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Lead shielding impact on fast neutron spectrum (>10MeV) in QUINTA uranium target.

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Lead shielding impact on fast neutron spectrum (>10MeV) in QUINTA uranium target.

Outline

1. Introduction

- **2. Irradiation details**
- **3. Experimental results**
- **4. Discussion**

1. Introduction

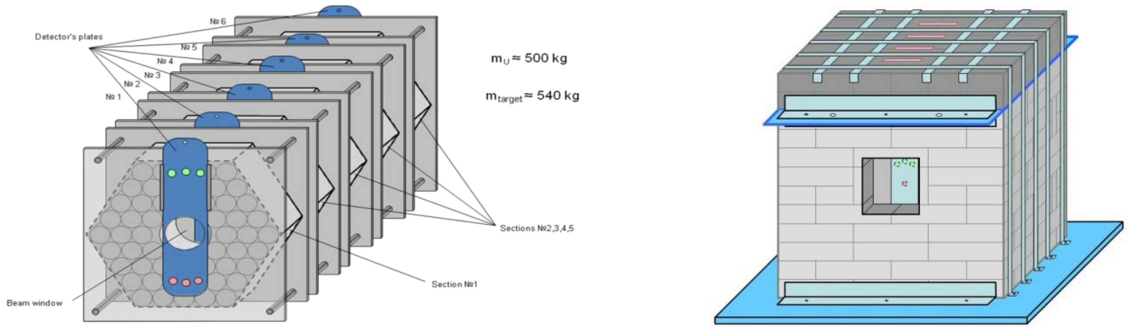


Figure 1. Schema of Quinta assembly. On the left there is a view on the uranium target and on the right there is a view on the lead shielding enfolding the target.

The Quinta target was irradiated with a pulsed deuteron beam of energy 4 GeV in March 2011 and also of energy 4 GeV in December. In case of the experiment session in March 2011 the Quinta uranium target was not shielded with lead as presented in Fig. 1 on the left side, while in the case of experiment session in December 2011 the Quinta uranium target was shielded with lead as in Fig. 1 on the right side.

Comparison of this two experimental data referring to the neutron flux measurement is a base for the analysis of lead shielding influence on fast neutron spectrum in the QUINTA assembly.

2. Irradiation details

- Fig. 2a. Distribution of deuteron pulses during the irradiation period as measured with an ionization chamber – without lead shielding (March 2011)
- - Irradiation duration - 18,5 h
- - Deuterons on target - 1.41(7)x10^{13}

- Fig. 2b. Distribution of deuteron pulses during the irradiation period as measured with an ionization chamber – with lead shielding (December 2011)
- - Irradiation duration - 17.5 h
- - Deuterons on target - 1.94(5) 10^{13}

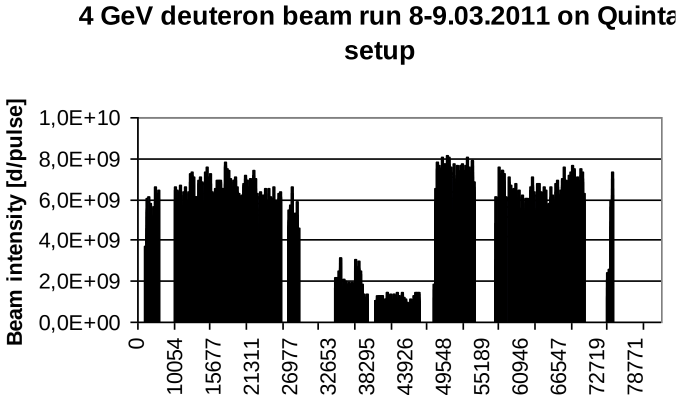


Fig. 2a.

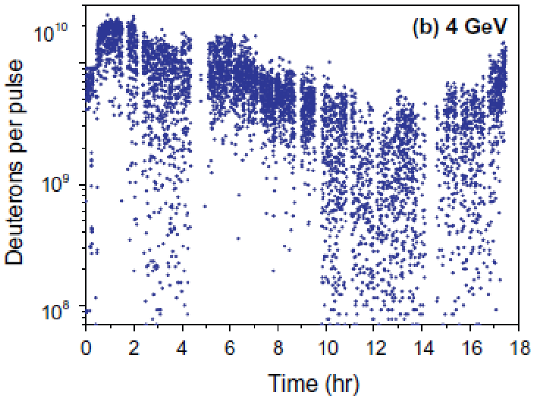


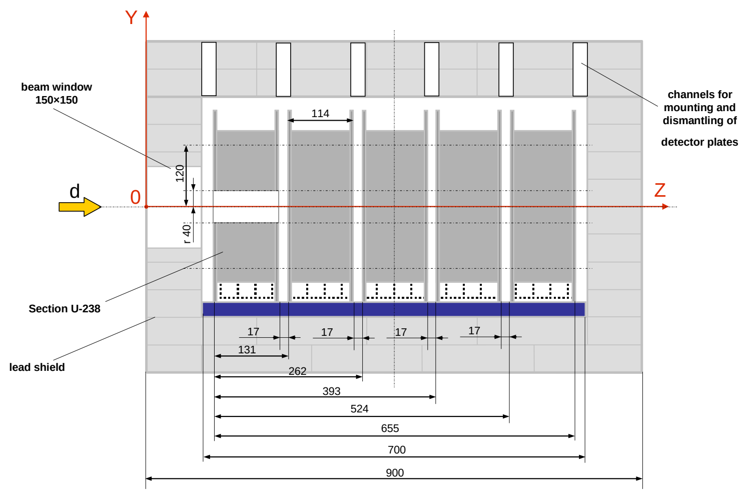
Fig. 2b.

2. Irradiation details- cont.

- **Table 1. Details of the three Quinta irradiations performed at the Nuclotron accelerator. Xc and Yc refer to the coordinates of the beam centre on the x–y plane**
- Incident ion Deuteron
- Experimental session in March 2011 in December 2011 + Lead shield

Ion energy	4 GeV	4GeV
Irradiation duration	18,5 h	17.5 h
Deuterons on target	1.41(7)x10^{13}	1.94(5) 10^{13}
X_c (cm)	1.2 ± 0.2	1.4 ± 0.2
Y_c (cm)	-0.7 ± 0.2	0.2 ± 0.2
$FWHM_x$ (cm)	2.2 ± 0.3	1.5 ± 0.3
$FWHM_y$ (cm)	2.3 ± 0.3	1.4 ± 0.3

2. Irradiation details- cont.



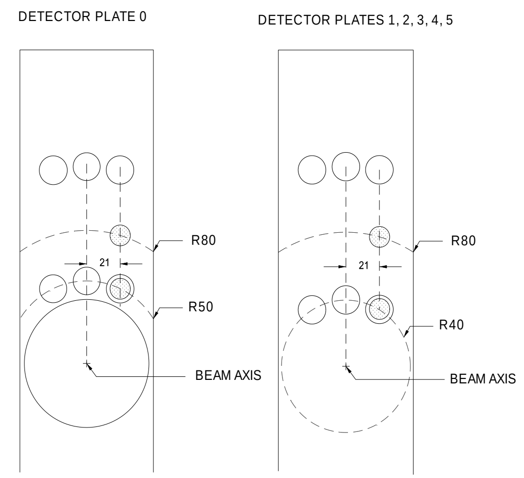


Figure 3. Dimensions of Quinta assembly and location of yttrium foils. On the left there is a longitudinal view of the assembly, on the right there are yttrium foils locations on the detector plates.

Two types of samples were used: solid yttrium foil with dimensions 25 × 25 × 0.64 mm3, with weight ~ 1.8 g and pills made of compressed yttrium powder with dimensions diameter 9 × 1.5 mm^3, with weight ~ 0.6 − 0.8 g.

3. Experimental results

Table 2a. Isotope production per one gram of ^{89}Y detector and per deuteron of energy equal to 4 GeV of the March session (without lead shielding).

Residual nuclei $T_{1/2}$, γ – lines used	**Radius cm**	**Radial distance from front of U target , cm**					
		0	**1(13.1)**	**2(26.2)**	**3(39.3)**	**4(52.4)**	**5(65.5)**
$^{89}Y(n,2n)^{88}Y$-11.5 MeV $T_{1/2}$=106.65 d, Eγ=898.0, 1836.0 keV	4.0	3,08E-06	2,37E-05	8,16E-05	3,15E-05	1,41E-05	5,04E-06
	8.0	1,90E-06	1,09E-05	1,96E-05	1,55E-05	6,98E-06	2,96E-06
$^{89}Y(n,3n)^{87}Y$-20.8 MeV $T_{1/2}$=3.32 d Eγ=388.5, 484.8 Kev	4.0	1,40E-06	7,98E-06	3,90E-05	1,47E-05	6,79E-06	2,76E-06
	8.0	9,17E-07	4,79E-06	1,08E-05	8,66E-06	4,44E-06	2,06E-06
$^{89}Y(n,4n)^{86}Y$-32.7 MeV $T_{1/2}$=0.614 d Eγ=1076.0 keV	4.0	2,88E-07	2,29E-06	1,47E-05	5,38E-06	2,37E-06	1,09E-06
	8.0	2,32E-07	1,20E-06	2,90E-06	2,56E-06	1,21E-06	5,80E-07
$^{89}Y(n,5n)^{85}Y$-42.1 MeV $T_{1/2}$= 2.86h Eγ= keV	4.0	7,83E-08	6,00E-07	5,09E-06	1,69E-06	8,15E-07	3,55E-07
	8.0	7,86E-08	3,42E-07	9,32E-07	9,37E-07	4,37E-07	2,53E-07

3. Experimental results – cont.

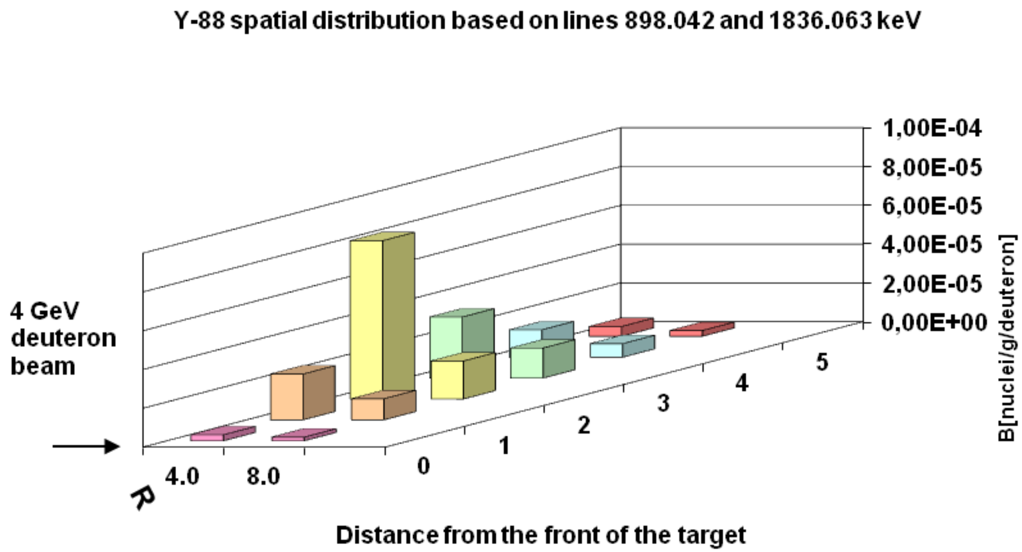


Fig. 4a. Spatial distribution (radial & axial) of Y88 production for the deuteron beam 4GeV in the first experimental session (March 2011) when the uranium target was not lead shielded.

3. Experimental results – cont.

Table 2b. Isotope production per one gram of ^{89}Y detector and per deuteron of energy equal to 4 GeV of the December session (with lead shielding).

Residual nuclei $T_{1/2}$, γ – lines used	**Radius cm**	**Radial distance from front of U target , cm**					
		0	**1(13.1)**	**2(26.2)**	**3(39.3)**	**4(52.4)**	**5(65.5)**
$^{89}Y(n,2n)^{88}Y$-11.5 MeV $T_{1/2}$=106.65 d, Eγ=898.0, 1836.0 keV	4.0	3,24E-06	2,49E-05	4,66E-05	2,77E-05	1,39E-05	6,43E-06
	8.0	1,99E-06	1,05E-05	2,03E-05	1,34E-05	7,39E-06	3,85E-06
$^{89}Y(n,3n)^{87}Y$-20.8 MeV $T_{1/2}$ =3.32 d Eγ=388.5, 484.8 Kev	4.0	1,34E-06	9,61E-06	2,23E-05	1,34E-05	6,88E-06	3,32E-06
	8.0	7,49E-07	4,05E-06	2,23E-05	6,63E-06	3,79E-06	2,05E-06
$^{89}Y(n,4n)^{86}Y$-32.7 MeV $T_{1/2}$ =0.614 d Eγ=1076.0 keV	4.0	3,65E-07	3,23E-06	7,86E-06	5,57E-06	2,84E-06	1,34E-06
	8.0	2,20E-07	1,25E-06	7,86E-06	2,46E-06	1,43E-06	8,01E-07
$^{89}Y(n,5n)^{85}Y$-42.1 MeV $T_{1/2}$ = 2.86h Eγ= keV	4.0	1,53E-07	0,00E+00	3,73E-06	2,86E-06	1,39E-06	6,91E-07
	8.0	9,12E-08	4,81E-07	1,64E-06	1,17E-06	6,78E-07	4,06E-07

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3. Experimental results – cont.

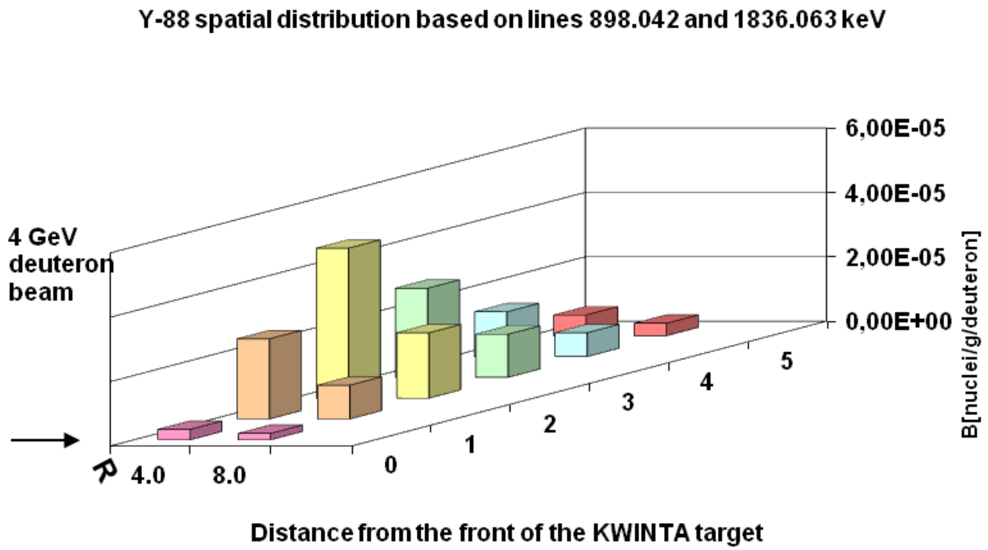


Fig. 4b. Spatial distribution (radial & axial) of Y88 production for the deuteron beam 4GeV in the second experimental session (December 2011) when the uranium target was lead shielded

3. Experimental results – cont.

Fig. 4a. Spatial distribution (radial & axial) of Y88 production for the deuteron beam 4GeV in the first experimental session (March 2011) when the uranium target was not lead shielded.

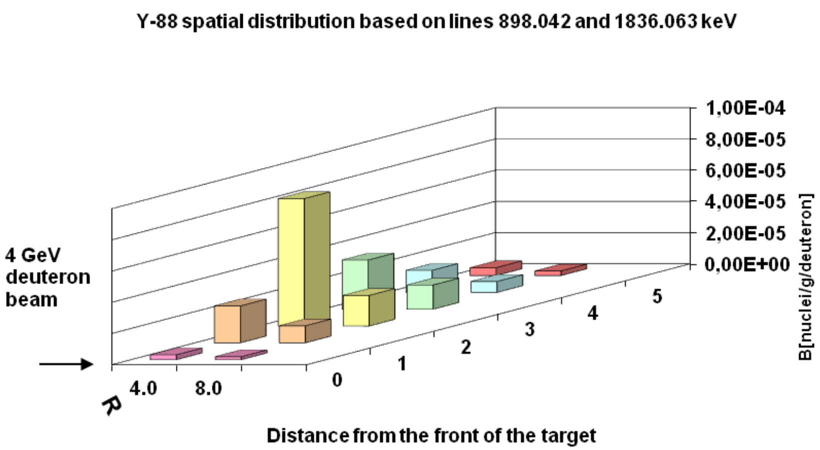
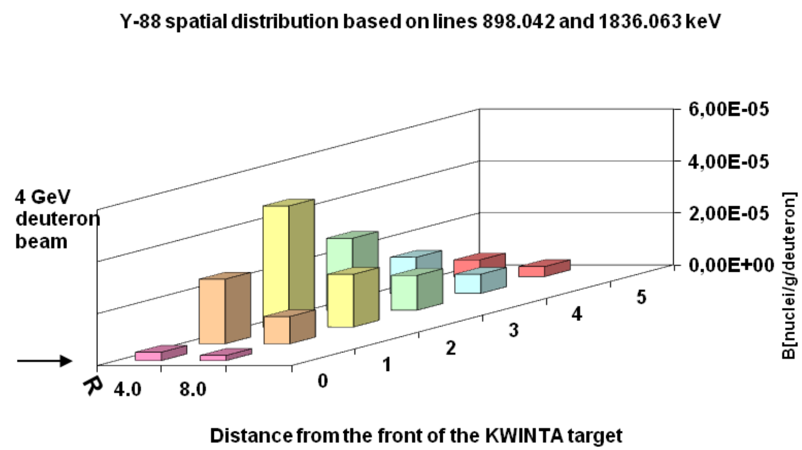


Fig. 4b. Spatial distribution (radial & axial) of Y88 production for the deuteron beam 4GeV in the second experimental session (December 2011) when the uranium target was lead shielded.



3. Experimental results – cont.

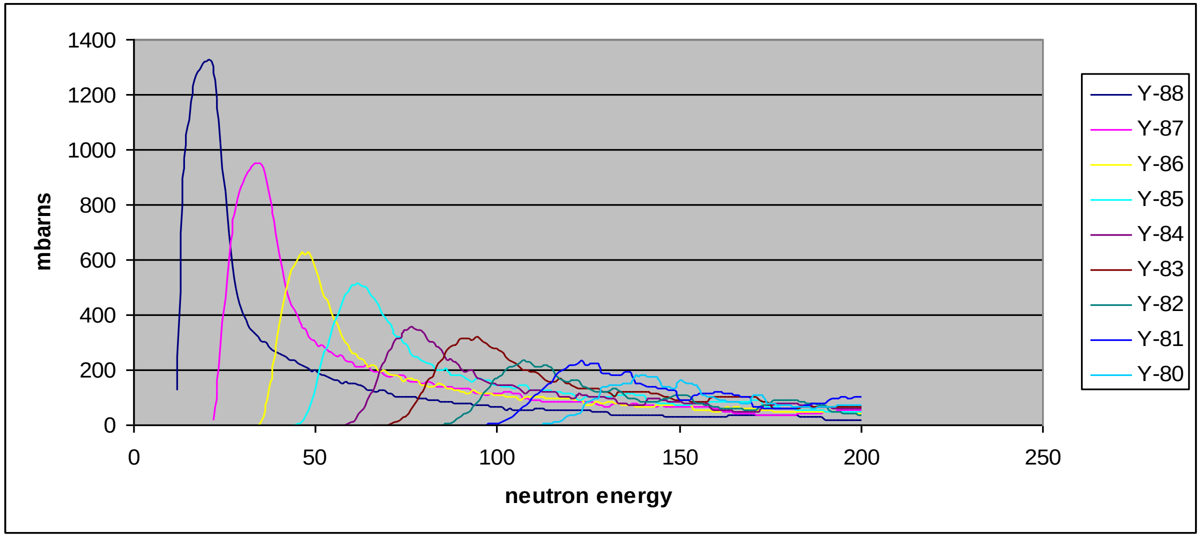


Fig. 5. Microscopic cross sections for several ^{89}Y(n, xn) reactions

To evaluate the high energy neutron field we need to know the microscope cross section for the (n,xn) reactions. Experimental data are available only for the cross section of ^{89}Y(n, 2n) reactions. Since the nuclear data libraries are poor we have used TALYS code for calculation of (n,xn) reactions for Y-89 cross sections (see Fig.5).

Using the microscopic cross sections for the reactions ^{89}Y(n, 2n), (n, 3n) and (n,4n) generated by TALYS code (see Fig. 5) and the experimental data (parameter B) we have evaluated the average high energy neutron flux in the yttrium 89 detectors located inside the Quinta assembly for the three energy ranges (11.5 - 20.8 MeV), (20.8 - 32.7MeV) and (32.7 – 100 MeV).

3. Experimental results – cont.

- Comparisons of average neutron flux densities for the three neutron energy ranges(11,5-20,8 MeV, 20,8-32,7 MeV, 32,7-100 MeV) and for the deuteron beam energy equal to 4 GeV of both experiments (in March and December 2011) were performed.

3. Experimental results – cont.

Fig. 6a. Average neutron flux densities in the Quinta uranium target at 4 cm radius enfolded with lead reflector and without it in the range of 11,5-20,8 MeV irradiated with deuterons of energy 4 GeV.

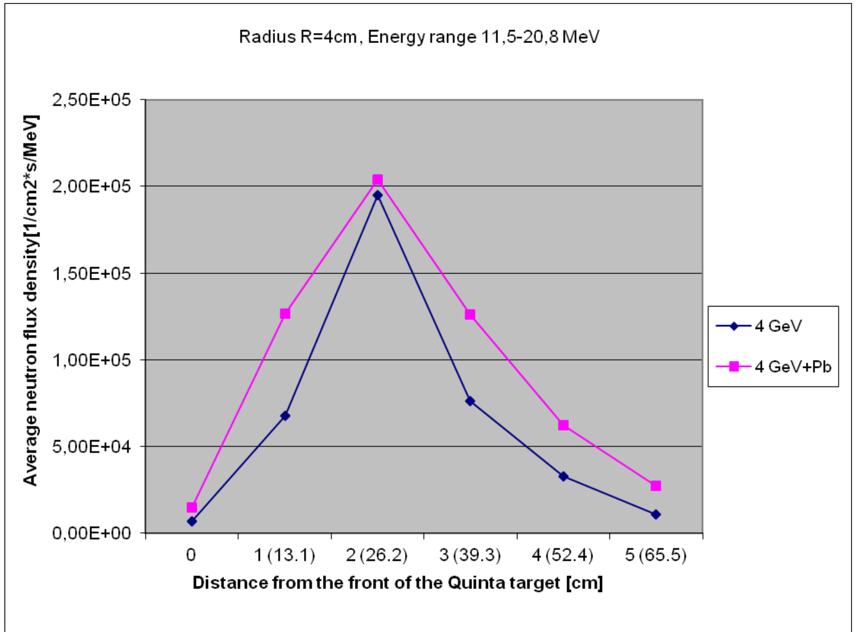
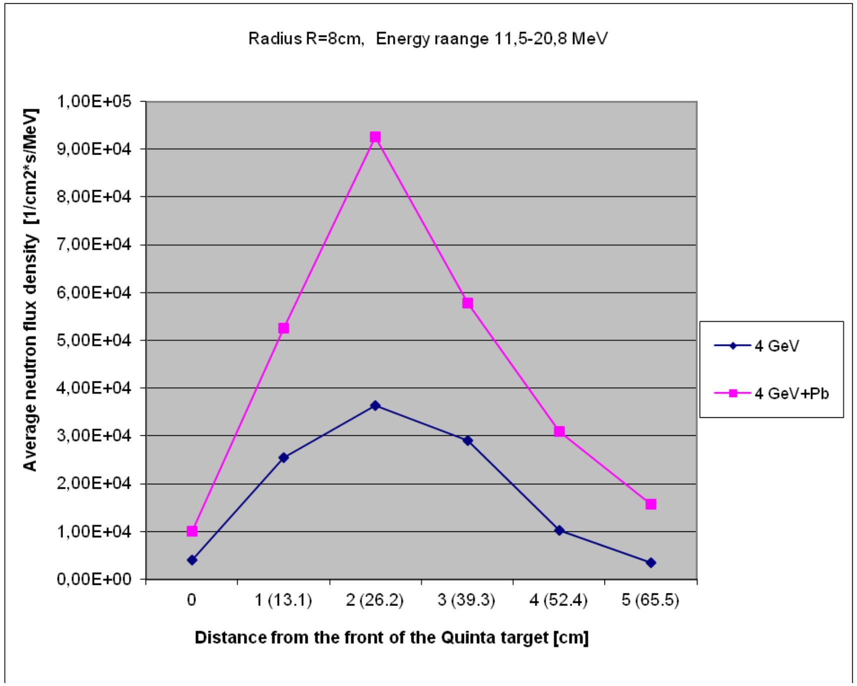


Fig. 6b. Average neutron flux densities in the Quinta uranium target at 8 cm radius enfolded with lead reflector and without it in the range of 11,5-20,8 MeV irradiated with deuterons of energy 4 GeV.



3. Experimental results – cont.

Fig. 6c. Average neutron flux densities in the Quinta uranium target at 4 cm radius enfolded with lead reflector and without it in the range of 20.8 - 32.7MeV irradiated with deuterons of energy 4 GeV.

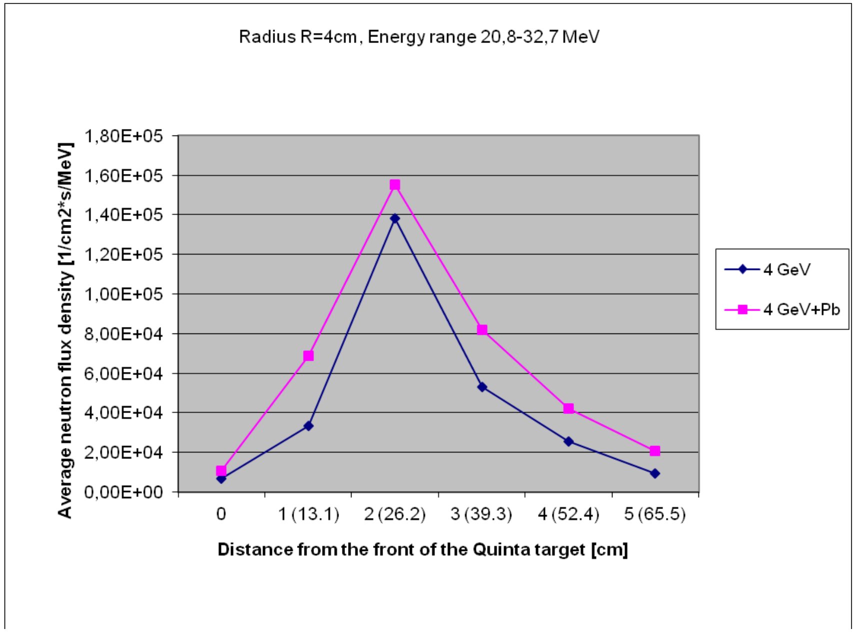
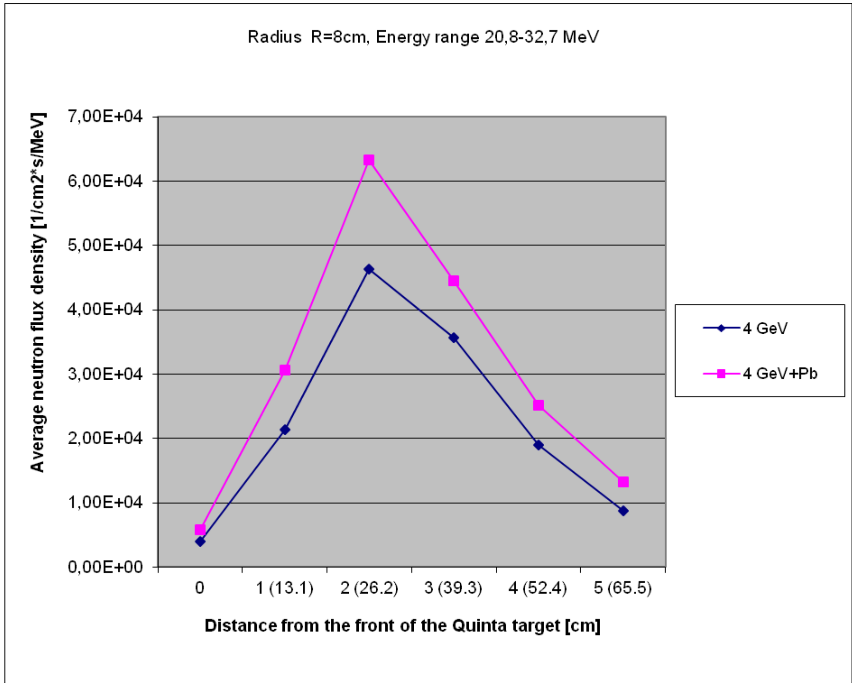


Fig. 6d. Average neutron flux densities in the Quinta uranium target at 8 cm radius enfolded with lead reflector and without it in the range of 20.8 - 32.7MeV irradiated with deuterons of energy 4 GeV.



3. Experimental results – cont.

Fig. 6e. Average neutron flux densities in the Quinta uranium target at 4 cm radius enfolded with lead reflector and without it in the range of 32.7 – 100 MeV irradiated with deuterons of energy 4 GeV.

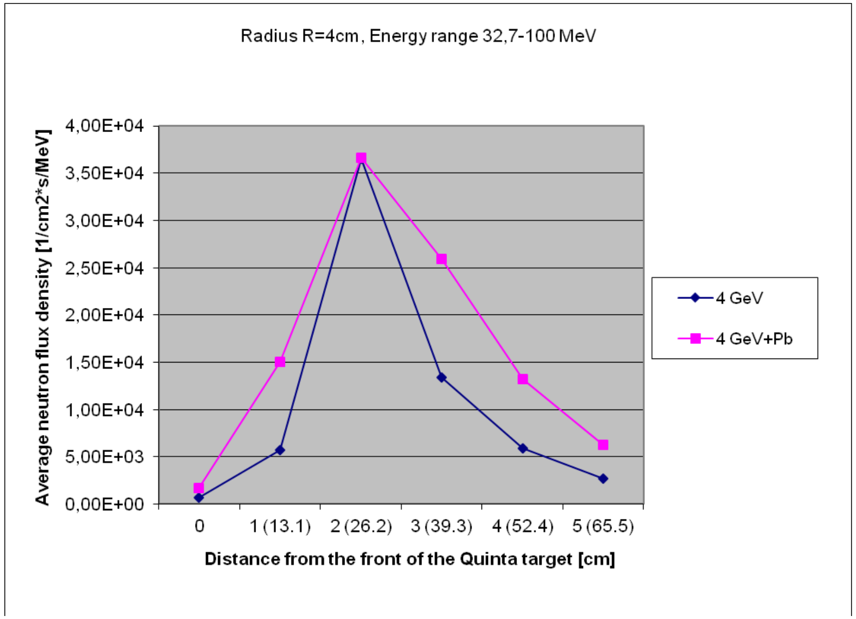
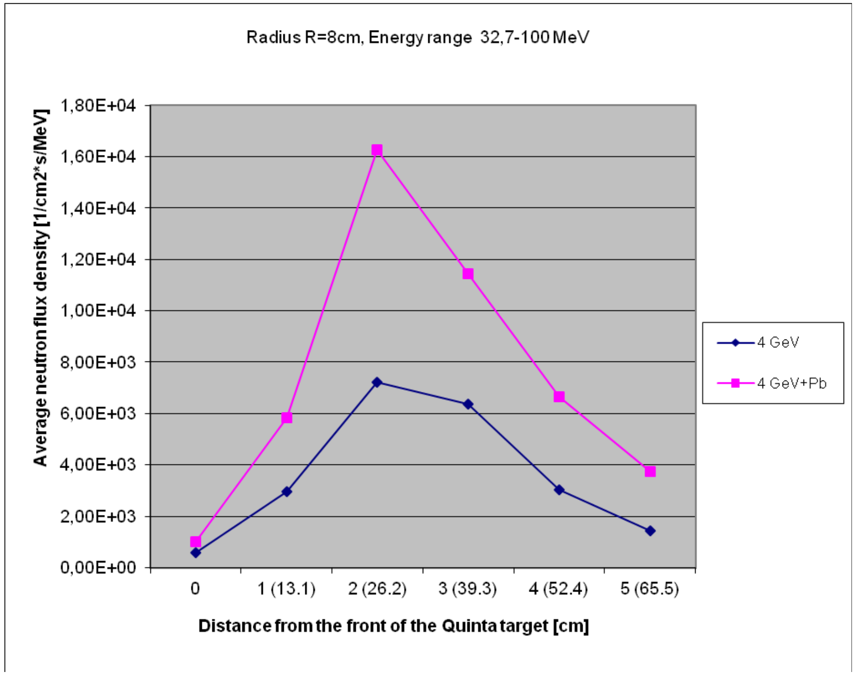


Fig. 6f. Average neutron flux densities in the Quinta uranium target at 8 cm radius enfolded with lead reflector and without it in the range of 32.7 – 100 MeV irradiated with deuterons of energy 4 GeV.



3. Experimental results – cont.

Table 3. Neutron densities increase in the volume of QUINTA uranium target caused by the lead reflector (shielding) in the case of 4 GeV deuteron irradiation.

Energy range [MeV]	Radious [cm]	Neutron density in the maximum point (without lead shield –March 2011) [$1/cm^2 \cdot s/MeV$]	Neutron density in the maximum point (with lead shield –December 2011) [$1/cm^2 \cdot s/MeV$]	Neutron density increase in the volume of QUINTA uranium target.
11,5-20,8	4 8	$1.95\ 10^5$ $3.64\ 10^4$	$2.04\ 10^5$ $9.25\ 10^4$	1.045 2.54
20,8-32,7	4 8	$1.82\ 10^5$ $4.63\ 10^4$	$1.55\ 10^5$ $6.33\ 10^4$	0.85 1.37
32,7-100	4 8	$3.65\ 10^4$ $7.20\ 10^3$	$3.66\ 10^4$ $1.63\ 10^4$	1.002 2.26

4. Discussion

- Since the curves of the neutron flux densities nearly overlap at the radius 4 cm in the area close to the spallation uranium target for both of the experiments with and without the lead shielding we can assume that the irradiation conditions were alike (see Figs 7a,7c and 7e).
- The measurement show that the neutron flux density increases in whole volume of the QUINTA assembly due to the lead shielding (see Figs 7a -7f).
- The lead shielding influence on the neutron spectra is more pronounced in the volume located closer to the shielding. This is clearly seen comparing the neutron flux densities distribution along the uranium target axis of the two experimental sessions for the same deuteron beam energy of 4 GeV with and without the lead shielding.
- .

4. Discussion

- In the separate energy ranges the neutron flux densities increases over 2 times but in the neutron range 20.8 – 32.7, which is only about 1.4 times (see Figs 7a – 7f and Table 4).
- Due to this increase the neutron flux distribution is more equal in the whole volume of the QUINTA assembly.
- This let us to infer that the layout of QUINTA assembly which is a deep subcritical nuclear core with hard neutron spectrum in a big volume to some extent is a suitable device for radioactive minor actinides burn-up in a big industrial scale after some innovation.

- Thank you for the attention.