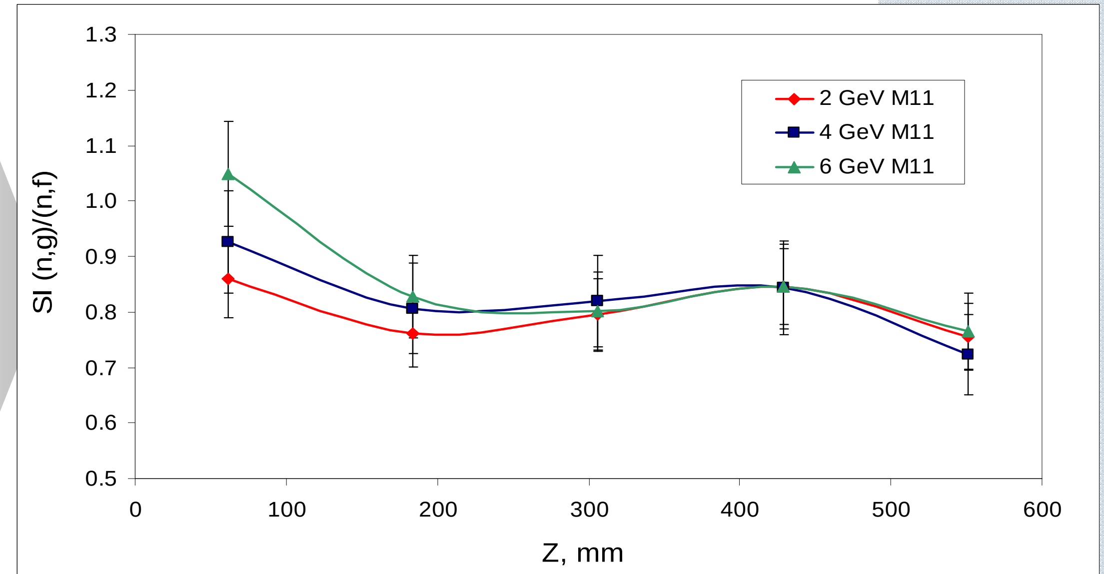
Radial distributions of density of ^{nat}**U(n,f)** reactions (**on the left**) and density of ^{nat}**U(n,γ)** reactions (**on the right**) per 1 deuteron per 1 GeV

Average spatial distributions of (n,f), (n,γ) reactions and spectral index

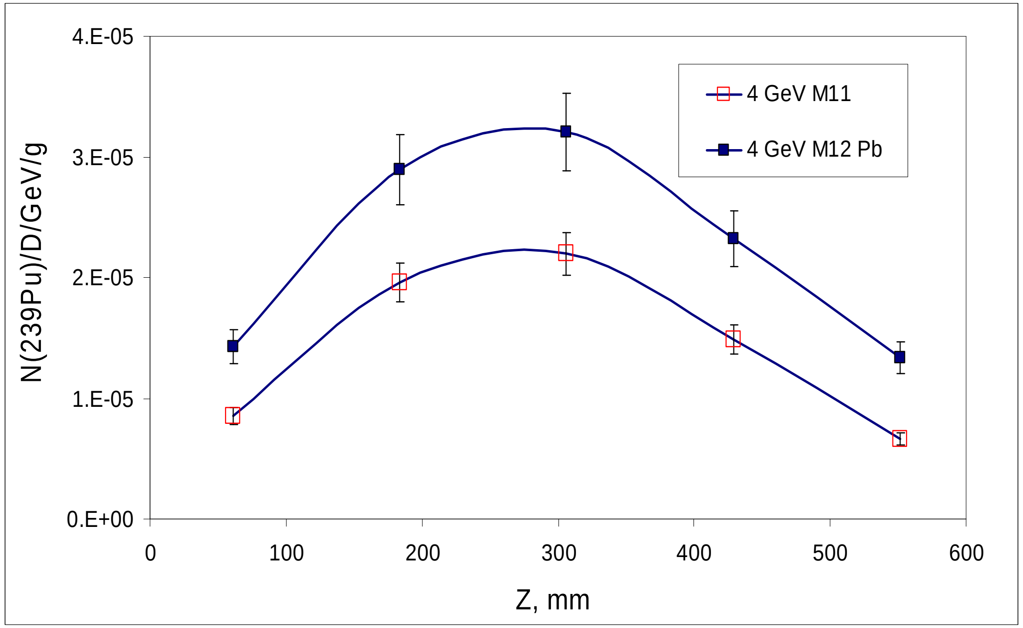


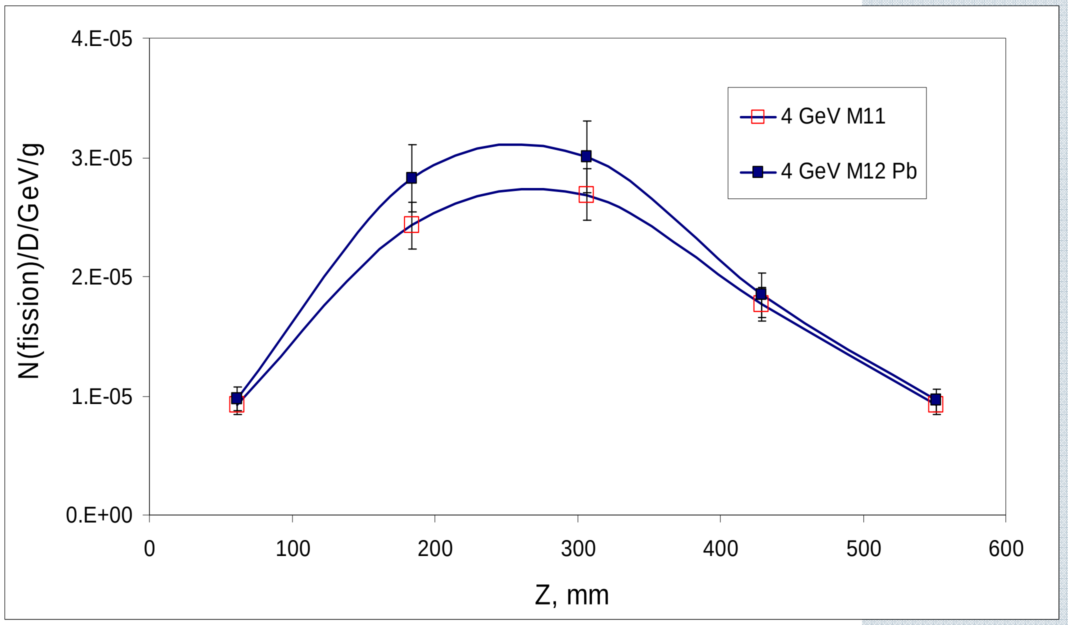


Densities of the number of fissions, the number of plutonium nuclei and spectral indices averaged over the radial cross sections of the uranium target. The maximum values of density of fission and plutonium accumulation was approximately at a distance of about 120 mm from the entrance of the beam at the target. This is observed for all similar axial distributions of deuterons energies from 1 to 8 GeV.

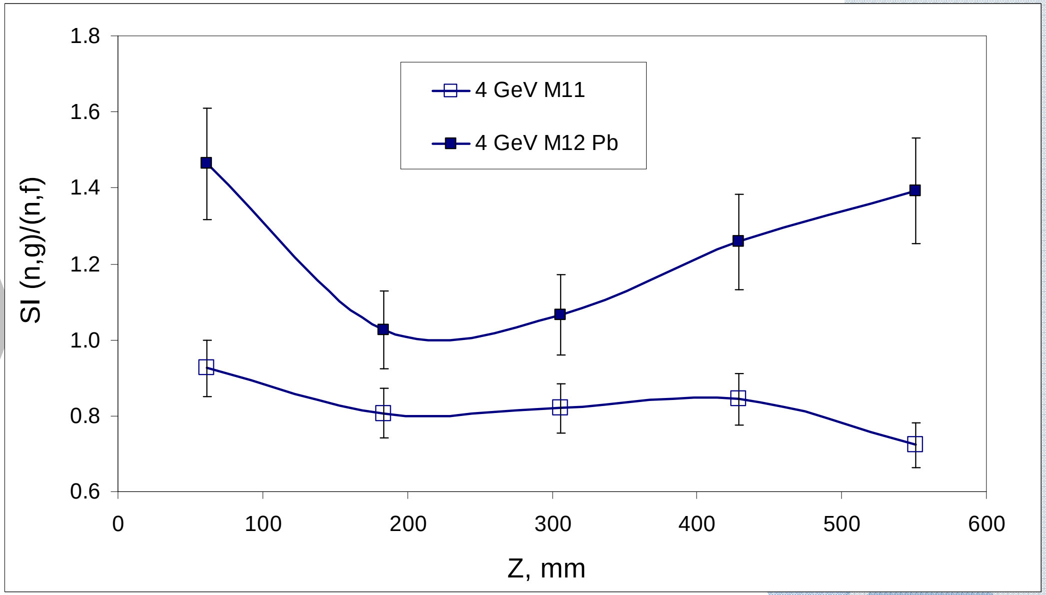


Average spatial distributions of (n,f), (n,γ) reactions and spectral index





Densities of the number of fissions, the number of plutonium nuclei and spectral indices averaged over the radial cross sections of the uranium target. The maximum values of density of fission and plutonium accumulation was approximately at a distance of about 120 mm from the entrance of the beam at the target.

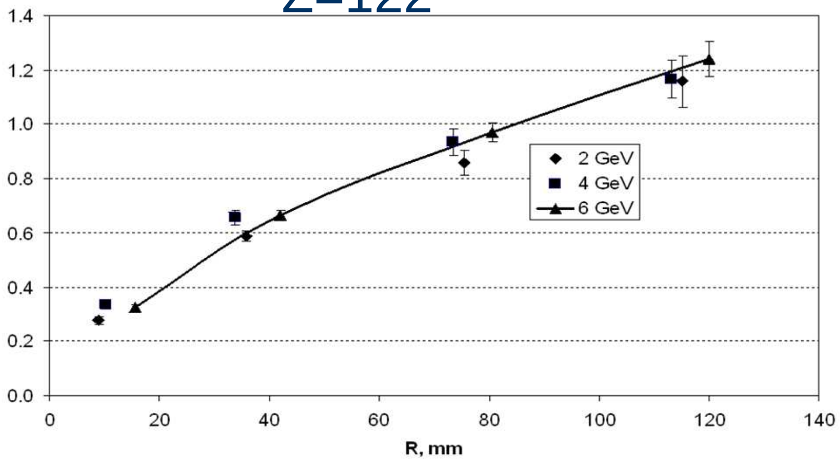


Radial distributions of spectral indices

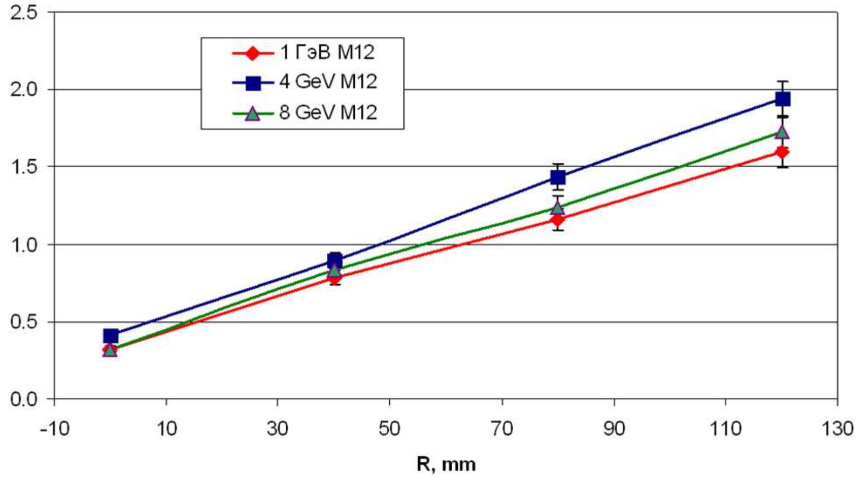
“QUINTA-M” in Run March 2011. Energy was 2, 4 and 6 GeV.

“QUINTA-M + Pb” in Run March 2012. Energy was 1, 4 and 8 GeV.

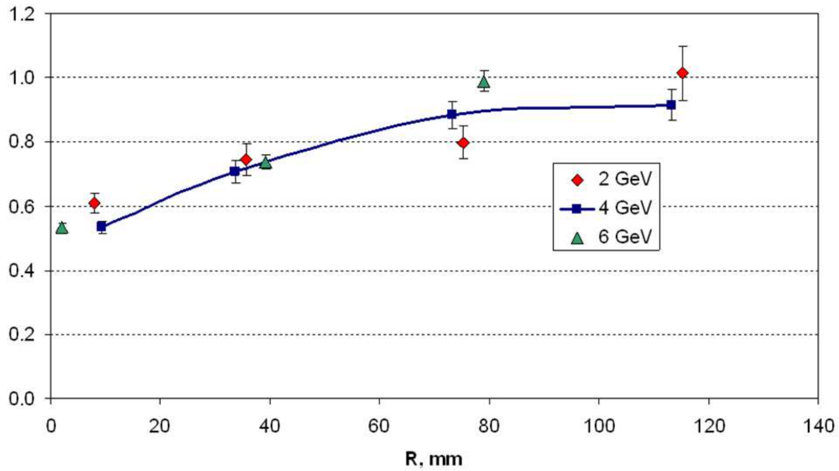
Z=122



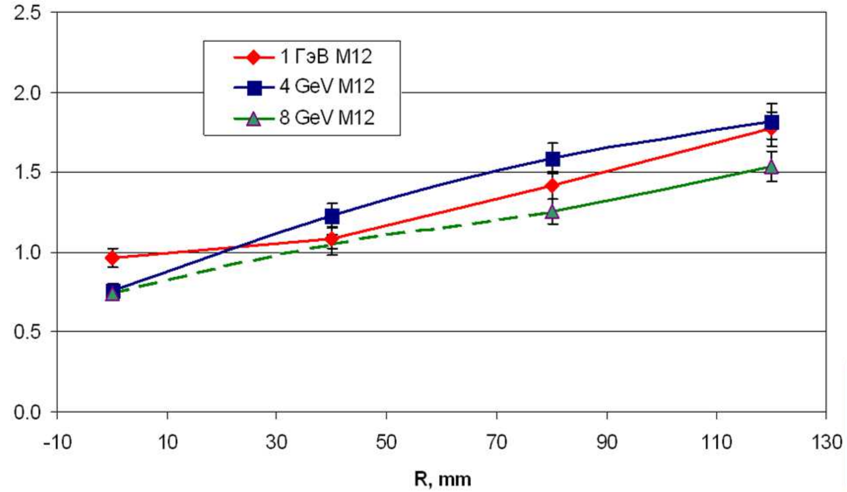
Z=122



Z=490



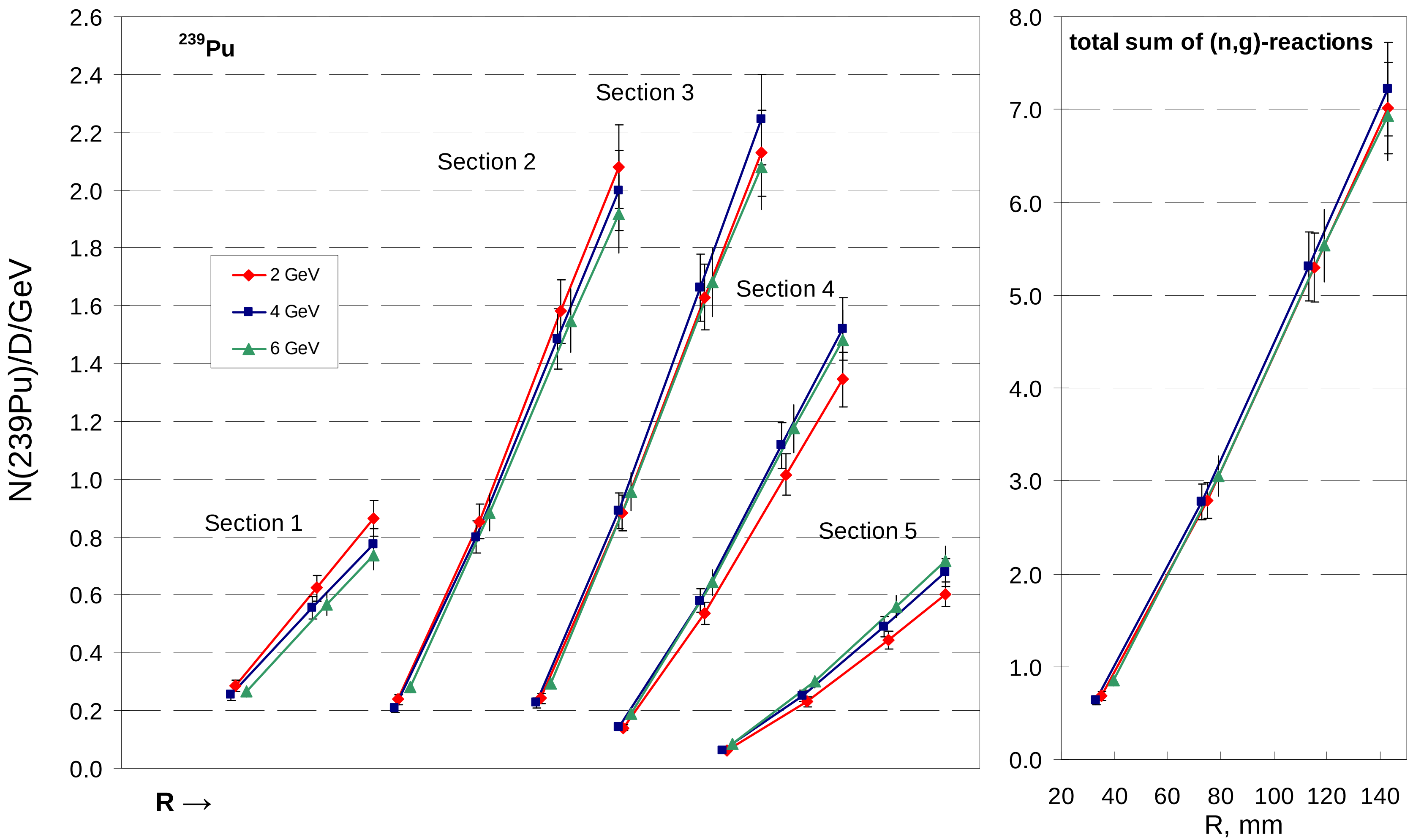
Z=490



Results

Integral distribution of (n,γ) reaction

(dependencies on uranium target radius)



Results

Integral distribution of (n,γ) reaction

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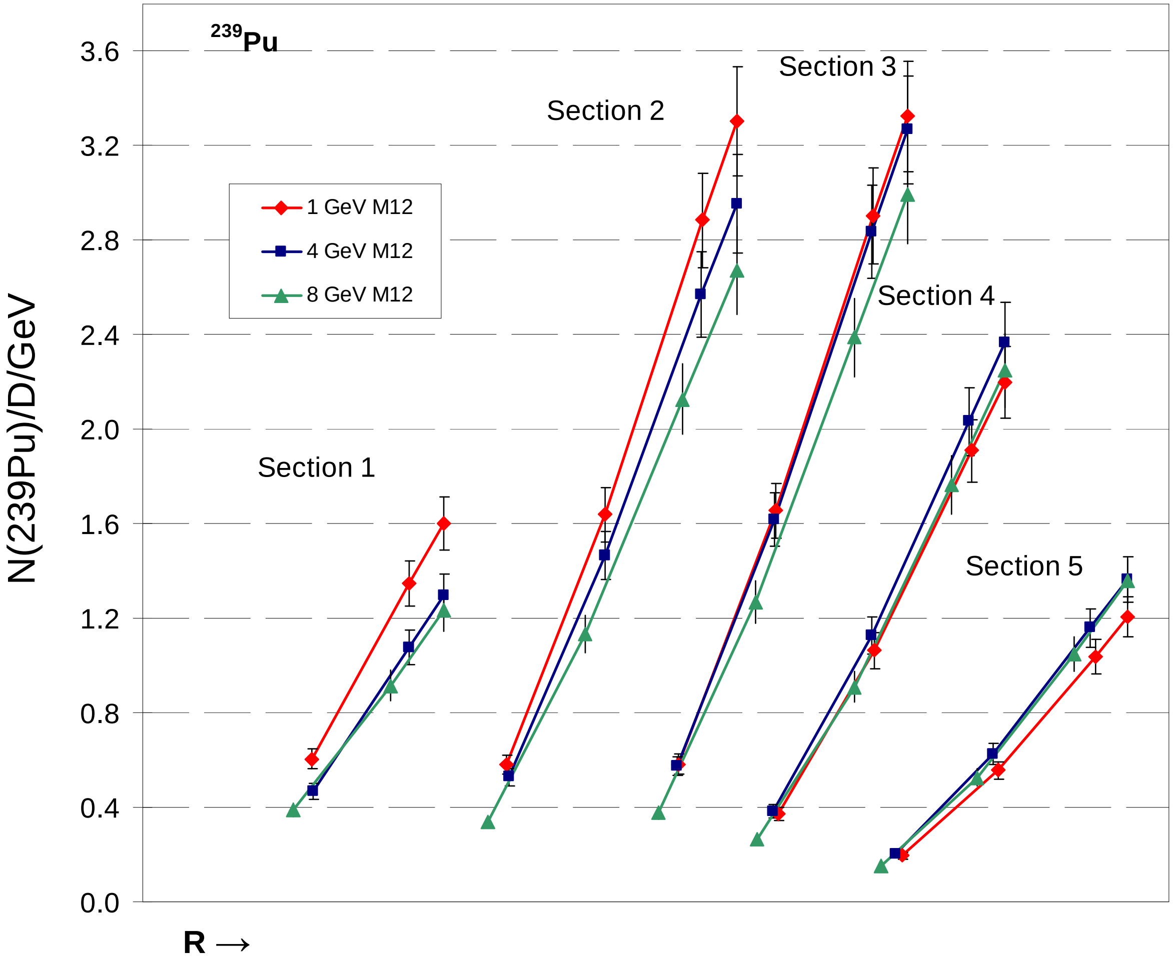
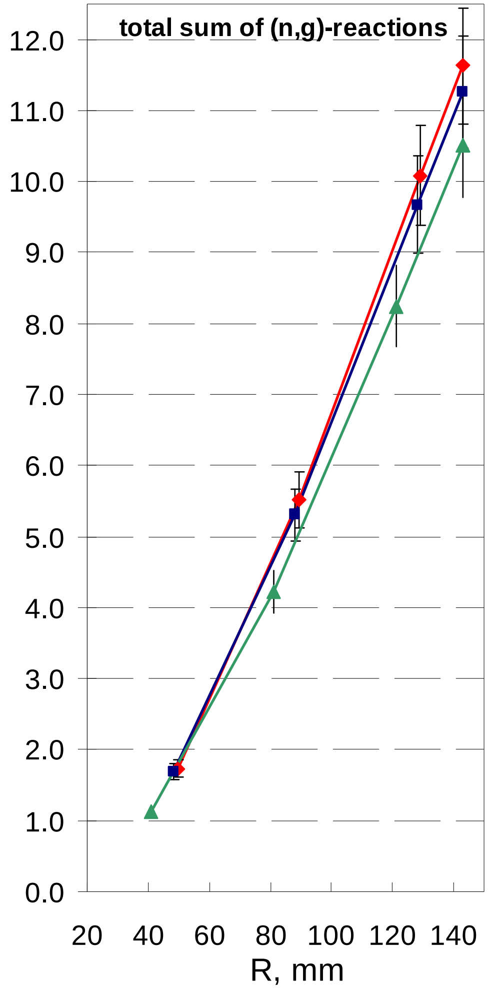
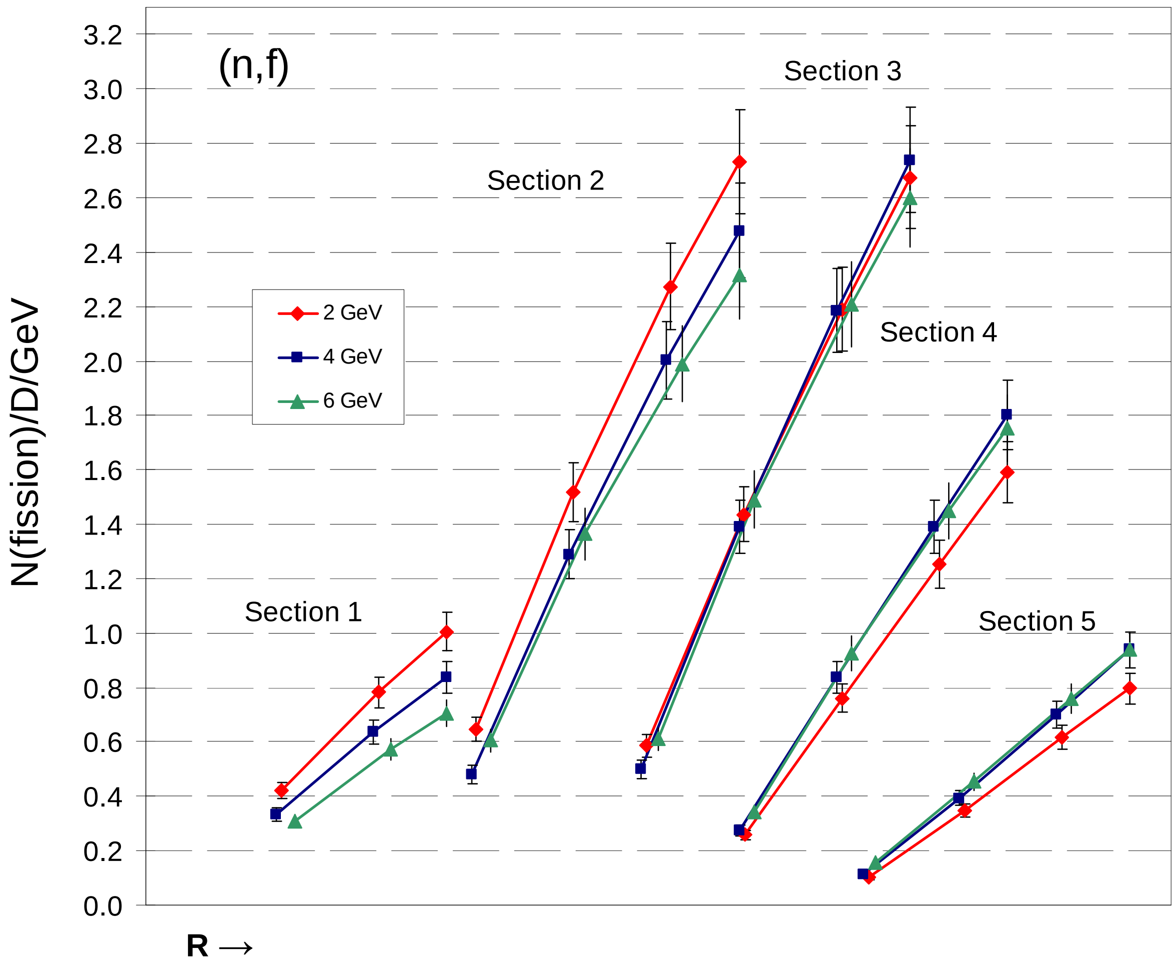


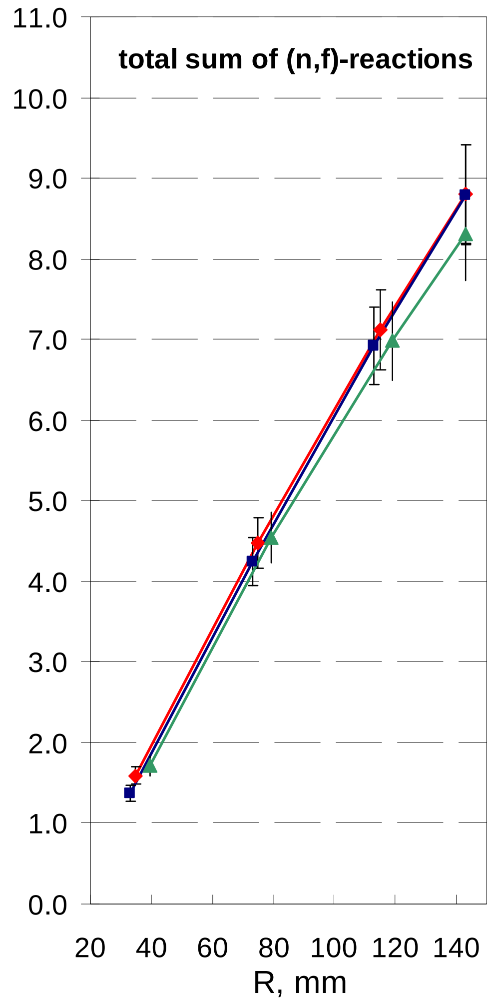


Results

Integral distribution of (n,f) reaction

(dependencies on uranium target radius)

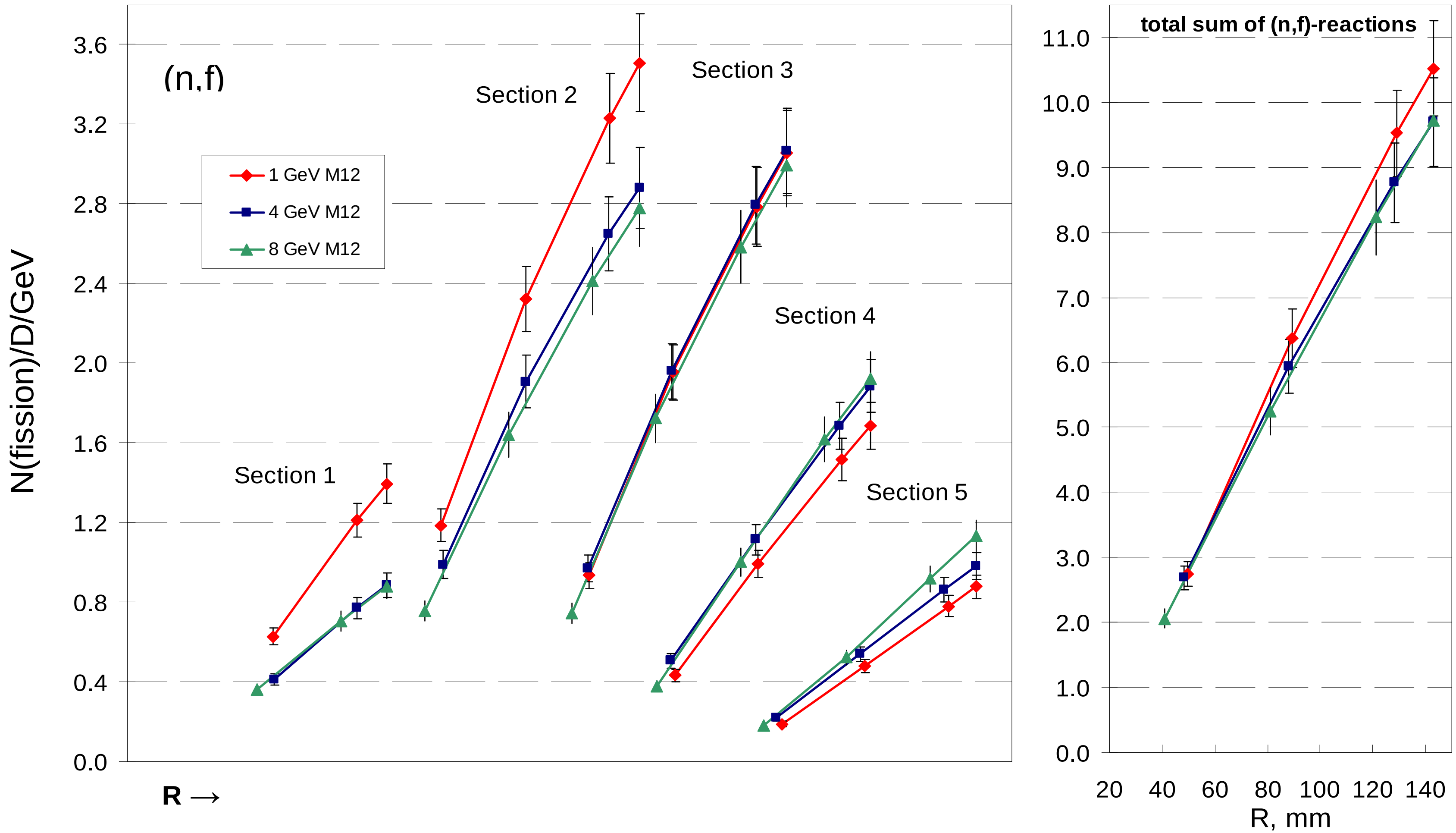




Results

Integral distribution of (n,f) reaction

(dependencies on uranium target radius)



Results

Integral numbers of ^{239}Pu accumulation and ^{nat}U fission in the volume of uranium target of assembly “QUINTA-M”

Run	E, GeV	^{239}Pu	^{nat}U fission
March 2011	2	(7.0 ± 0.3) ± 0.8	(8.8± 0.4) ± 1.0
	4	(7.2± 0.4) ± 0.8	(8.8± 0.4) ± 1.0
	6	(6.9± 0.3) ± 0.7	(8.3± 0.4) ± 0.9
Dec. 2011	1	(11.8± 0.6) ± 1.2	(10.6± 0.5) ± 1.1
	4	(10.8± 0.5) ± 1.1	(8.5± 0.4) ± 1.0
March 2012	1	(11.6± 0.6) ± 1.2	(10.5± 0.5) ± 1.1
	4	(11.3± 0.5) ± 1.1	(9.7± 0.4) ± 1.0
	8	(10.5± 0.5) ± 1.1	(9.7± 0.5) ± 1.1

Conclusions

- The spectral index changes from the deuteron beam axis to the periphery of the uranium target from about 0.3 to 1 for “QUINTA-M” and from about 0.6 to 2 for “QUINTA-M+Pb” does not depend on the energy of the deuteron beam in the range from 1 to 8 GeV .

- The total number of fissions in the volume of uranium target of “QUINTA-M”, that was defined by activation method, remains approximately constant within our statistical errors for all energies of the deuteron beam in the range from 1 to 8 GeV (per a deuteron and per 1 GeV primal energy of the deuteron).

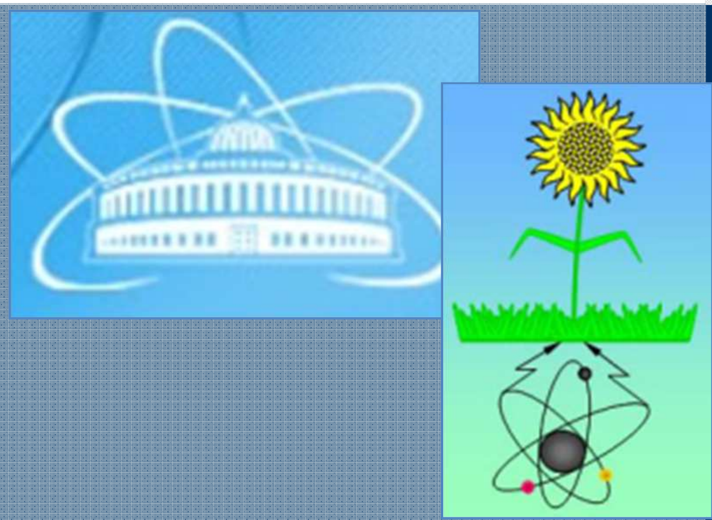
- The total number of accumulating ^{239}Pu nuclei in the whole volume of the uranium target, calculated per a deuteron and per 1 GeV energy of the deuteron, does not depend on the primal energy of the deuteron beam, but increases by more than 50% in the presence of a lead blanket.

Conclusions

Type of spatial distributions of the density of number of uranium fission and the number of accumulating ^{239}Pu per unit of power of the primary deuteron beam energy depend on the deuteron energy: the growth of primary energy deuterons decreases the number density of uranium fission and the number of ^{239}Pu nuclei accumulation in the near zone to the entrance of the deuteron beam at the target and at the same time, there is an increase in the density of uranium fission and ^{239}Pu accumulation to the periphery of the target.

For a given sizes of uranium targets of “QUINTA-M” assembly, for a deuteron energies exceeding 1 GeV, we can’t experimentally estimate (at least, by the activation technique) required size of the uranium target, satisfying it quasi-infinity and, therefore, it is impossible to estimate the total number of fissions and accumulated ^{239}Pu nuclei for quasi-infinite target. This requires the measurement of uranium targets of larger mass.

ХФТИ



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