On results of Y-89 Irradiation with deuteron beam on QUINTA -assembly \"E+T - RAW\" using Nuclotron (JINR Dubna)

M. Bielewicz [1], S. Kilim [1], A. Polanski [1], E. Strugalska-Gola [1], M. Szuta [1], A. Wojciechowski [1], I. Adam [2], M. Kadykov [2], V. Pronskikh [2],

S.Tyutyunnikov [2], V. Wagner [3], O.Svoboda [3], V.Chilap [4]

(for collaboration **„E+T - RAW"**)

1. *National Centre for Nuclear Research, Otwock-Świerk 05-400, Poland*
2. *Joint Institute for Nuclear Research, 141980 Dubna, Russia*
3. *Nuclear Physics Institute of CAS, 25068 Rez, Czech Republic*
4. *CPTP "Atomenergomash", Moscow, Russia*

Comparison of High Energy Neutron Spectrum in Quinta Assembly for Four Deuteron Beams of 1.0, 2.0, 4.0 and 6.00 GeV from JINR Nuclotron (Dubna).

Outline

1. Introduction
2. Spatial distribution of yttrium isotope production.
3. Average neutron flux densitie per deuteron for the deuterons beams.
4. Calculations Made for the Energy plus Transmutation Experimental Facility Using Monte Carlo Methodology
5. Conclusions

1. Introduction . Last KWINTA Experiments parameters

Accelerator:	**JINR LWE Nuclotron**				
Time:	**Mar 2011**	**Mar 2011**	**Mar 2011**	**Dec 2011**	**Dec 2011**
Beam:	**Deuteron**	**Deuteron**	**Deuteron**	**Deuteron**	**Deuteron**
Energy:	**2 GeV**	**4 GeV**	**6 GeV**	**1 GeV**	**2 GeV**
Irrad. Time:	**67829 s**	**82381 s**	**66952 s**	**76026 s**	**63060 s**
Collected beem particles:	**$1{,}54*10^{13}$**	**$1{,}50614*10^{13}$**	**$2.17*10^{13}$**	**$6{,}791*10^{13}$**	**$3{,}37*10^{13}$**
Target "KWINTA":	**Model U/U without shield**			**Model U/U + Pb shield**	

Activation Detectors: **Yttrium 89 – disc shape, h ≅1-2 mm, d = 10 mm**

Yttrium Activaction detectors

Sample Material: Y-89

Reaction	Threshold Energy	Half Live Time
(n,2n) MeV	11,5	106,65 d
(n,3n) MeV	20,8	79,8 h
(n,4n) MeV	32,7	14,74 h
(n,5n) MeV	42,1	2,68 h
(n,6n) MeV	54,4	39,5 m

Arrangement of the 89Y detectors on the detector plates in the Quinta Assembly. .

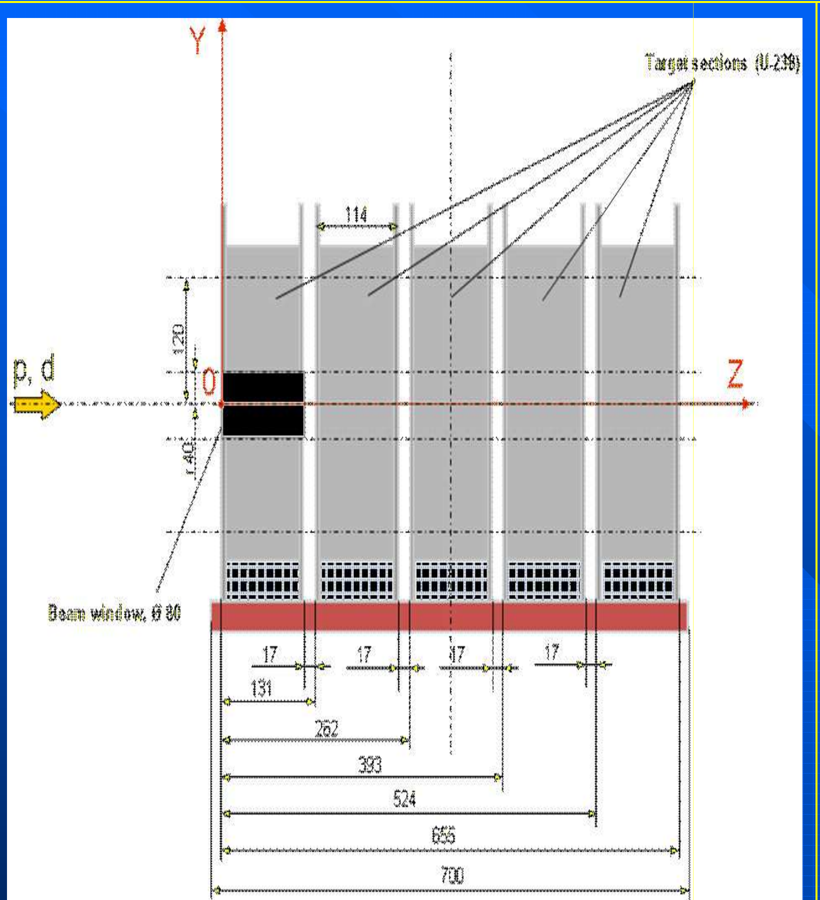


Fig. 1. Longitudinal view of the Quinta assembly

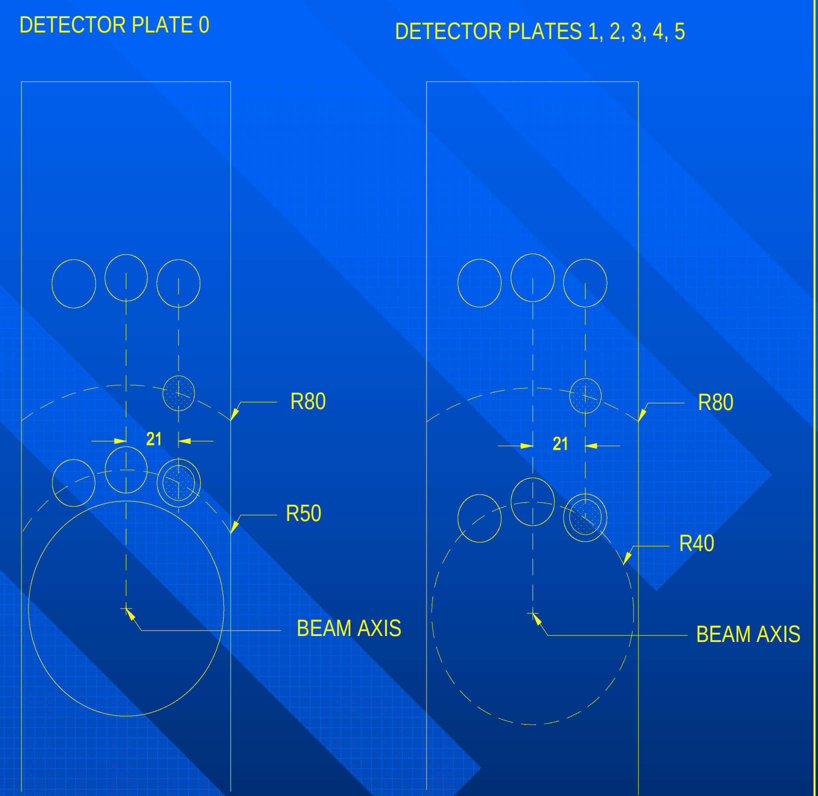


Fig. 1a Yttrium detectors location on the detector plates.

Our calibration formula

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

where:

- B number of nuclei per gram of a sample material and per one primary deuteron

- 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 function of energy and geometry

ΔS(G), ΔS(G) calibrations function for thickness and shape of detectors

- I total number of primary protons
- λ decay constant ($\lambda = \ln(2)/t_{1/2}$)
- $t_{1/2}$ half life time
- t_{ira} elapsed time of irradiation
- t_+ time between the end of irradiation and the beginning of measurement
- t_{real} time of the measurement
- m mass of the sample (target) in grams

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

2. Spatial distribution of yttrium isotope production

Table 1. Isotope production per one gram of 89Y detector and per deuteron of energy equal to 2 GeV – March 2011.

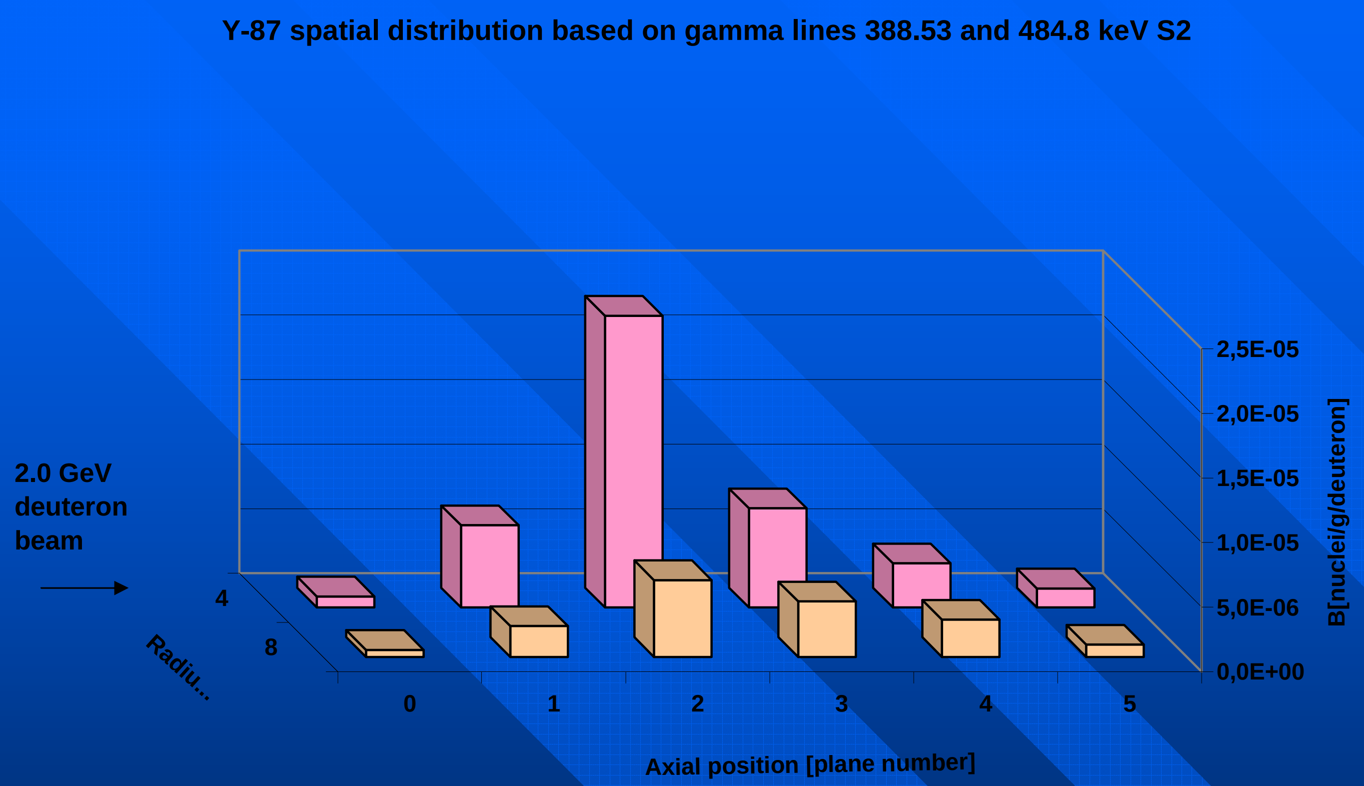
residual nuclei, $T_{1/2}$, Used γ–lines	Radius, cm	Axial position					
		0	1	2	3	4	5
$^{89}Y(n,2n)^{88}Y$-11.5 MeV $T_{1/2}$=106.65 d, Eγ=898.0keV(93.7%) and 1836.0 keV(99.4%)	4.0 8.0	2,04E-06 8,24E-07	1,46E-05 5,61E-06	3,99E-05 1,12E-05	1,46E-05 7,26E-06	5,83E-06 3,53E-06	2,13E-06 1,39E-06
$^{89}Y(n,3n)^{87}Y$-20.8 MeV $T_{1/2}$ =3.32 d Eγ=388.5keV(82.0%) and 484.8 keV(89.7%)	4.0 8.0	8,62E-07 5,34E-07	6,38E-06 2,39E-06	2,26E-05 5,94E-06	7,70E-06 4,31E-06	3,43E-06 2,87E-06	1,49E-06 9,43E-07
$^{89}Y(n,4n)^{86}Y$-32.7 MeV $T_{1/2}$ =0.614 d Eγ=1076.0 keV(82.0%)	4.0 8.0	2,19E-07 1,06E-07	1,42E-06 5,91E-07	7,82E-06 1,72E-06	2,66E-06 1,12E-06	1,13E-06 5,35E-07	4,79E-07 2,47E-07
$^{89}Y(n,5n)^{85}Y$-42.1 MeV $T_{1/2}$ = 2.86h Eγ= 231.67keV(84.0%)	4.0 8.0	6,83E-08 4,17E-08	3,64E-07 1,28E-07	2,69E-06 5,35E-07	8,53E-07 3,91E-07	3,86E-07 2,21E-07	1,59E-07 1,44E-07

2. Spatial distribution of yttrium isotope production– cont.

- Threshold reactions in ^{89}Y with the half-life of the reaction product and strongest emitted gamma-lines.
- Threshold energies, half-lives and gamma-lines information were taken from Evaluated Nuclear Structure Data File (ENSDF), http://www.nndc.bnl.gov/ensdf

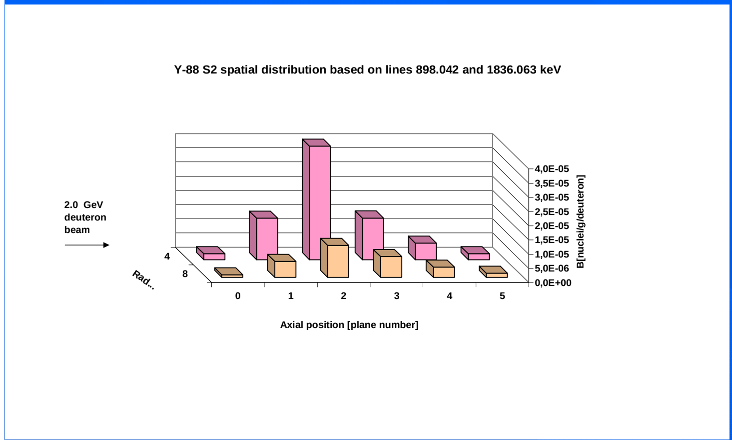
Reaction	Threshold energy [MeV]	Half-life	Used γ-line [keV]	Intensity of used γ-line [%]
$^{89}Y\,(n,\gamma)\,^{90m}Y$	0	3.19 h	202.5	97.3
			479.2	90.7
$^{89}Y\,(n,2n)\,^{88}Y$	11.6	106.65 d	898.0	93.7
			1836.1	99.2
$^{89}Y\,(n,3n)\,^{87}Y$	21.1	79.8 h	388.5	82
			484.8	89.7
$^{89}Y\,(n,3n)\,^{87m}Y$	21.6	13.37 h	380.8	78
$^{89}Y\,(n,4n)\,^{86}Y$	33.0	14.74 h	627.7	32.6
			703.3	15.4
			777.4	22.4
			1076.6	82
			1153.0	30.5
			1854.4	17.2
			1920.7	20.8
$^{89}Y\,(n,4n)\,^{86m}Y$	33.2	48 m	208.1	94
$^{89}Y\,(n,5n)\,^{85}Y$	42.6	2.68 h	231.7	84
			504.5	60
			913.9	9

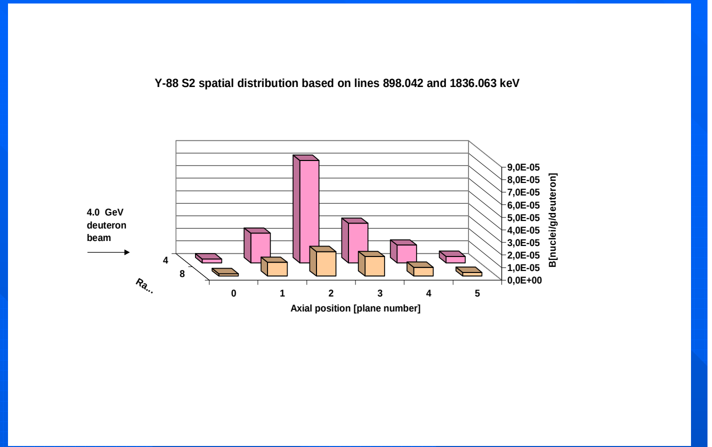
2. 2 GeV deuteron beam Experimental data

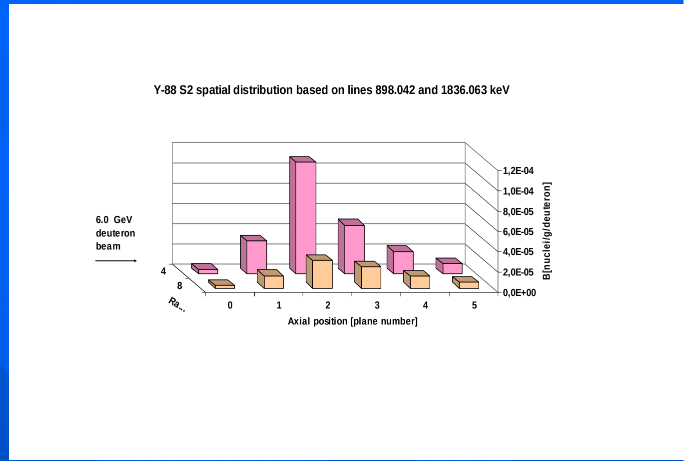


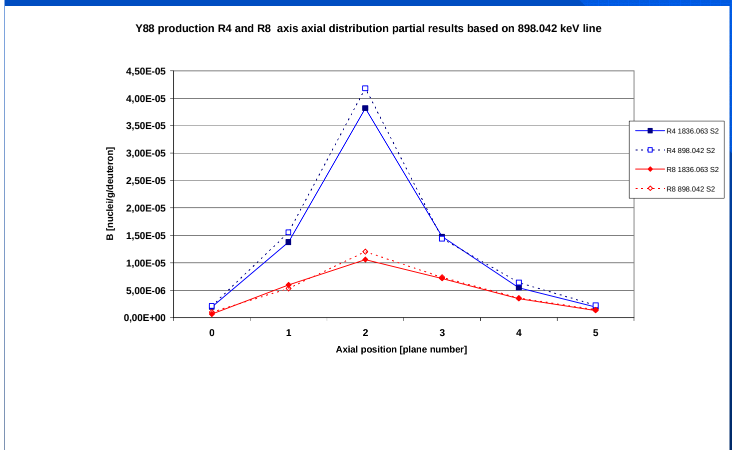
Spatial distribution (radial & axial) of Y87 production. The deuteron beam 2 GeV. The general feature of the experimental spatial distribution of 88Y, 87Y, 86Y and 85Y isotopes production is that the maximum yield is at about 13.1 cm from the front of the U238 spallation target and that the yield is decreasing with increasing radial distance from the target axis.

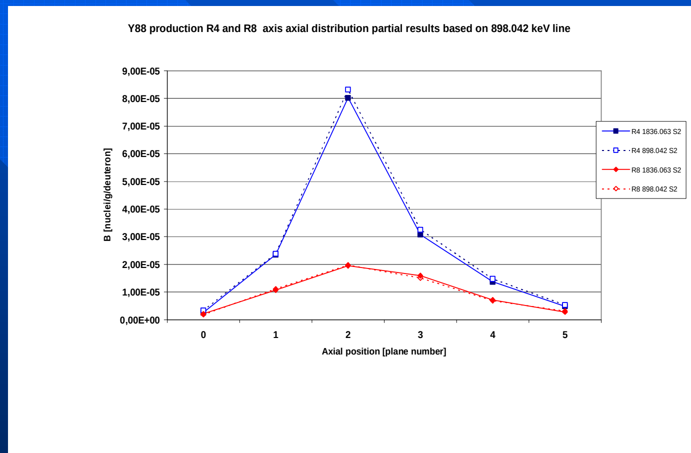
Y-88 production spatial distribution comparison. Experiment III.2011

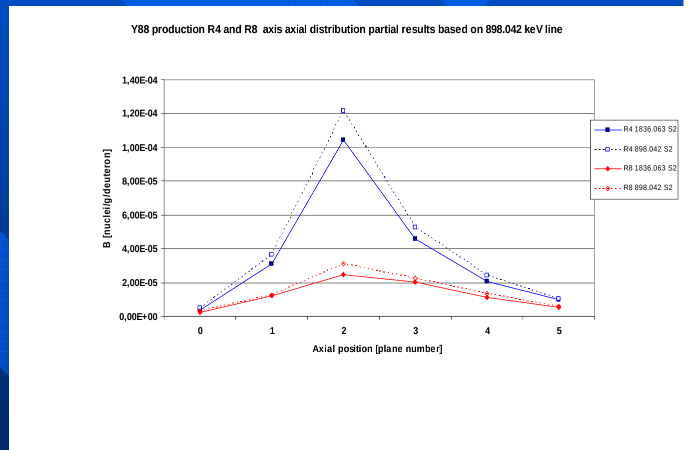








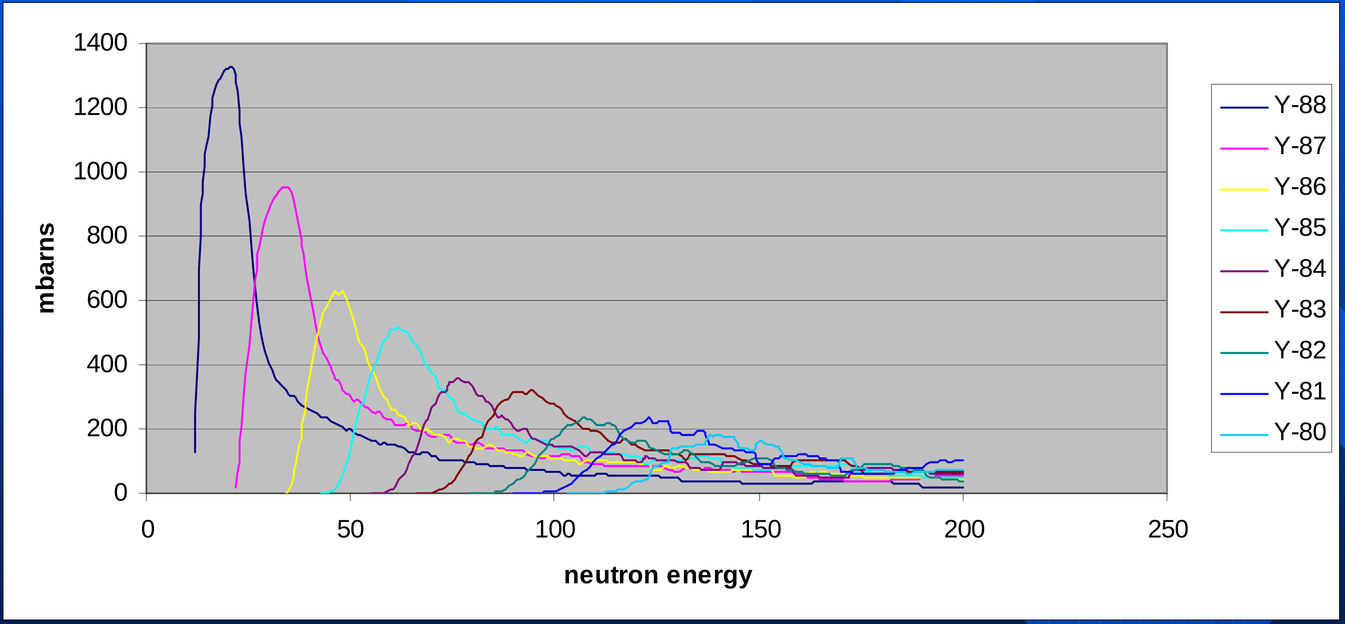




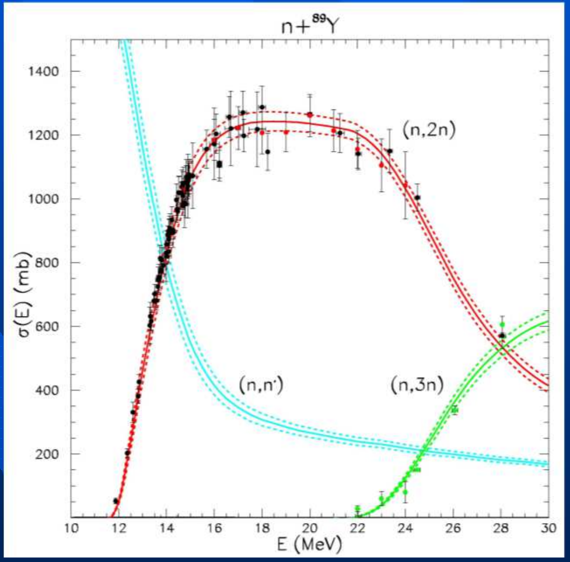
For Energy 2 GeV | For Energy 4 GeV | For Energy 6 GeV

3. Average neutron flux densities per deuteron for the four deuteron beams.

To evaluate the high energy neutron field we need to know the microscope cross section for the (n,xn) reaction of ^{89}Y. The available experimental data of microscopic cross section for the reaction ^{89}Y(n, 2n)^{88}Y and the small part for reaction ^{89}Y(n, 3n)^{87}Y are going from EXFOR data base. Since the nuclear data libraries are poor we have used TALYS code for calculation of (n,xn) reactions cross sections.



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

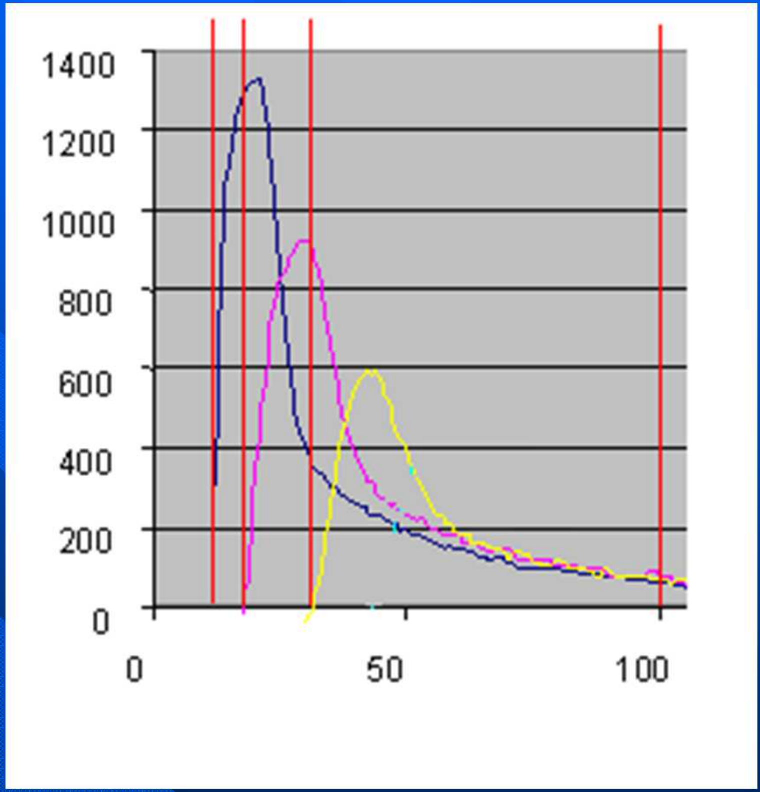


Experimental data from EXFOR data base

3. Average neutron flux densities per deuteron for the three deuteron beams

- In order to find explanation for the aberration of the neutron flux shape for the spatial distribution of the isotopes refering to the deuteron beam of energy equal to 2.52 GeV we have decided to compare the average neutron flux densities per deuteron for the three deuteron beams of energies equal to 1.6 GeV, 2.52 GeV and 4.0 GeV.

- It is expected that for the deuteron beam energies higher than 1GeV the average neutron flux densities per deuteron should be equal.
- Fig. On the right presents cross-sections of the three yttrium n.xn reactions – threshold energies: E1 = 11,5 MeV Y88 E2 = 20,8 MeV Y87 E3 = 32,7 MeV Y86



3. Average neutron flux densities per deuteron for the four deuteron beams.

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

$$\overline{\phi_1} = \frac{C}{\overline{\sigma_{11}}}\left[B^{88} - B^{87}\frac{\overline{\sigma_{12}}}{\overline{\sigma_{22}}} + B^{86}\left(\frac{\overline{\sigma_{23}}}{\overline{\sigma_{33}}}\frac{\overline{\sigma_{12}}}{\overline{\sigma_{22}}} - \frac{\overline{\sigma_{13}}}{\overline{\sigma_{33}}}\right)\right]$$

$$\overline{\phi_2} = \frac{C}{\overline{\sigma_{22}}}\left[B^{87} - B^{86}\frac{\overline{\sigma_{23}}}{\overline{\sigma_{33}}}\right]$$

$$\overline{\phi_3} = \frac{C}{\overline{\sigma_{33}}}B^{86}$$

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

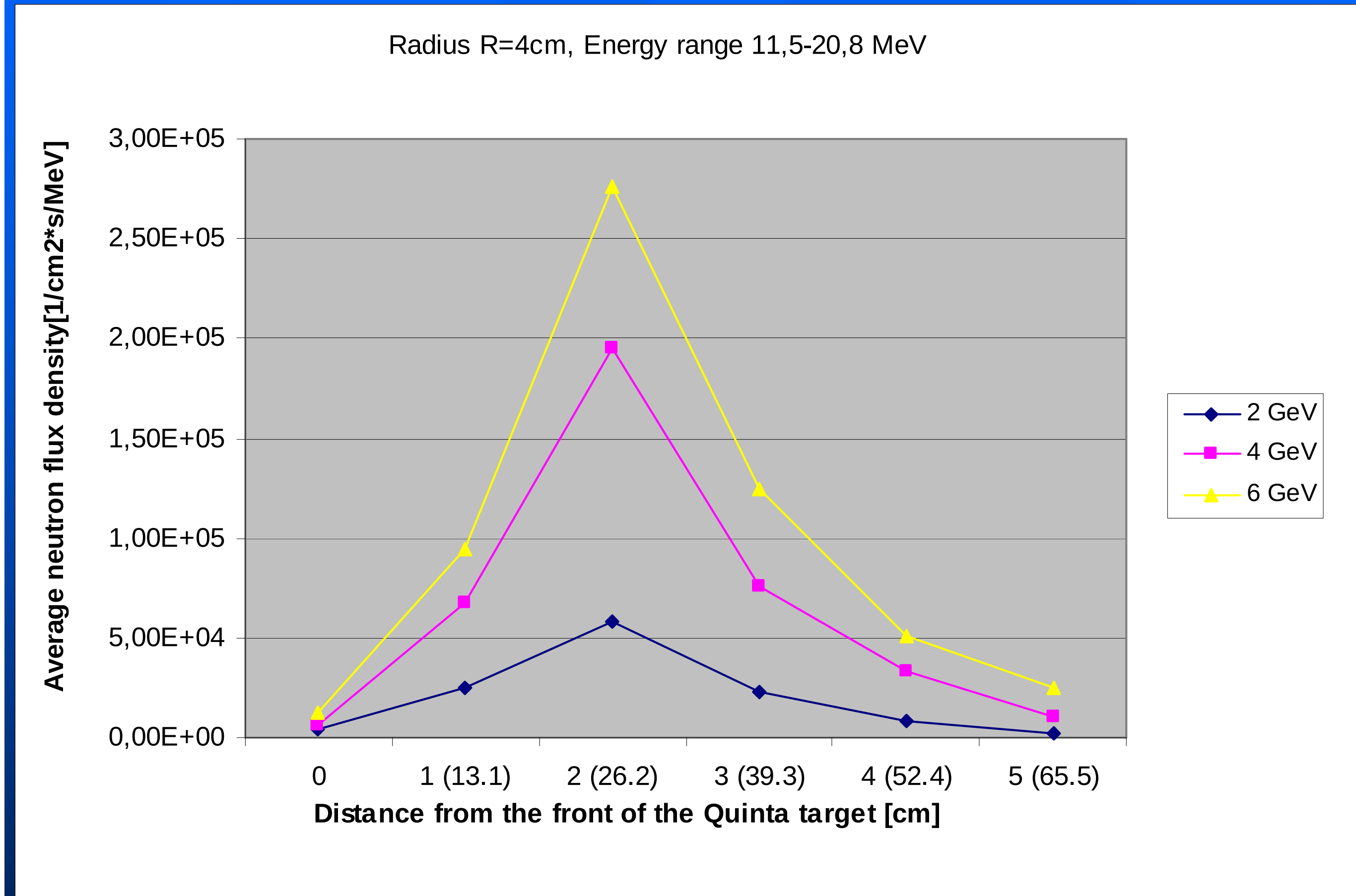
3. Average neutron flux densities per deuteron for the four deuteron beams.

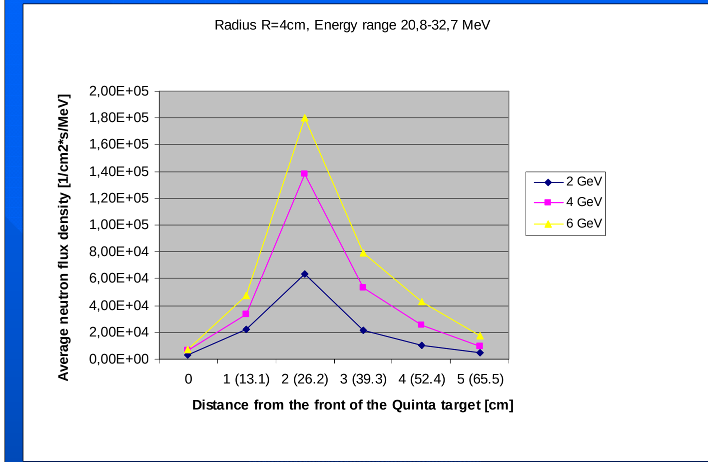
Table 3. Evaluated neutron flux density distribution per deuteron in the Quinta assembly for three energy ranges for the deuteron beam of 4.0 GeV.

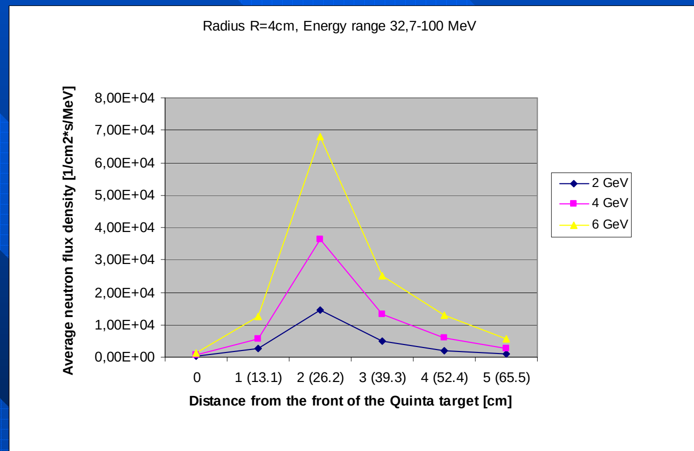
(4.0 GeV) Energy range [MeV]	**Radius, cm**	**Average neutron flux density per deuteron for 4.0 GeV [netron/cm2/MeV/deuteron]** Axial position [cm]					
		0	**1**	**2**	**3**	**4**	**5**
Neutron flux 1 11,5-20,8 MeV (delta 9,3)	4.0 8.0	2,35E-05 1,43E-05	2,37E-04 8,92E-05	6,83E-04 1,28E-04	2,67E-04 1,02E-04	1,15E-04 3,58E-05	3,76E-05 1,25E-05
Neutron flux 2 20,8-32,7 MeV (delta 11,9)	4.0 8.0	2,35E-05 1,42E-05	1,17E-04 7,48E-05	4,85E-04 1,62E-04	1,86E-04 1,25E-04	8,90E-05 6,67E-05	3,31E-05 3,05E-05
Neutron flux 3 32,7-100 MeV (delta 27,3)	4.0 8.0	2,51E-06 2,02E-06	1,99E-05 1,04E-05	1,28E-04 2,53E-05	4,68E-05 2,23E-05	2,07E-05 1,06E-05	9,48E-06 5,06E-06

3. Average neutron flux densities per deuteron for the three deuteron beams.

Fig. 9. Comparison of neutron flux density per 1MeV in Quinta assembly for three deuteron beams and for radius 4 cm – experiment in March 2011



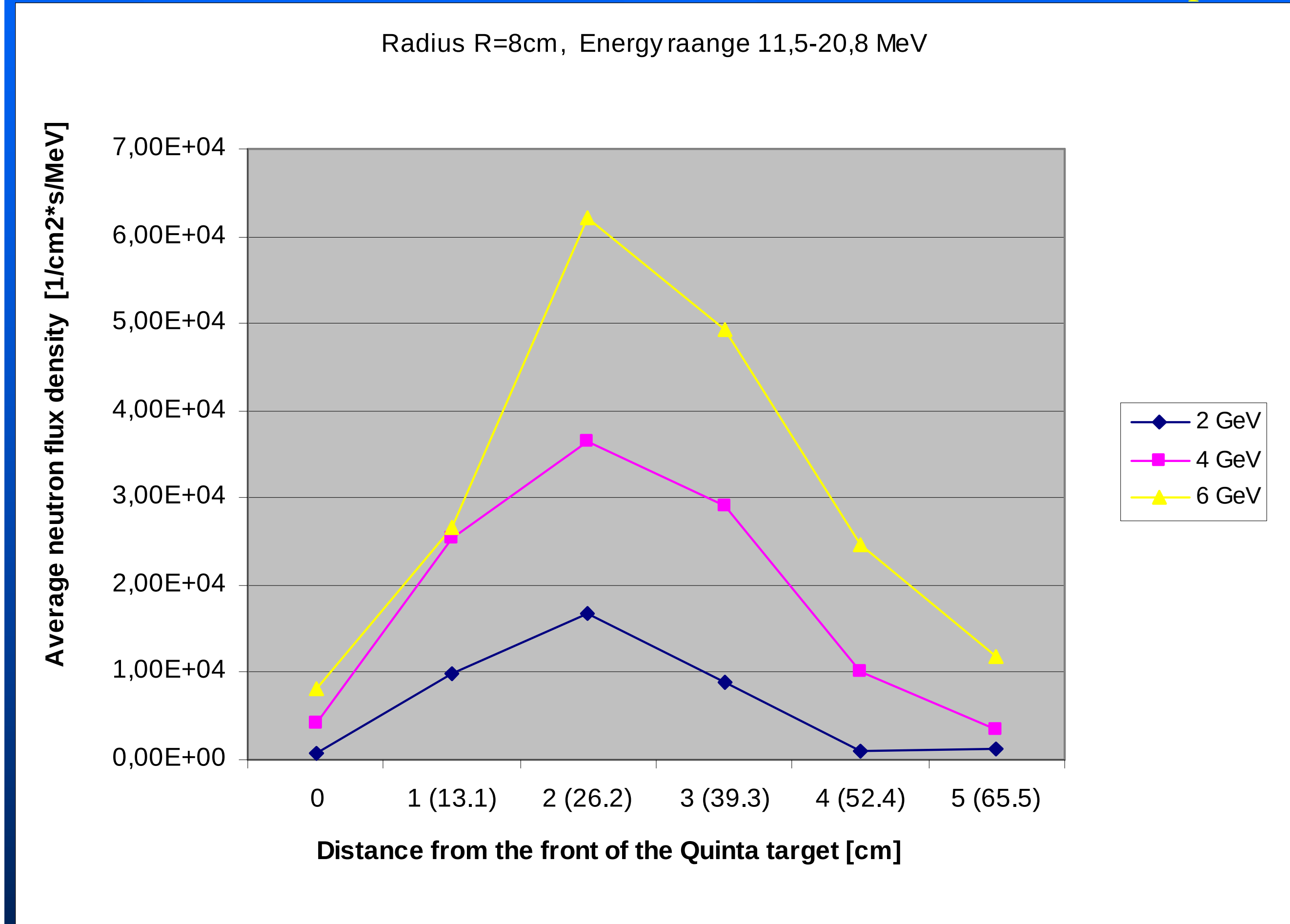


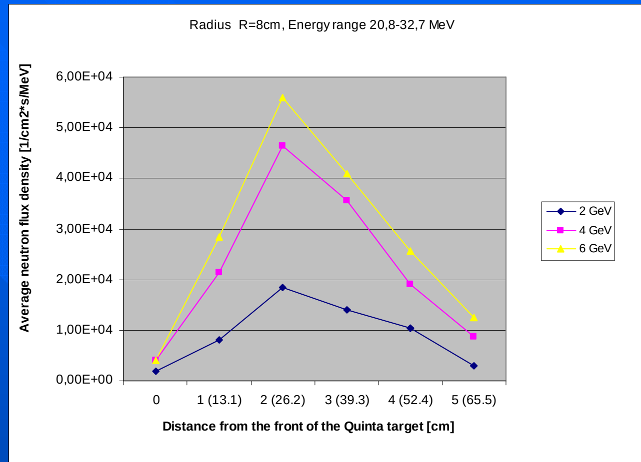


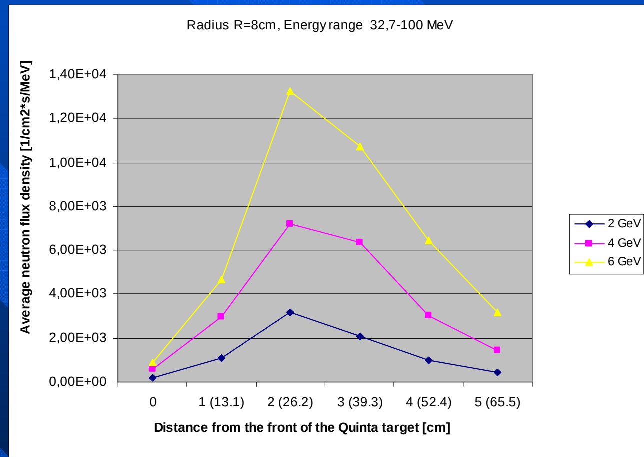
The general feature of the experimental neutron flux density per 1MeV in the Quinta assembly is that the maximum occurs at about 13.1 cm from the front of the U238 spallation target and that it is decreasing with increasing radial distance from the target axis.

3. Average neutron flux densities per deuteron for the three deuteron beams.

Fig. 10. Comparison of neutron flux density per 1MeV in Quinta assembly for three deuteron beams and for radius 8 cm – experiment in March 2011



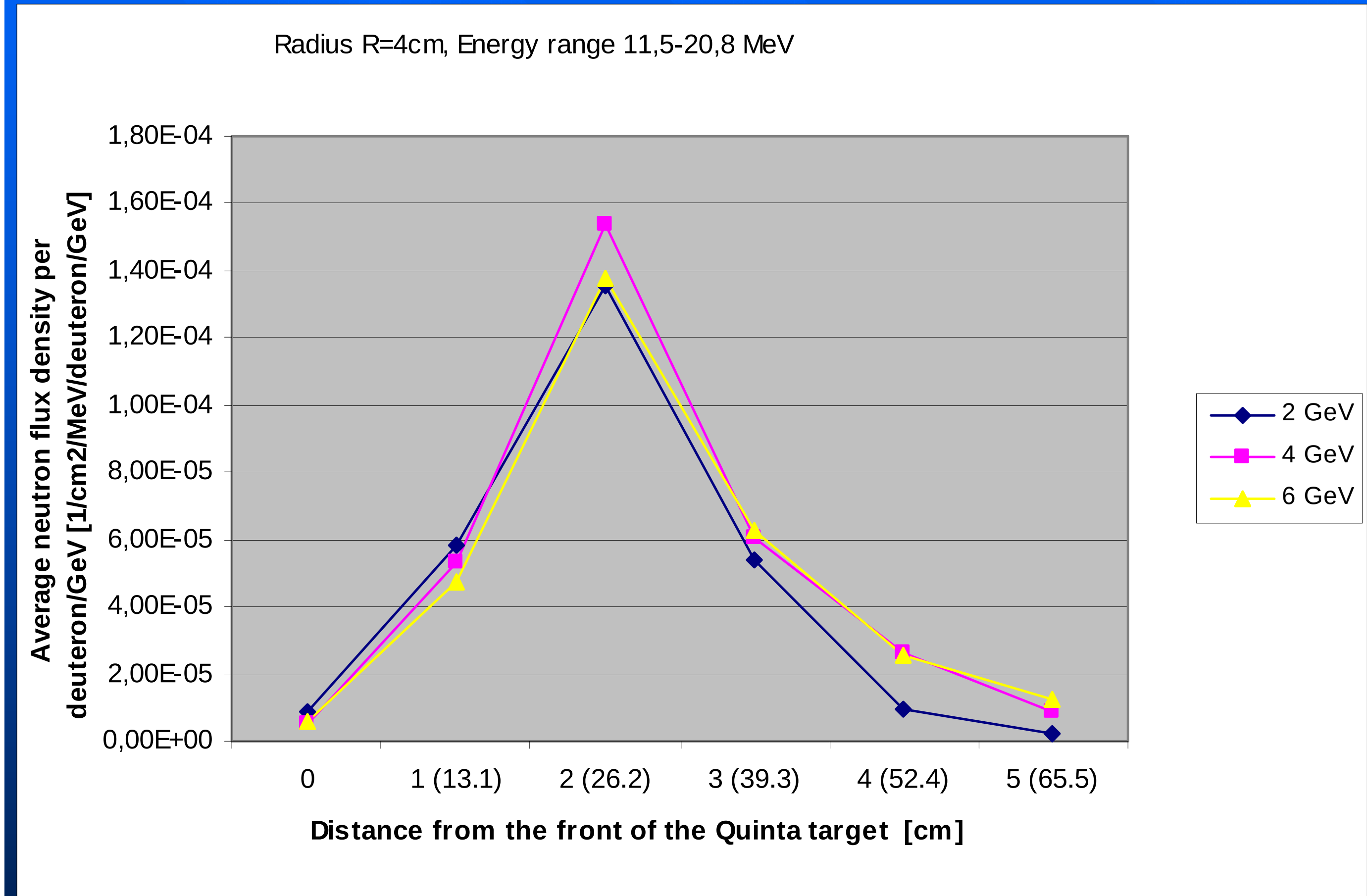


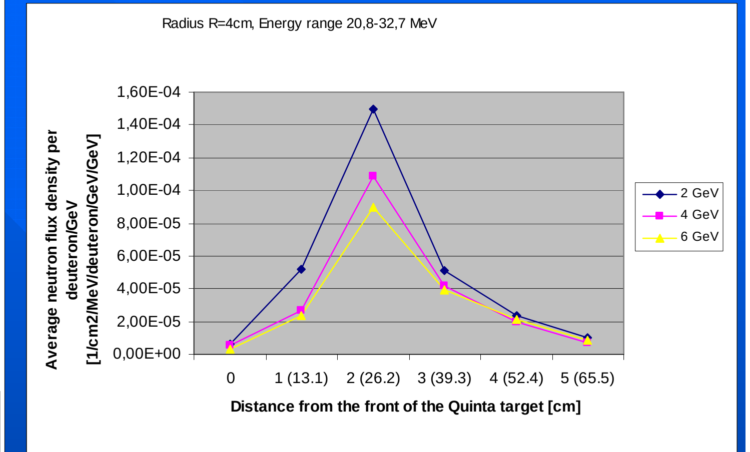


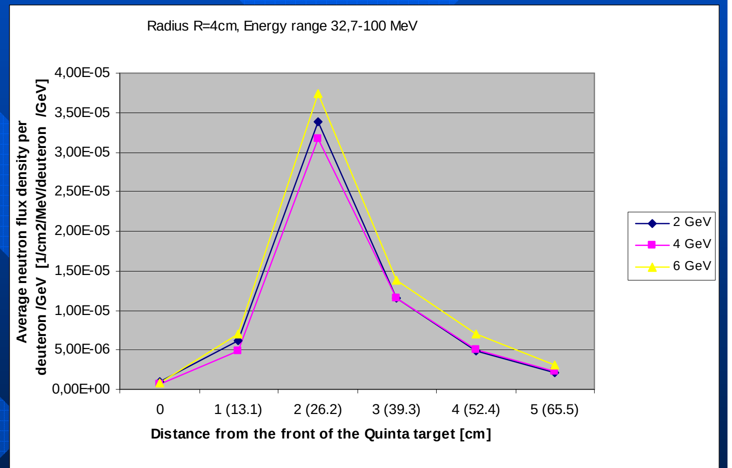
Shape of neutron flux density per 1MeV in the Quinta assembly produced by the neutrons generated in the assembly irradiated by the relativistic deuteron beam of 2 GeV, 4 GeV and 6 GeV energies in general is the same.

3. Average neutron flux densities per deuteron for the three deuteron beams.

Comparison of neutron flux density per 1MeV per 1deuteron and per deuteron energy in Quinta assembly for three deuteron beams and for radius 4 cm – experiment in March 2011



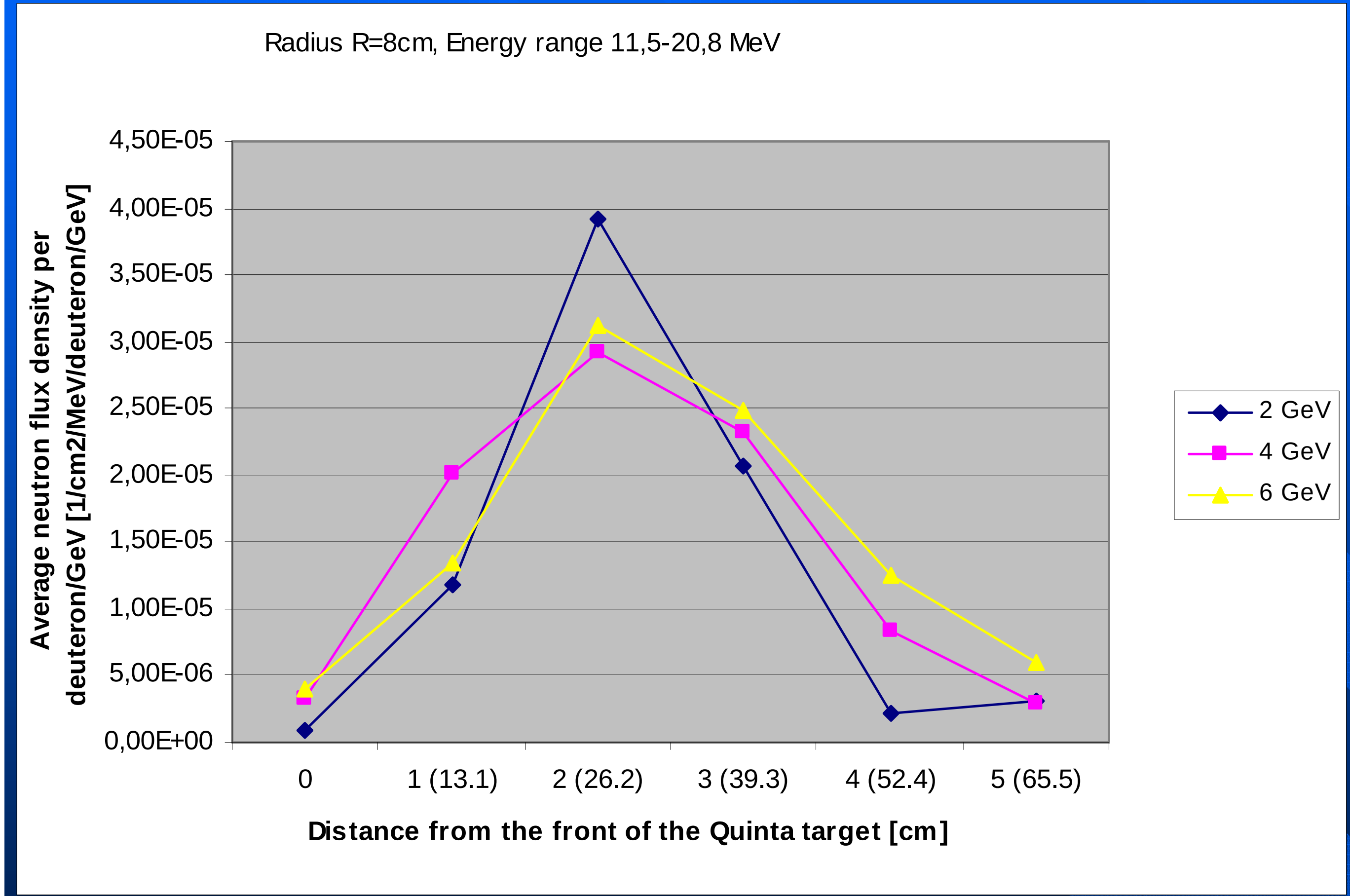


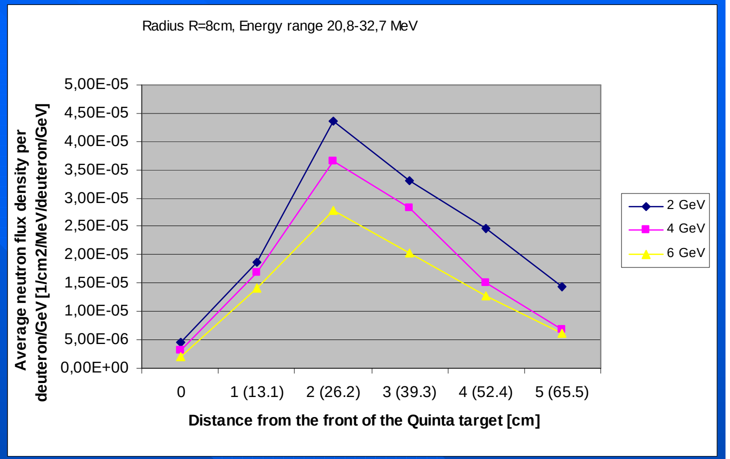


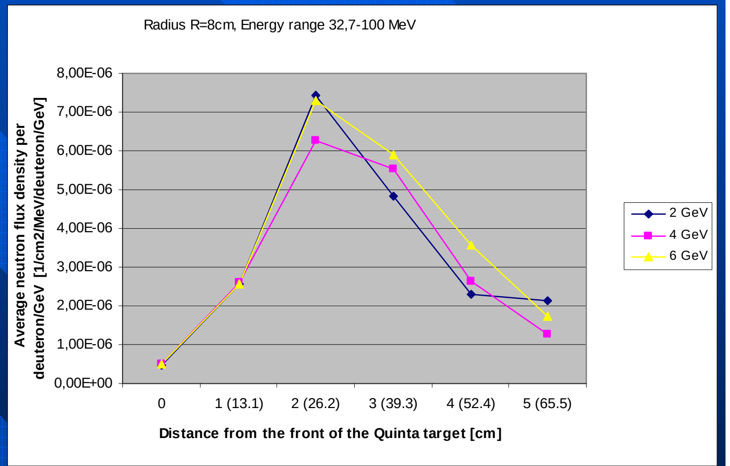
The curves of the neutron flux density per deuteron and its energy overlap in the energy ranges 11.5-20.8 MeV and 32.7-100 MeV, nearly overlap in the energy range 20.8-32.7 MeV for radius 4 cm

3. Average neutron flux densities per deuteron for the three deuteron beams.

Comparison of neutron flux density per deuteron and its energy in Quinta assembly for three deuteron beams and for radius 8 cm – experiment in March 2011



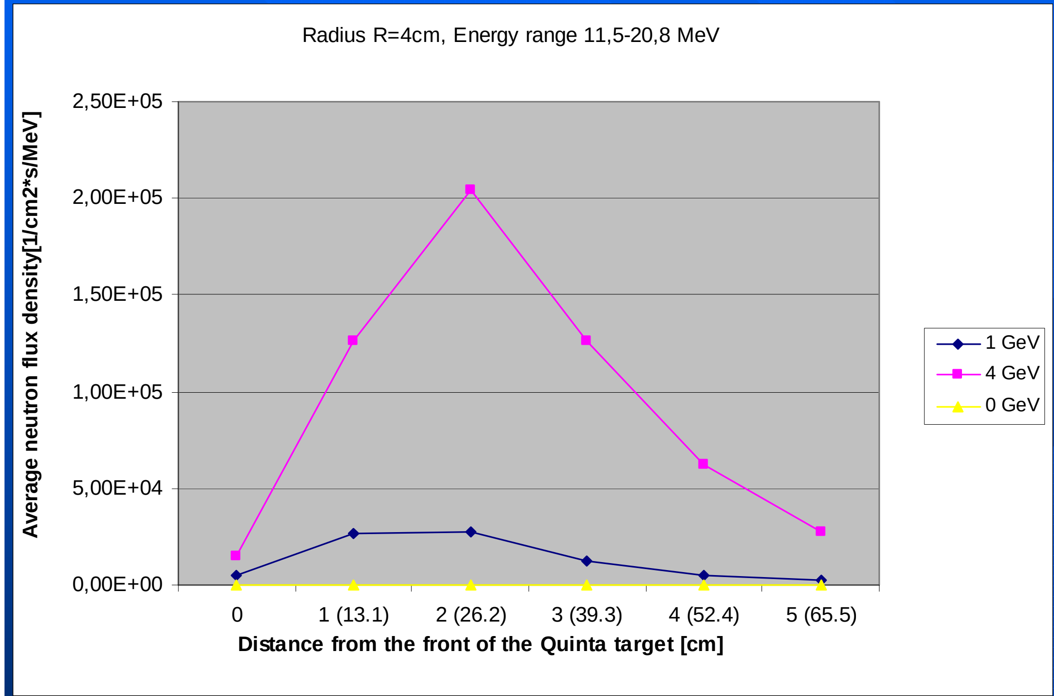


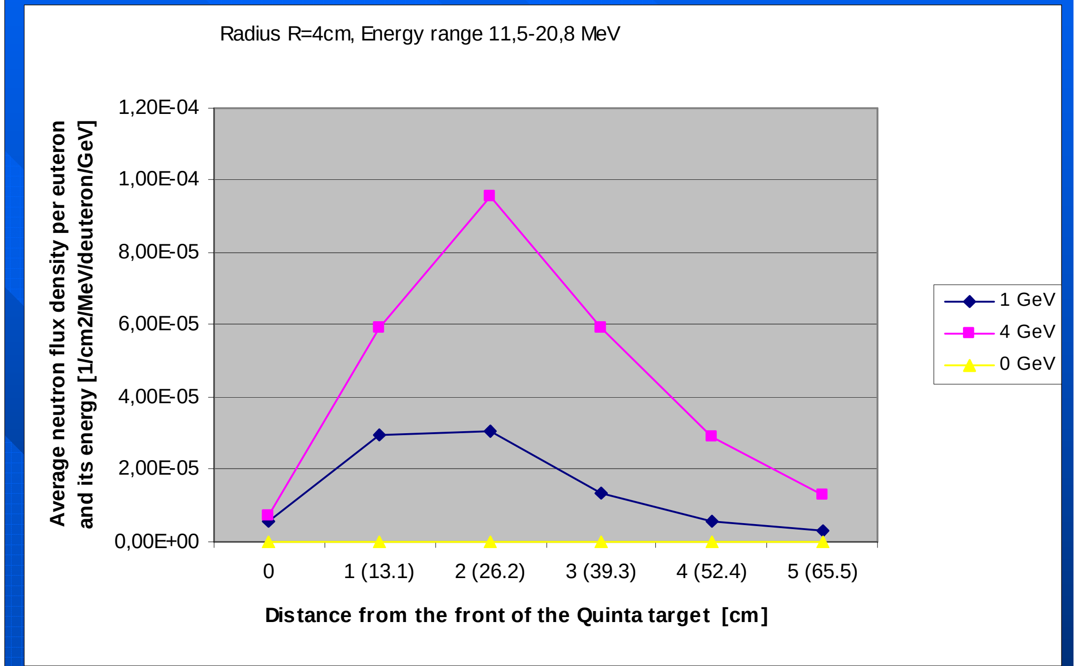


The curves of the neutron flux density per deuteron and its energy nearly overlap in all the three the energy rangies 11.5-20.8 MeV, 20.8-32.7 MeV, 32.7-100 MeV for radius 8 cm..

3. Average neutron flux densities per deuteron for the four deuteron beams.

Comparison of neutron flux density per deuteron and its energy in Quinta assembly for deuteron beams 1 GeV and for radius 4 cm – experiment in December 2011

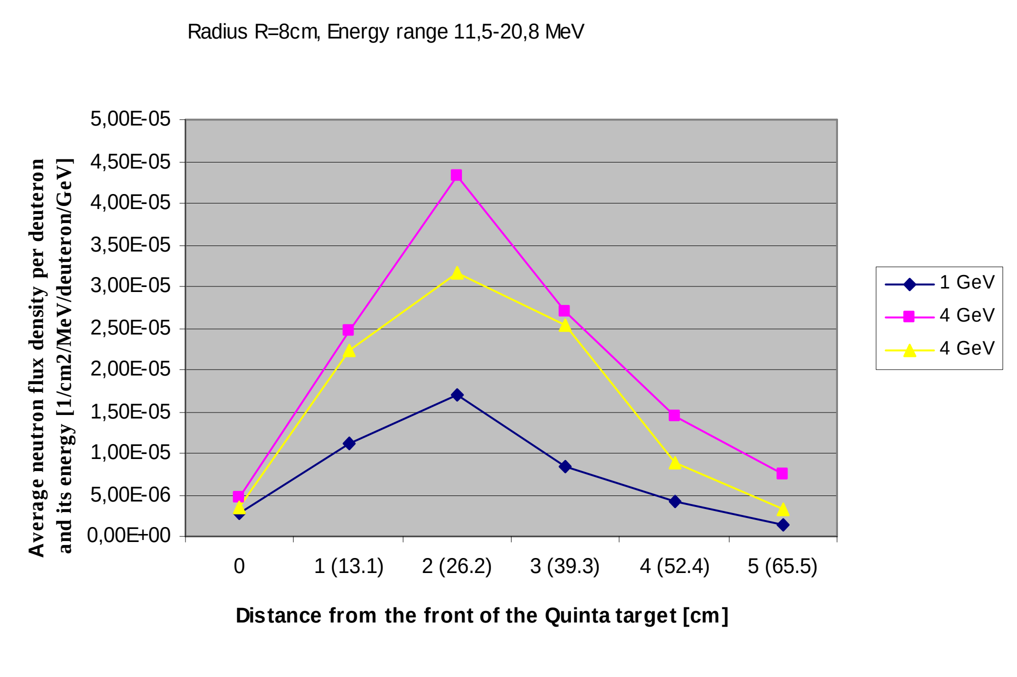


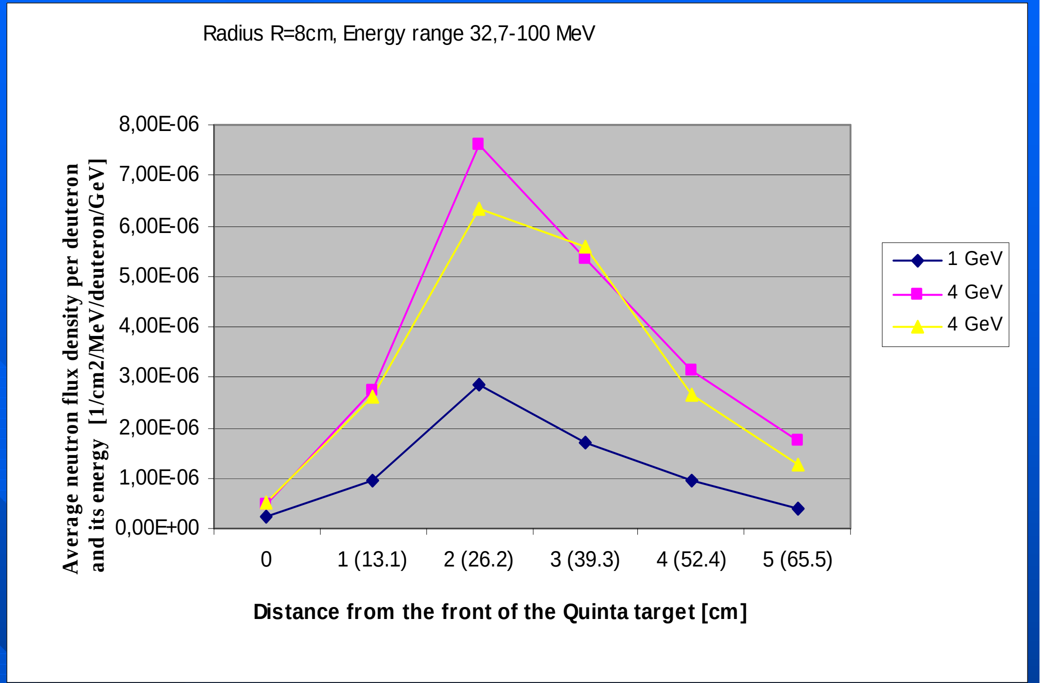


Here, this overlapping is not observed for the deuteron energies (1 and 4 GeV) for 4 cm and 8 cm in the experiment of December 2011 in all the neutron energies 11.5-20.8 MeV, 20.8-32.7 MeV, 32.7-100 MeV

3. Average neutron flux densities per deuteron for the four deuteron beams.

Average neutron flux density per deuteron and per unit energy of deuteron at radius 8 cm for the two deuteron beams of energies equal to 1 and 4 GeV (experiment in December 2011 – lead shielded Quinta assembly) compared with the deuteron beam of energy equal to 4 GeV (March 2011).





- Yellow curve refers to the experiment in March 2011 for the deuteron energy 4 GeV and red curve refers to the experiment in December 2011 (lead shielded Quinta assembly) also for the deuteron energy 4 GeV. Lead shield causes increase of neutron flux. Certain overlapping of the curve occurs for the harder neutrons.

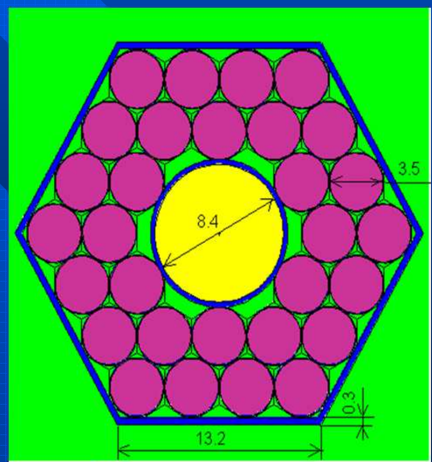
- However at the radius 8cm, there is not observed overlapping of the curves for the deuteron energies 4 GeV in March and December experiments. Influence of the lead shield on the neutron flux density increase is more pronounced in all the neutron energies 11.5-20.8 MeV, 20.8-32.7 MeV, 32.7-100 MeV.

4. Calculations Made for the Energy plus Transmutation Experimental Facility Using Monte Carlo Methodology

- Defining each material with its density and composition we obtained the experimental Energy plus Transmutation facility simulation.
- We used for calculation the MCNPX 2.5. code. Number of (n,2n) reaction in detector 89Y was calculated using definition

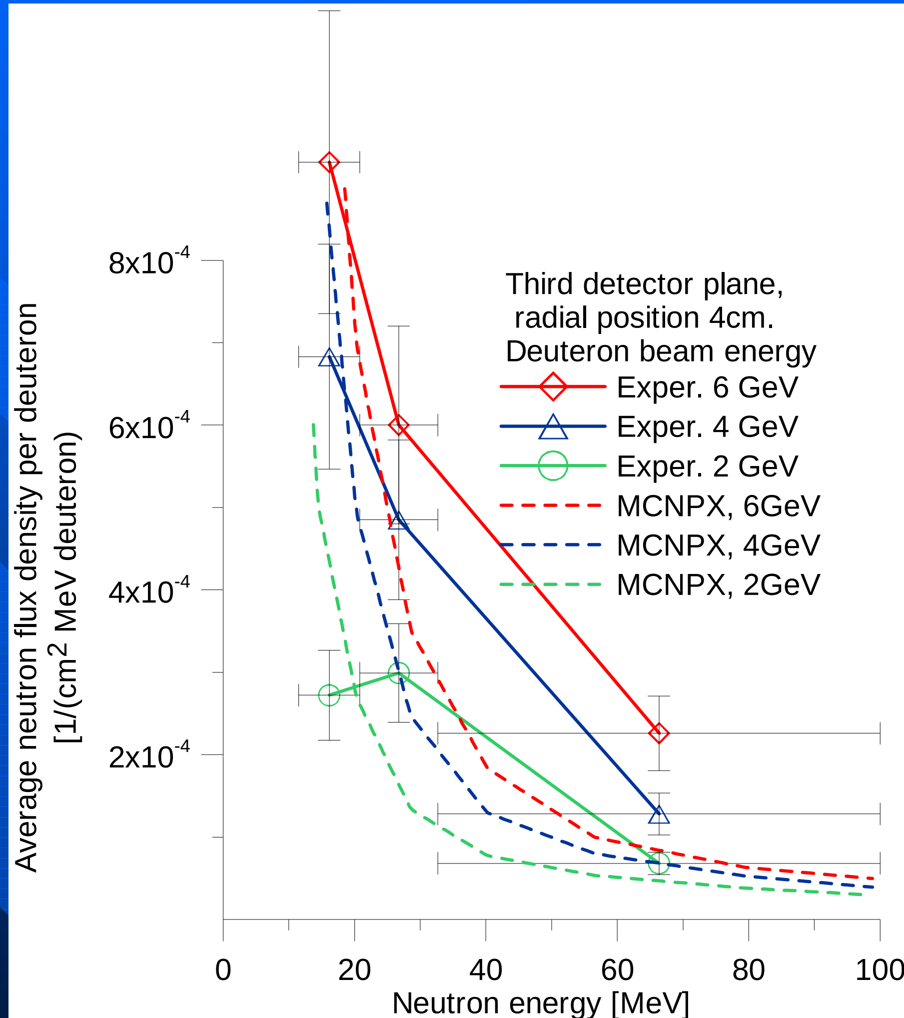
$$n = \int_{E\,\mathrm{min}}^{E\,\mathrm{max}} \phi(E)\sigma(E)\rho dE$$

Emin, Emax - means threshold energy
$\phi(E)$ was calculated using MCNPX code in detector
$\sigma(E)$ cross section for (n,2n) reaction. It was obtained from EXFOR data from range (1 - 100MeV) and interpolated.
ρ -density of 89Y.



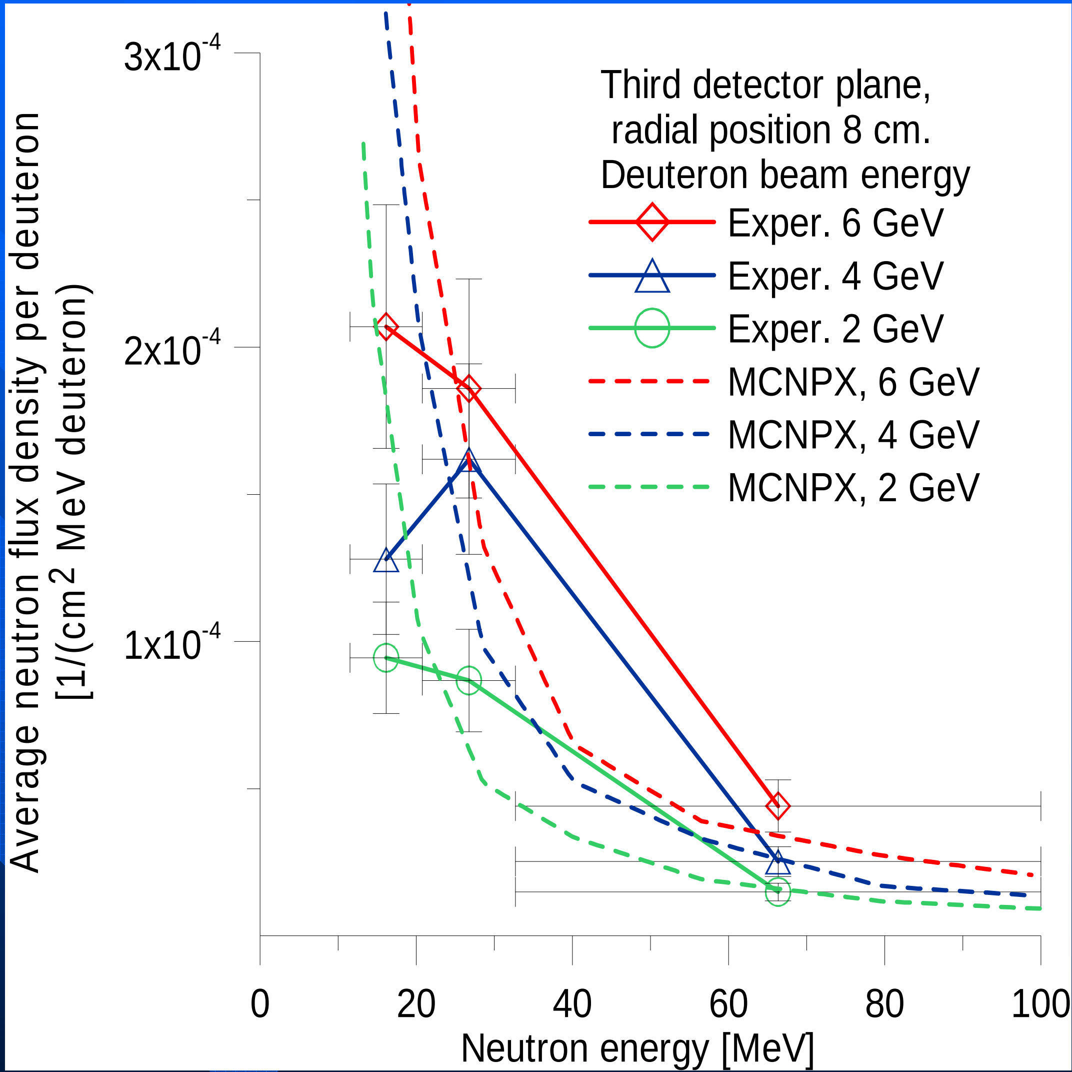
3. Average neutron flux densities per deuteron for the three deuteron beams.

- Average neutron flux density per deuteron in the third detector plane (where maximum occurs) and radius 4 cm for deuteron beam energy 2.0, 4.0 and 6.0 GeV compared with the Monte Carlo simulation using MCNPX 2.6 code. (March 2011)



3. Average neutron flux densities per deuteron for the three deuteron beams.

- Average neutron flux density per deuteron in the third detector plane (where maximum occurs) and radius 8 cm for deuteron beam energy 2.0, 4.0 and 6.0 GeV compared with the Monte Carlo simulation using MCNPX 2.6 code. (March 2011)



4. Conclusions

- The general feature of the experimental spatial distribution of 88Y, 87Y, 86Y and 85Y isotopes production is that the maximum yield is at about 13.1 cm from the front of the U238 spallation target and that the yield is decreasing with increasing radial distance from the target axis.
- Y87 isomer complicates the evaluation of high neutron spectrum in Quinta assembly.
- Shape of neutron flux density per deuteron in the Quinta assembly produced by the neutrons generated in the assembly irradiated by the relativistic deuteron beam of 2 GeV, 4 GeV and 6 GeV energies in general is the same.
- Monte Carlo simulation using MCNPX 2.6 code of the neutron flux density in the Quinta assembly is roughly in agreement with the obtained experimental data.

4. Conclusions

- While the lead shield of the Quinta assembly causes decrease of neutron flux for the area close (4 cm) to the spallation target (especially in the position where maximum of flux occurs), inversely away from (8 cm) the spallation target it causes increase of the flux comparatively.
- At higher distances from the spallation target axis (8 cm), influence of the lead shield on the neutron flux density increase is more pronounced in all the neutron energies 11.5-20.8 MeV, 20.8-32.7 MeV, 32.7-100 MeV.
- Presented here results and inferences are not final ones and show just the tendencies and our suggestions have to be proved.

Thank you for the cooperation