EXPERIMENTS OF HIGH ENERGY NEUTRON SPECTRUM INVESTIGATION ON U/Pb - ASSEMBLY USING 1.60 AND 2.52 GeV DEUTERON BEAM FROM JINR NUCLOTRON (DUBNA)

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(for collaboration **„Energy plus Transmutation”**)

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Outline

1. Experiment description
2. Experimental data
3. Neutron Fields
4. Conclusions

1. Experiment description

E+T Model and Detectors

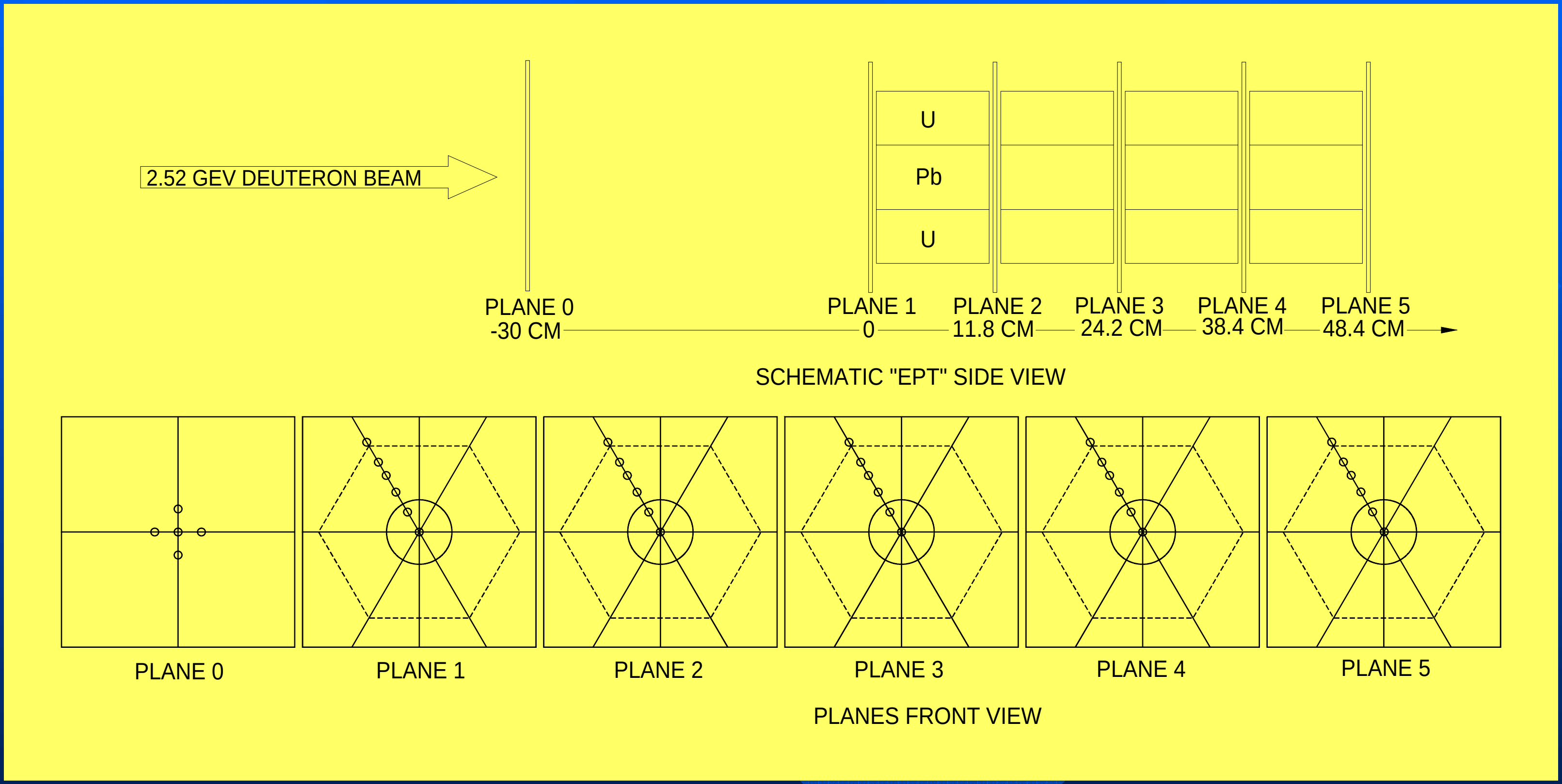
Experiments parameters

Accelerator:	JINR LWE Nuclotron		
Time:	June 2004	Nov 2005	Dec 2006
Beam:	Proton	Deuteron	Deuteron
Energy:	0,7 GeV	2,52 GeV	1,6 GeV
Irradiation Time:	31860 s	21600 s	22135 s
Collected beem particles:	$2*10^{13}$	$5.9*10^{12}$	$2.08*10^{13}$
Target:	Model U/Pb assembly "Energy+Transmutation"		
Activation Detectors:	Yttrium 89 – disc shape, h ≅1-2 mm, d = 10 mm		

Y-89 isotopes basic data

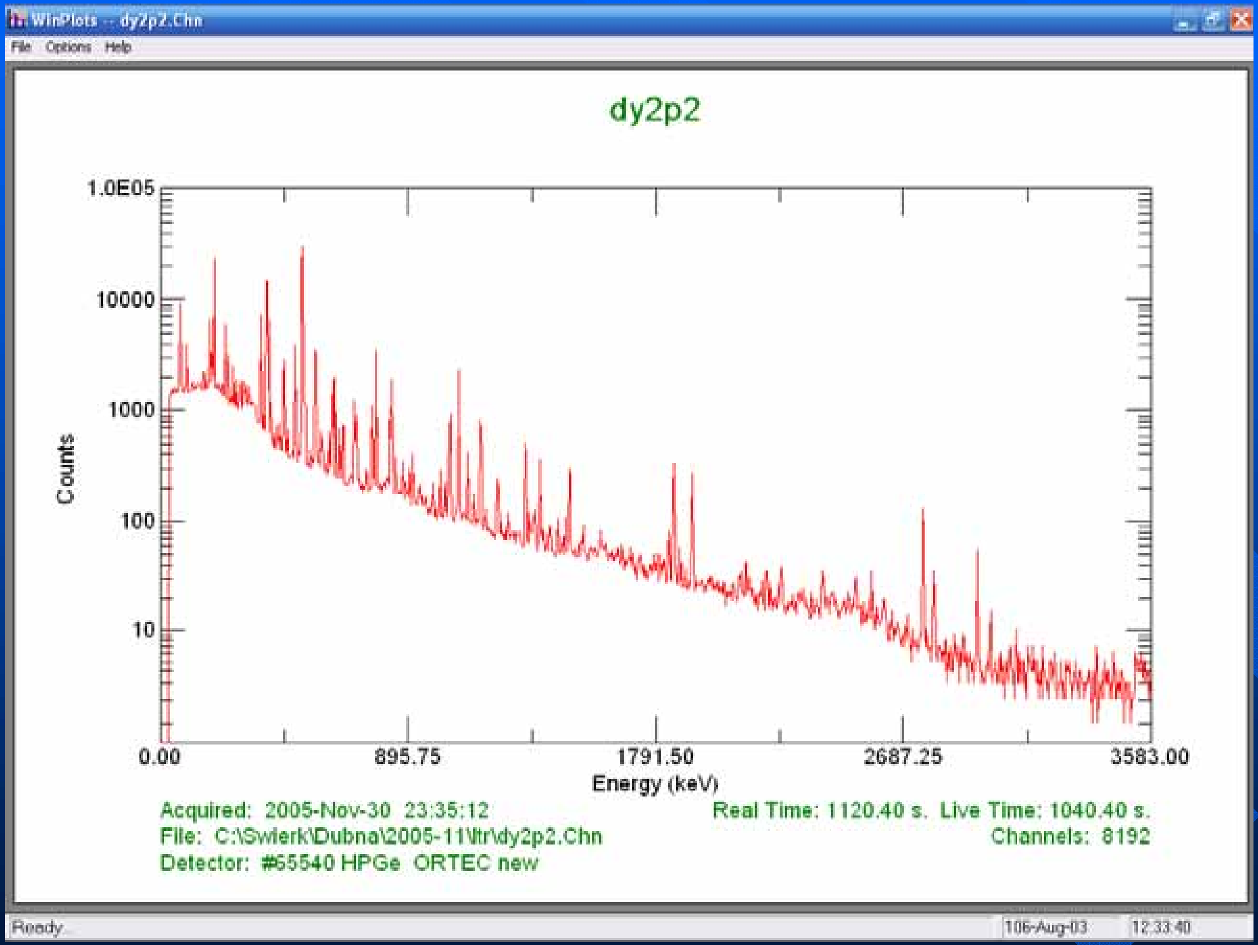
Nr	Reaction	Produced Isotope	Half Life	Ethr [Mev]	Energy [keV]	Intensity [%]
1	(n,g)	Y90	3,19h	-6,9	202,5	97,3
					497,2	90,74
2	(n,2n)	Y88	106,65d	11,5	**898**	**93,7**
					1836,1	**99,2**
3	(n,3n)	Y87	79,8h	20,8	**388,5**	**82**
					484,8	**89,7**
			13,37h		380,8	78
4	(n,4n)	Y86	14,74h	32,7	627,7	32,6
					703,3	15,4
					777,4	22,4
					1076,6	**82**
					1153	30,5
					1854,4	17,2
					1920,7	20,8

Fig. 1. Y-89 sample location in "Energy plus Transmutation" set-up.



Experimental data from ORTEC New gamma spectrometer.

Fig. 2. Sample 2 (plane 0, radius 0) gamma spectrum dY2p2 as an example of experimental data.



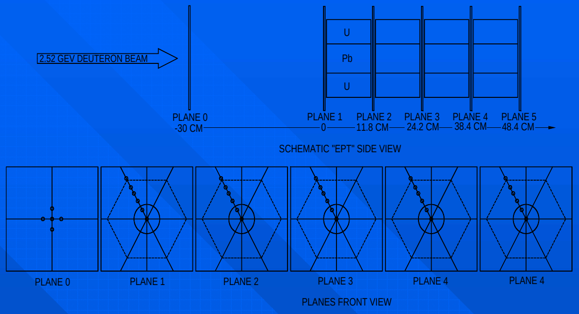
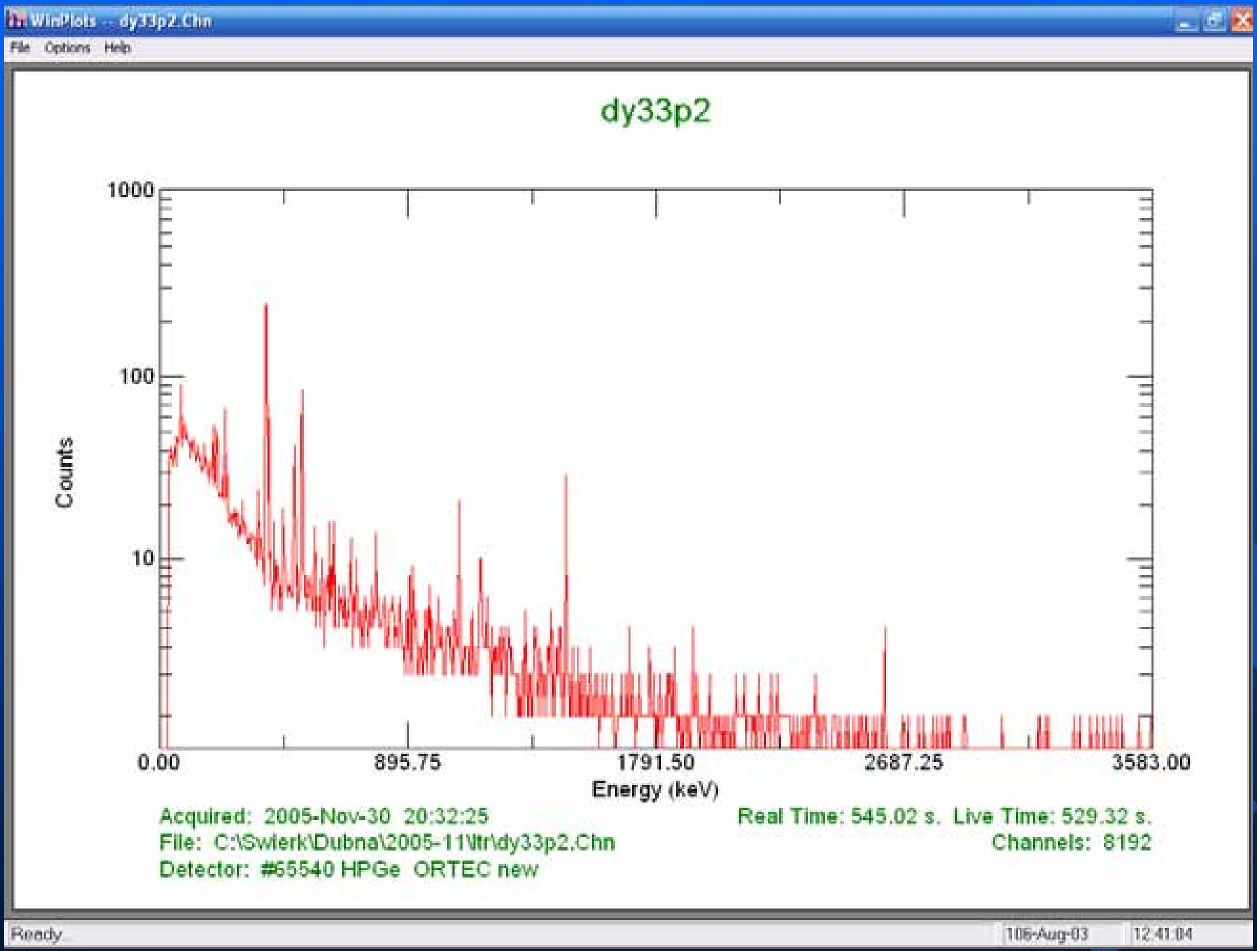
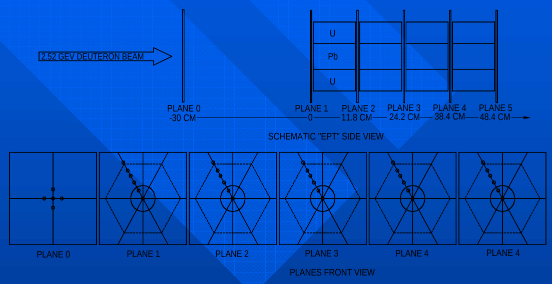


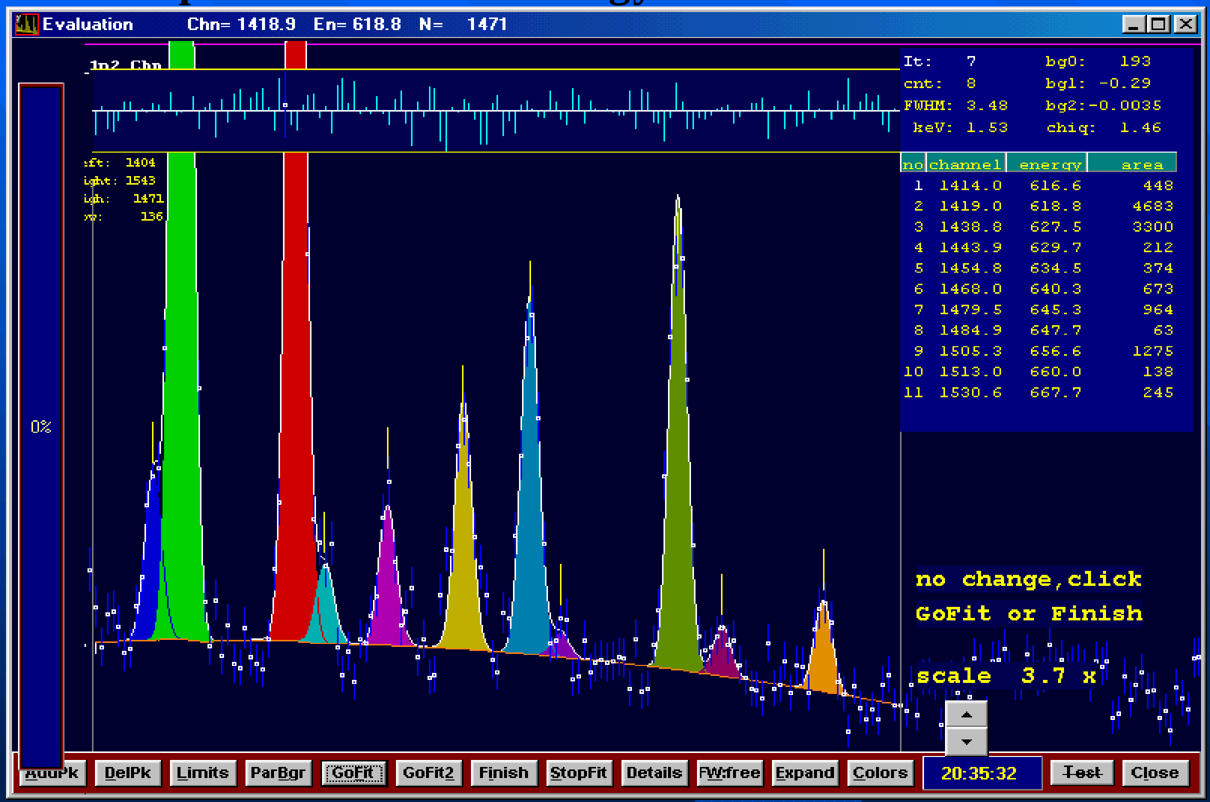
Fig. 4. Sample 33 (plane 2, radius 13.5) dY33p2 spectrum, one more example of the experimental data.





- Spectra analysis with Czech program DEIMOS. Peak areas as a result.
- Correction for time, irradiation time, weight and so on

Spectrum lines in energy area 616 -- 617 keV



Below is the calibration formula

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

where:

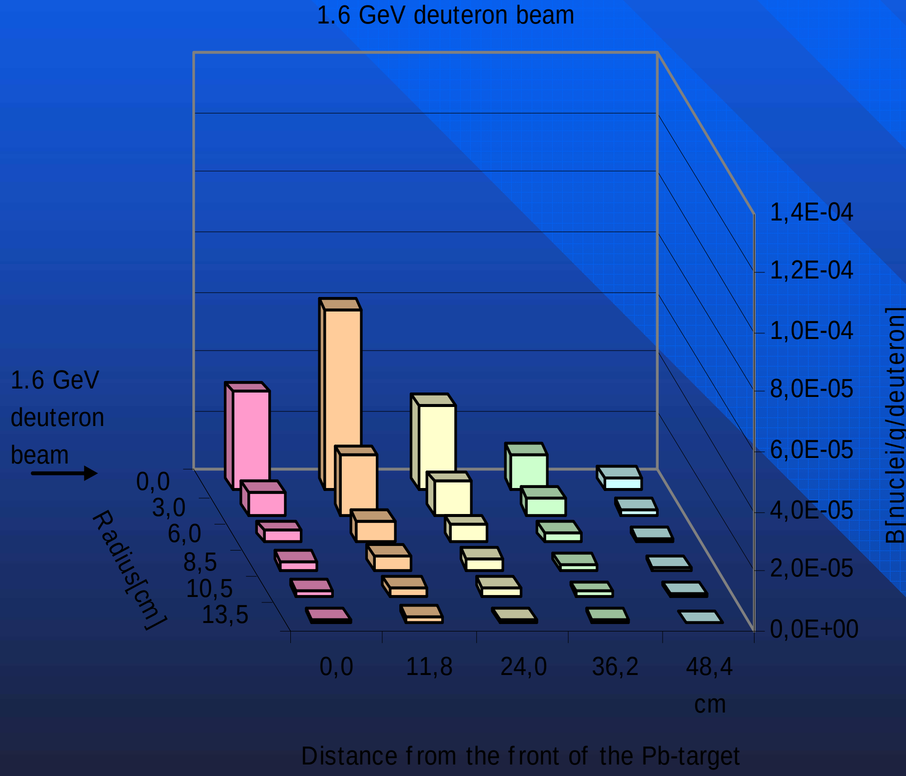
- B — number of nuclei per gram of a sample material and per one primary deuteron

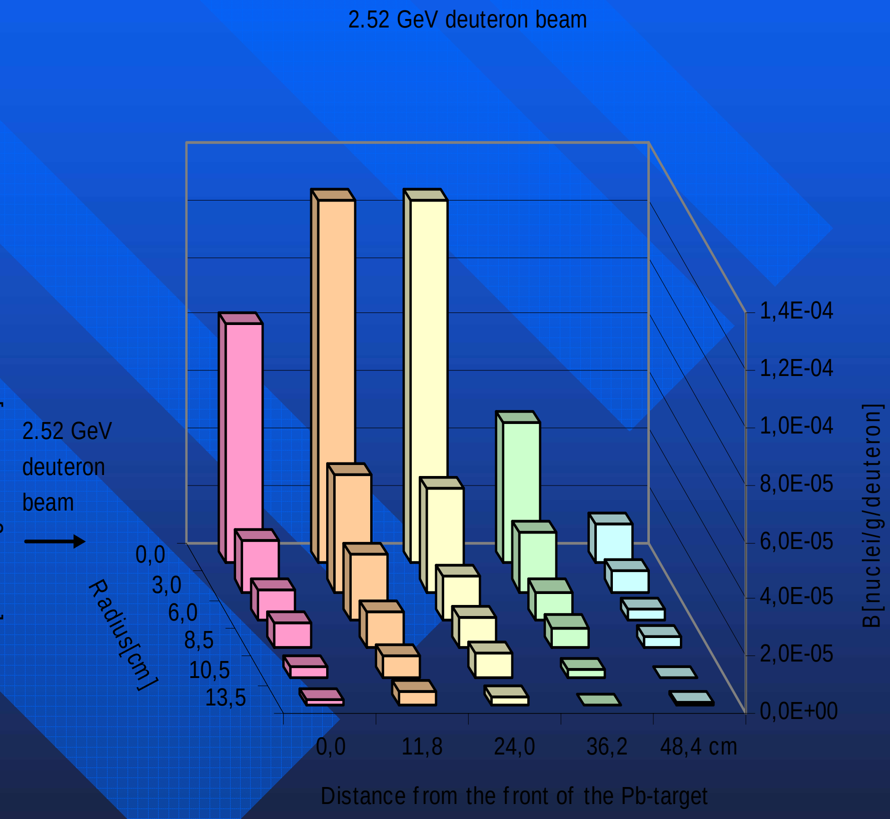
- N_1 — peak (line) area
- N_{abs} — the absolute intensity of given line in percent [%]
- $\varepsilon_p(E)$ — detector efficiency function of energy (polynomial)
- COI(E,G) — cascade effect coefficient function of energy and geometry
- I — total number of primary protons
- λ — decay constant ($\lambda=\ln(2)/t_{1/2}$)
- $t_{1/2}$ — 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.

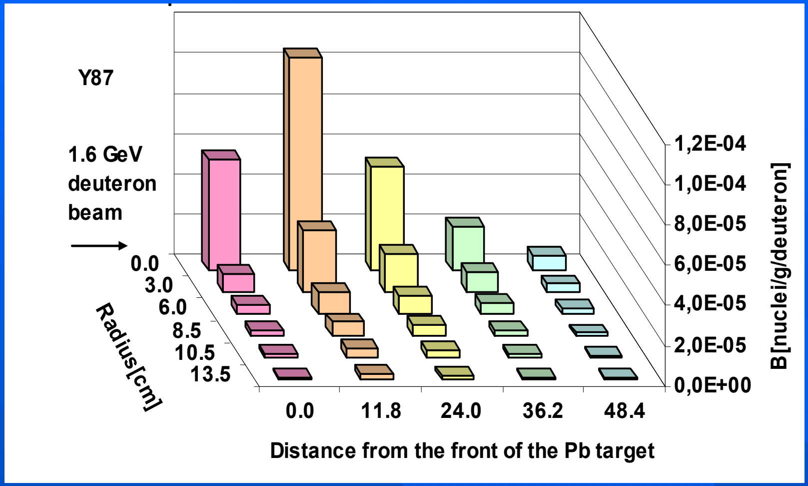
2. Experimental Data

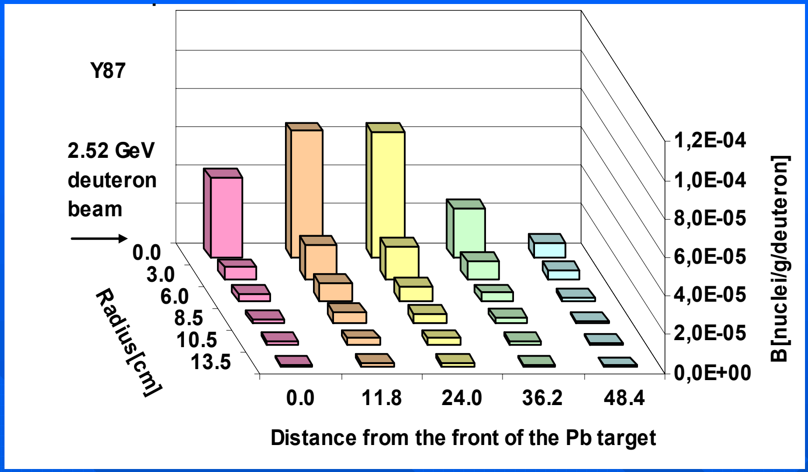
Results of Y-88 production spatial distribution on “Energy plus Transmutation” set-up witch 1.6 and 2.52 GeV deuteron beam .



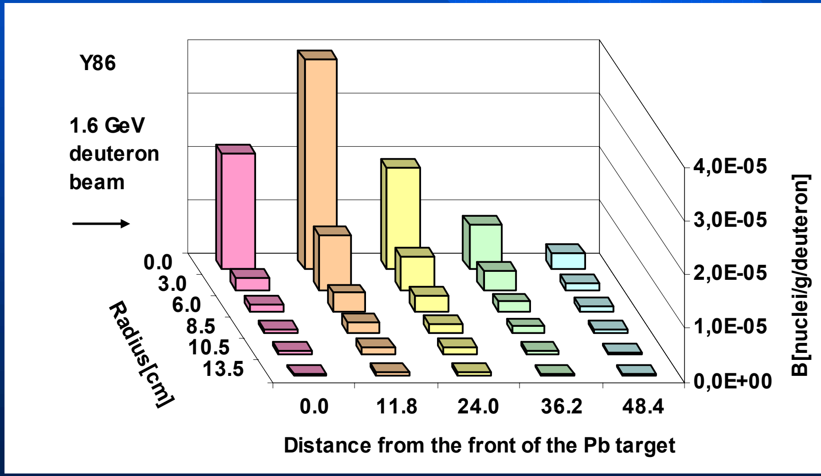


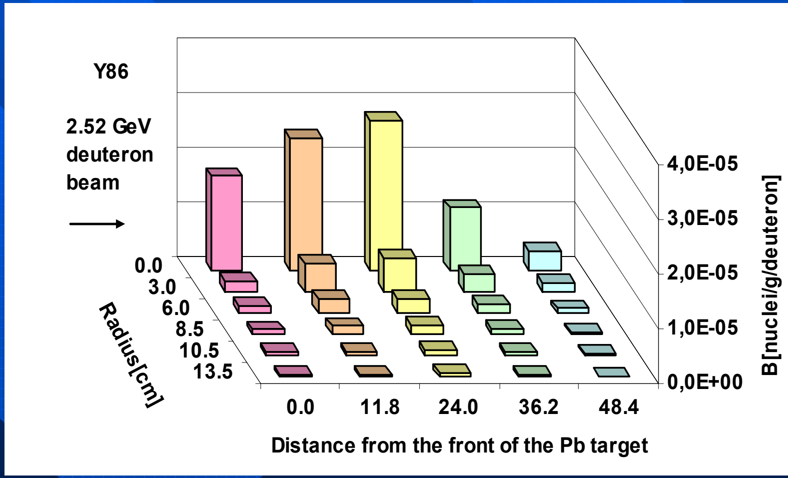
Y-87 and Y-86 production spatial distribution comparison





Y87

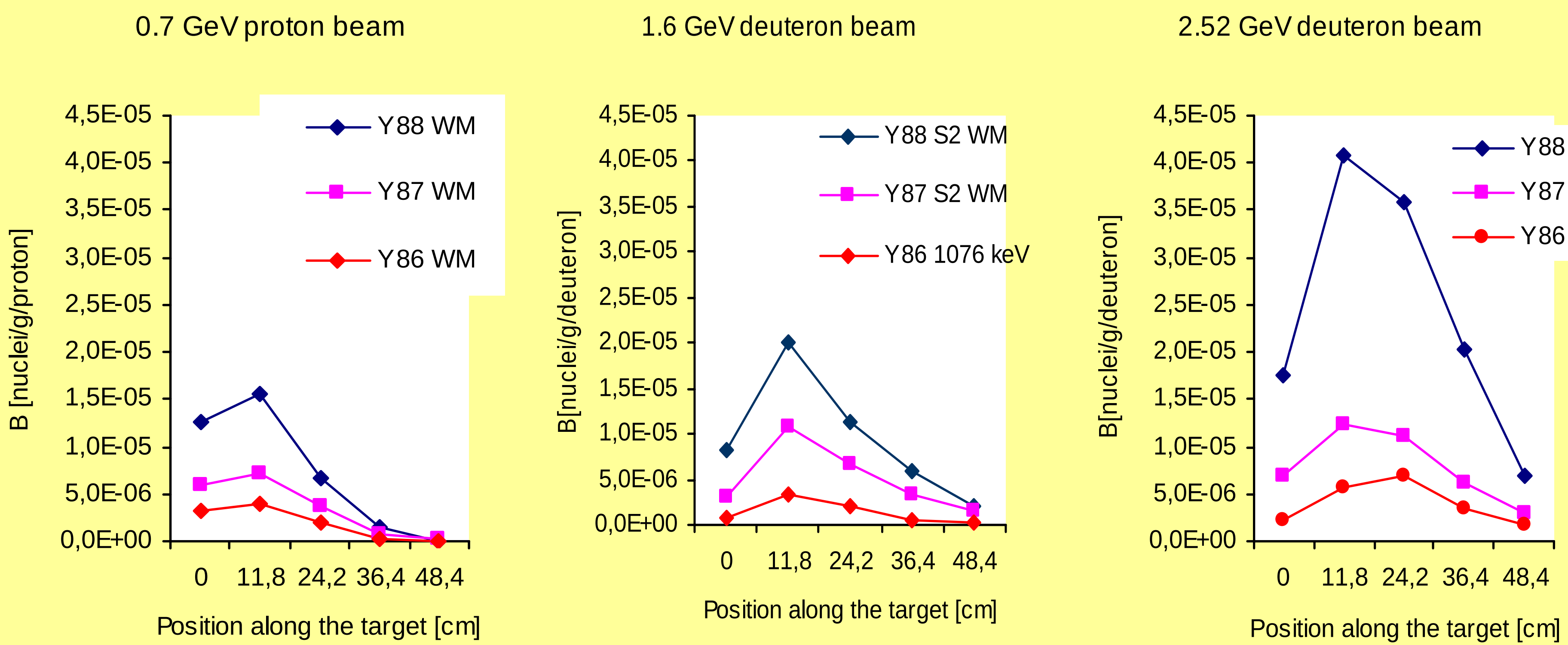




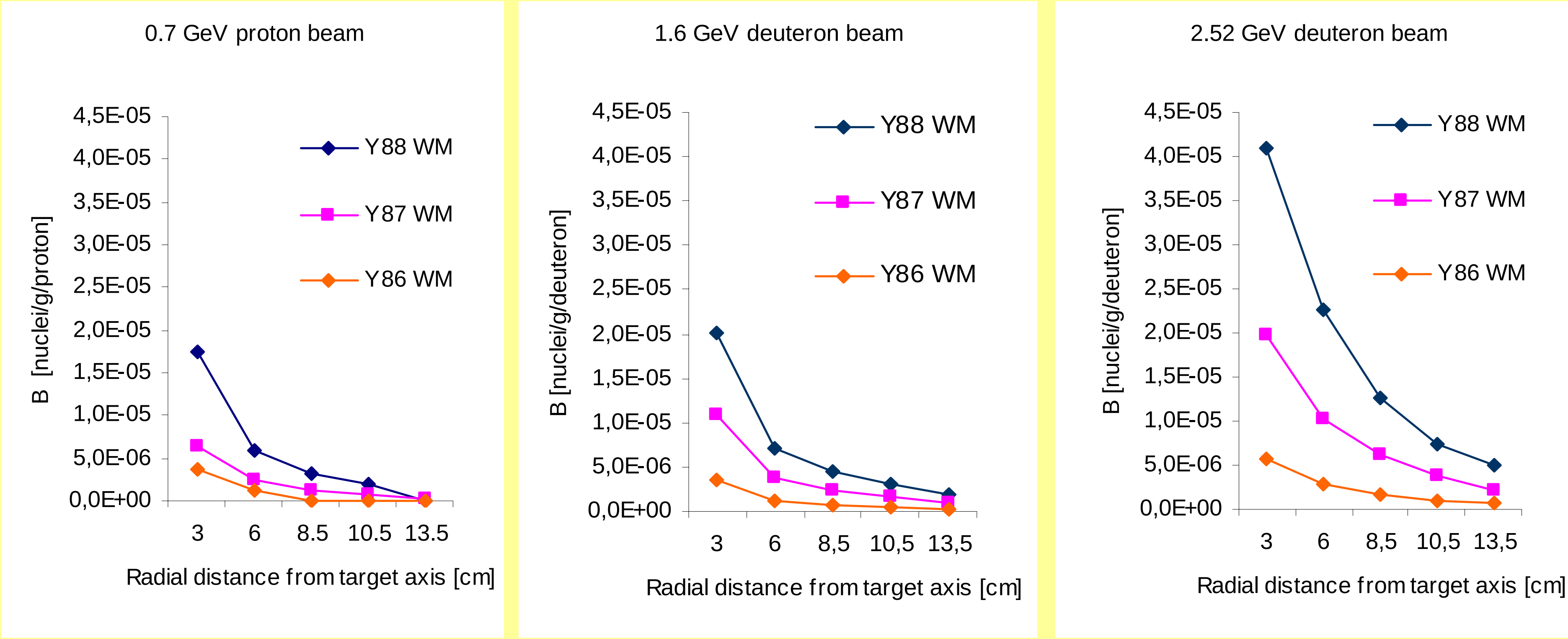
Y86

For Energy 1,6 GeV

For Energy 2,52 GeV



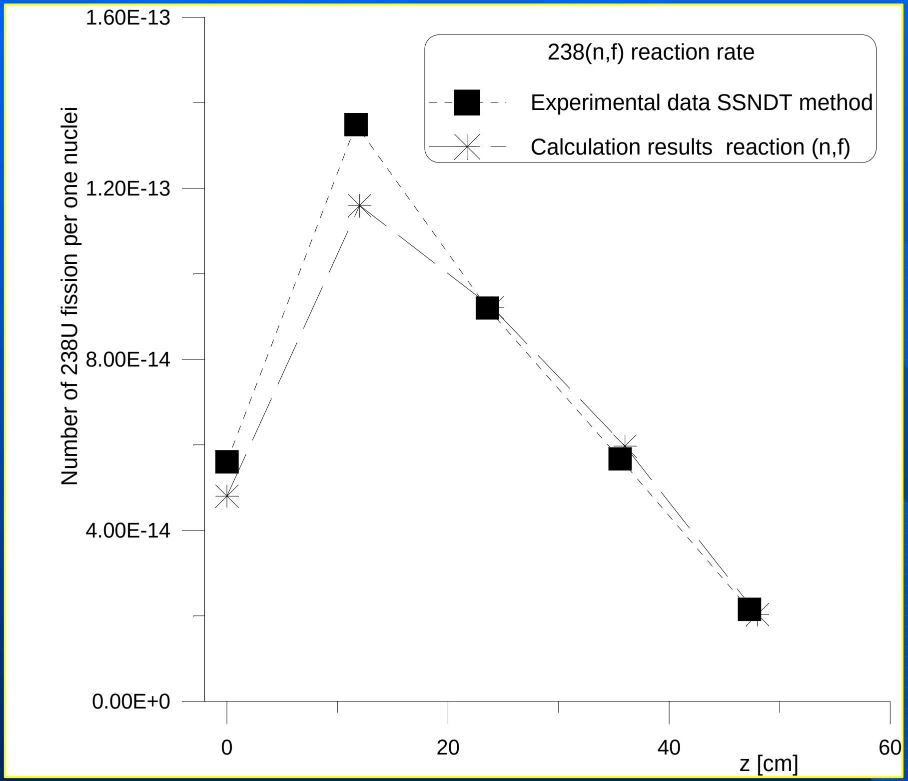
Axial distribution of the Y-88, Y-87 and Y-86 isotopes’ production per beam particle along R=3 cm line. The lines connect the results of the same isotope.



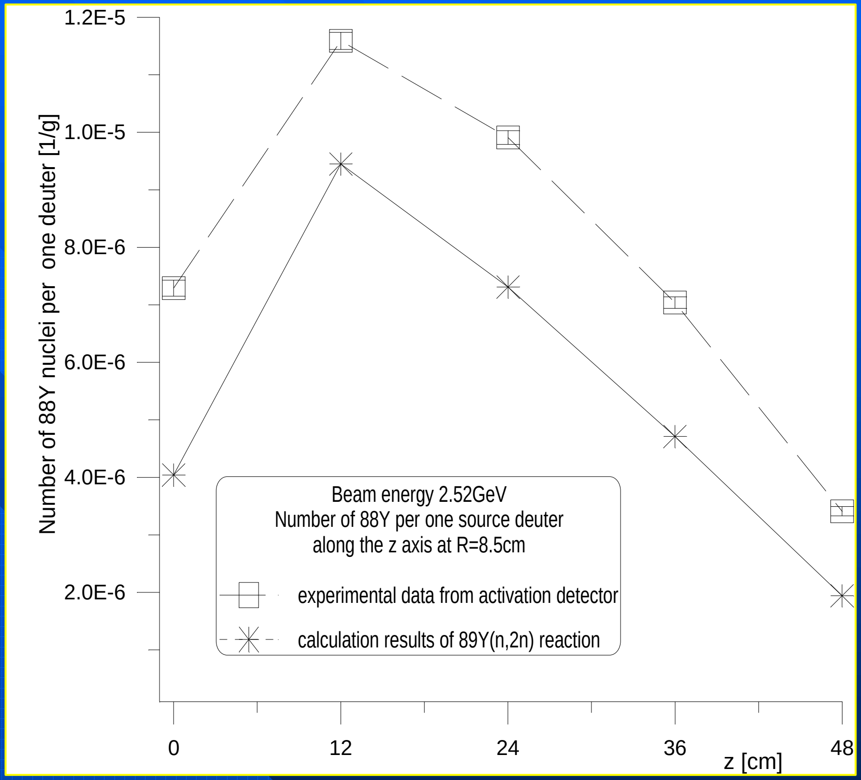
Radial distribution of the Y-88, Y-87 and Y-86 isotopes' production per beam particle at Plane 2 of the assembly. The lines connect the results of the same isotope.

Comparision witch MCMPX calculations

Axial distributions of nuclei produced (radial dystance 8,5cm)



Results from Belarus detector



Results from Y89 detectors

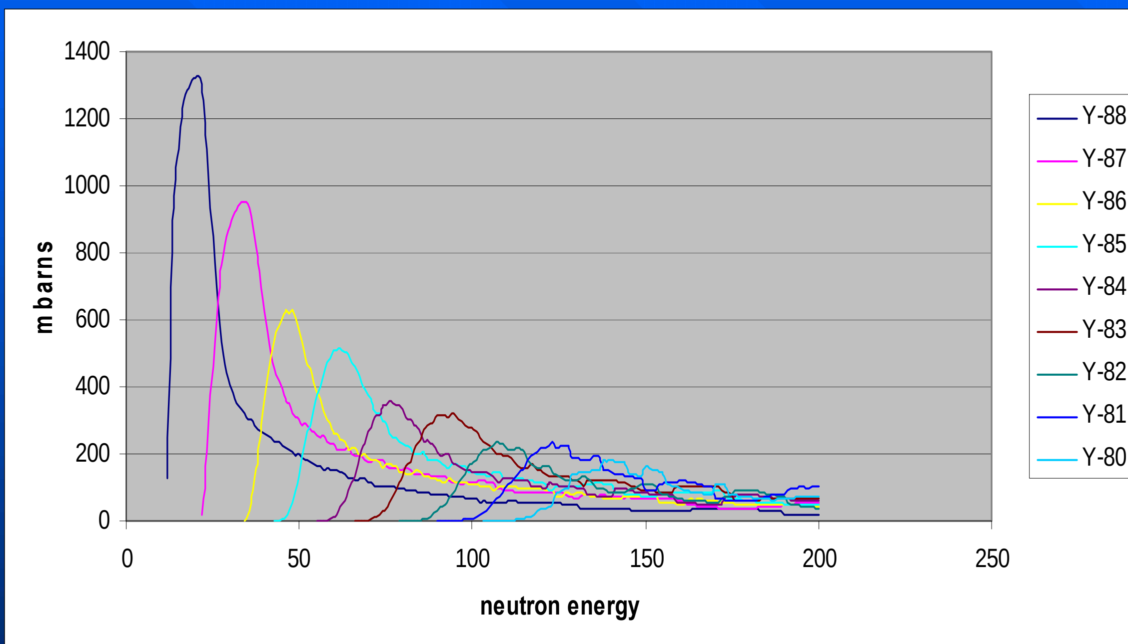
3. Neutron Fields

How to get neutron energy spectrum from these results?

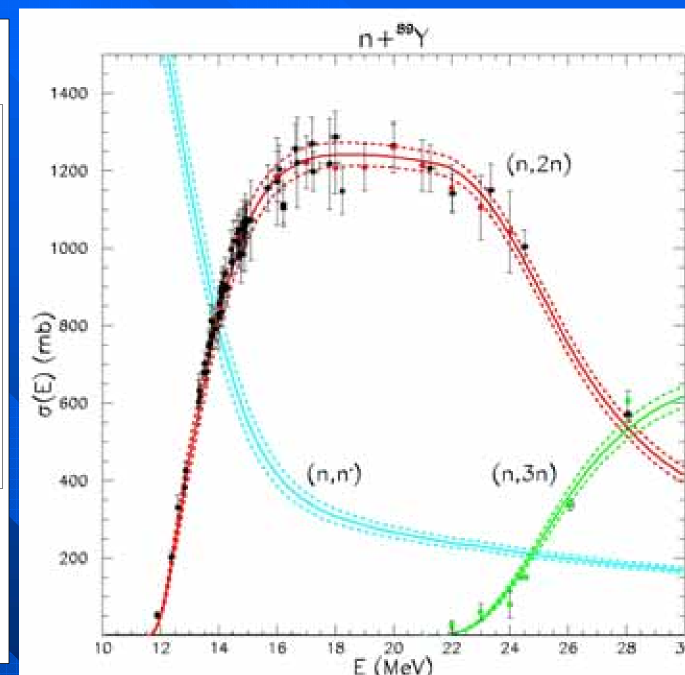
- Use **Threshold Reaction** channel
- Use MCNPX code for independent calculation
- Use spectral indexes – quotient of various isotope production [2]. Many reactions, many isotopes needed.

Use **Threshold Reaction** channel

We need Cross-Section for Y89 reaction

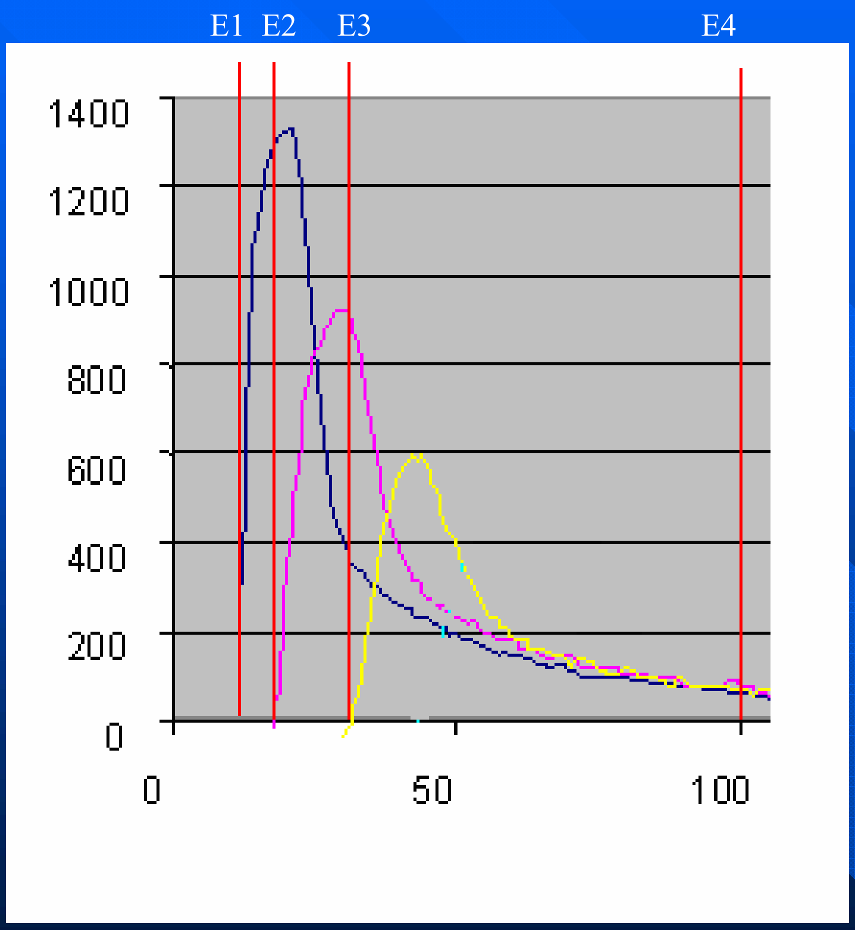


Result from TALYS symulations



Experimental data from EXFORA database

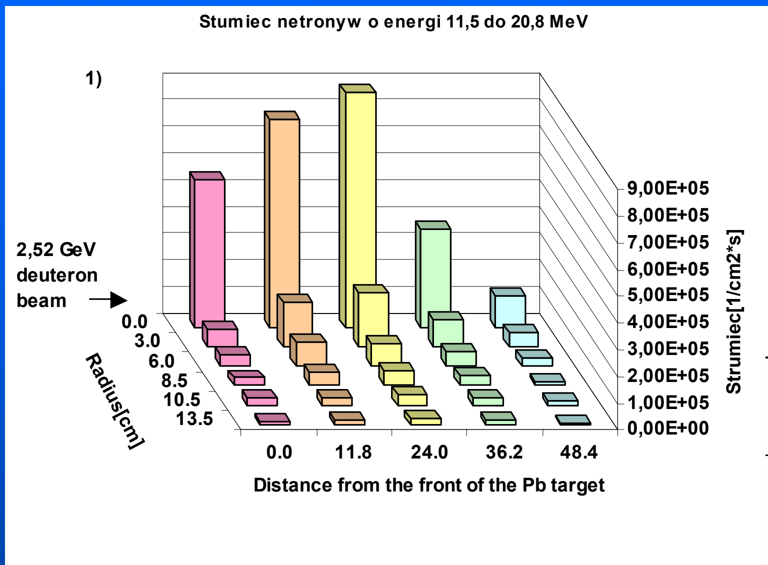
Use **Threshold Reaction** channel



E1 = 11,5 MeV Y88
E2 = 20,8 MeV Y87
E3 = 32,7 MeV Y86
E4 = 100 MeV

Φ1 from E1 to E2
Φ1 from E2 to E3
Φ1 from E3 to E4

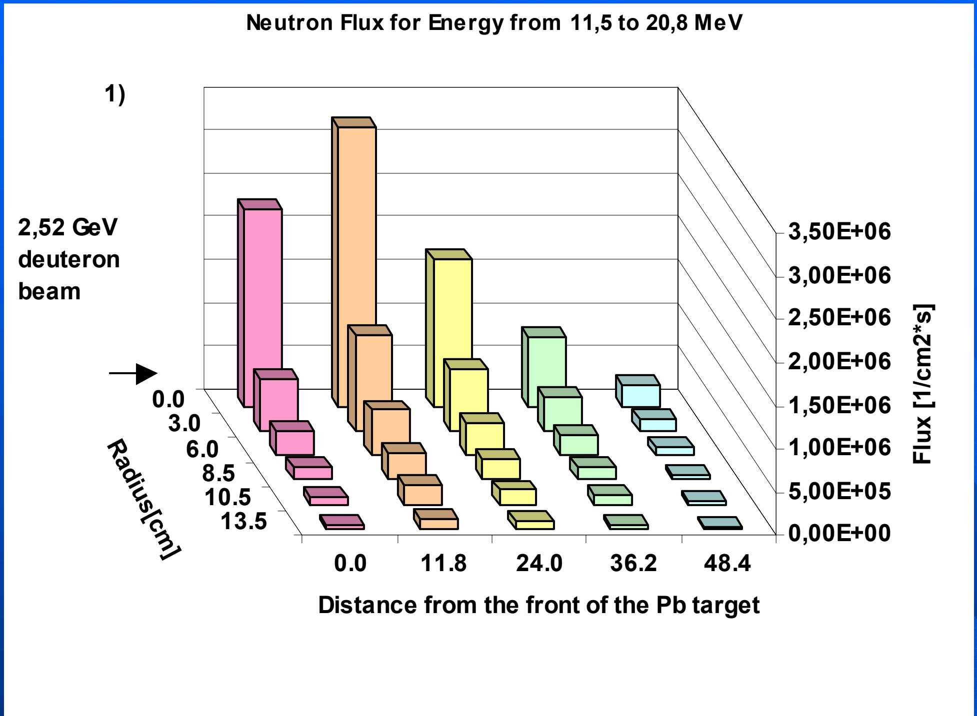
Use **Threshold Reaction** channel



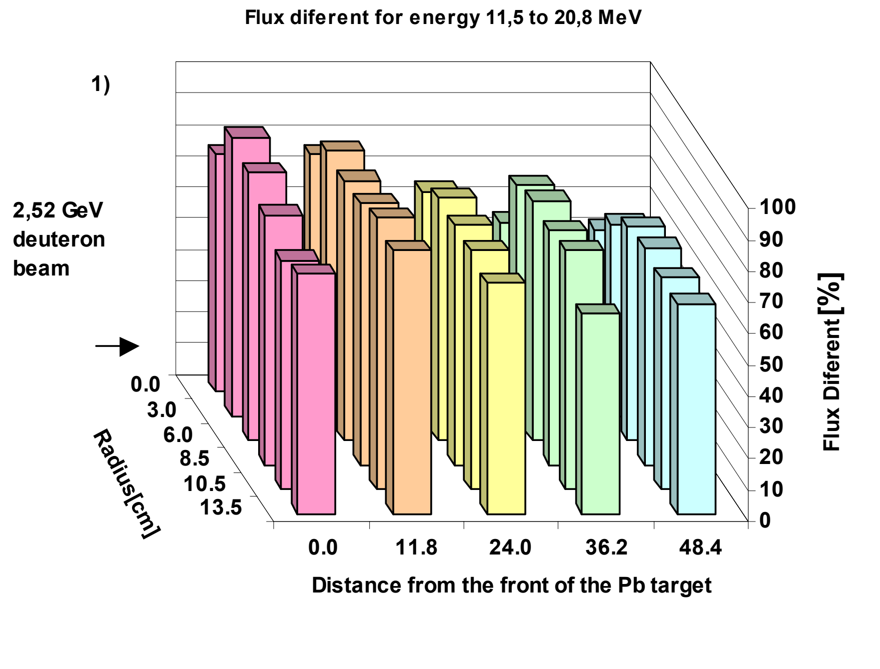
Neutron Flux at Energy range from 11,5 to 20,8 MeV

	Radial dyst. cm	Neutron Flux from Y89 detectors Axial position, cm				
		0.0	11.8	24.0	36.2	48.4
FLUX 1	0.0	5,51E+05	7,77E+05	8,77E+05	3,67E+05	1,16E+05
	3.0	6,53E+04	1,65E+05	2,00E+05	1,02E+05	5,35E+04
from 11,5 MeV	6.0	4,09E+04	8,84E+04	8,52E+04	5,38E+04	2,84E+04
to 20,8 MeV	8.5	2,90E+04	5,06E+04	5,35E+04	3,66E+04	1,67E+04
	10.5	2,49E+04	2,88E+04	3,86E+04	2,48E+04	1,33E+04
(delta 9,3)	13.5	1,22E+04	1,75E+04	2,20E+04	1,75E+04	7,64E+03
FLUX 2	0.0	1,51E+06	2,63E+06	2,36E+06	8,53E+05	2,66E+05
	3.0	2,79E+05	8,56E+05	7,13E+05	4,13E+05	1,91E+05
from 20,8 MeV	6.0	1,63E+05	4,34E+05	3,23E+05	1,74E+05	8,82E+04
to 32,7 MeV	8.5	9,73E+04	2,63E+05	2,11E+05	1,14E+05	5,88E+04
	10.5	6,30E+04	1,73E+05	1,45E+05	8,46E+04	4,30E+04
(delta 11,9)	13.5	4,98E+04	9,40E+04	7,98E+04	4,74E+04	2,79E+04
FLUX 3	0.0	3,01E+06	4,24E+06	4,79E+06	2,00E+06	6,36E+05
	3.0	3,57E+05	9,03E+05	1,09E+06	5,57E+05	2,92E+05
od 32,7 MeV do	6.0	2,23E+05	4,83E+05	4,65E+05	2,94E+05	1,55E+05
do 100	8.5	1,58E+05	2,76E+05	2,93E+05	2,00E+05	9,12E+04
	10.5	1,36E+05	1,57E+05	2,11E+05	1,35E+05	7,24E+04
(delta 67,3)	13.5	6,69E+04	9,59E+04	1,20E+05	9,57E+04	4,17E+04

MCMPX calculation of Neutron Flux



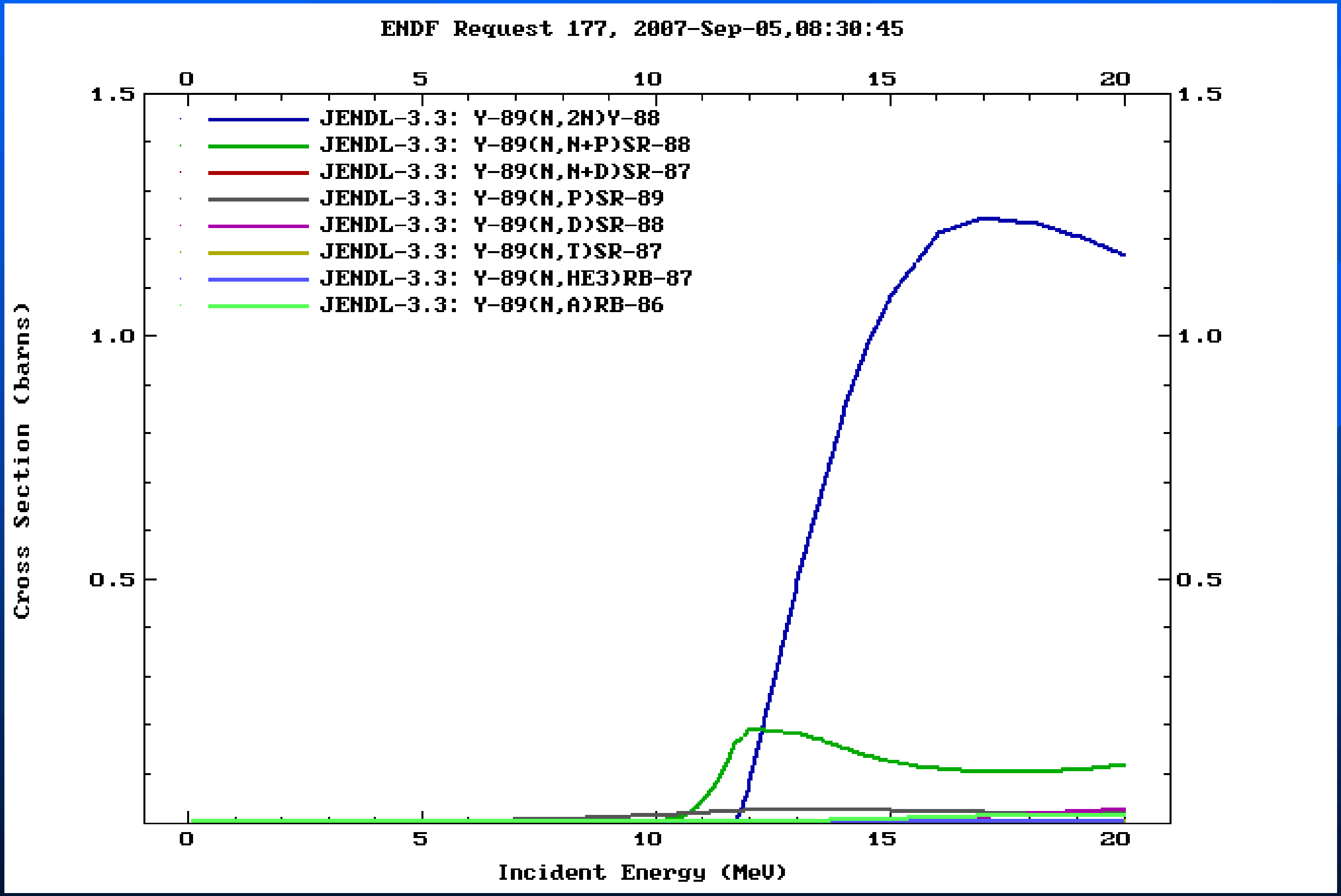
MCMPX calculation



Comparision betwee results from
Threshold Reaction channel
And MCMPX calculation in %

3. Neutron Fields - Use spectral indexes

Y-89(n,?) reaction cross sections available in ENDFs



Basic definitions

Isotope k production per one Y89 gram

$$I_k = N \int_{E_{thr,k}}^{\infty} \varphi(E)\sigma_k(E, E_{thr,k})dE$$

$N = 6.77\times10^{21}$ [nuclei/g]

$E_{thr,k}$ – reaction k threshold energy [MeV]

$\varphi(E)$ – neutron energy spectrum [n/cm^2/d/MeV]

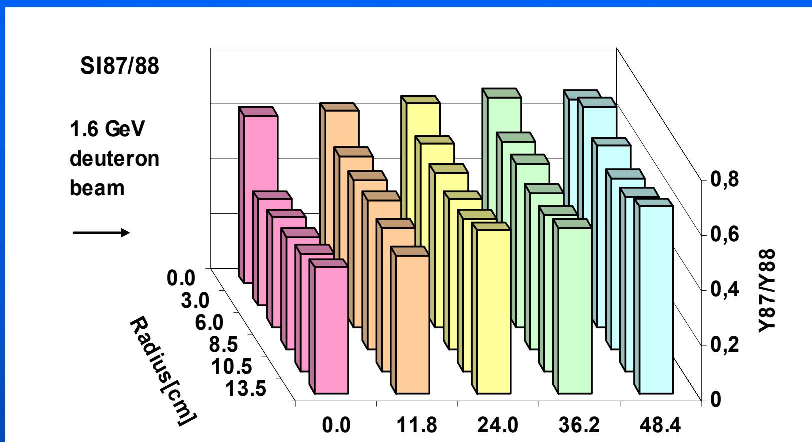
$\sigma_k(E)$ – reaction k cross section [cm^2]

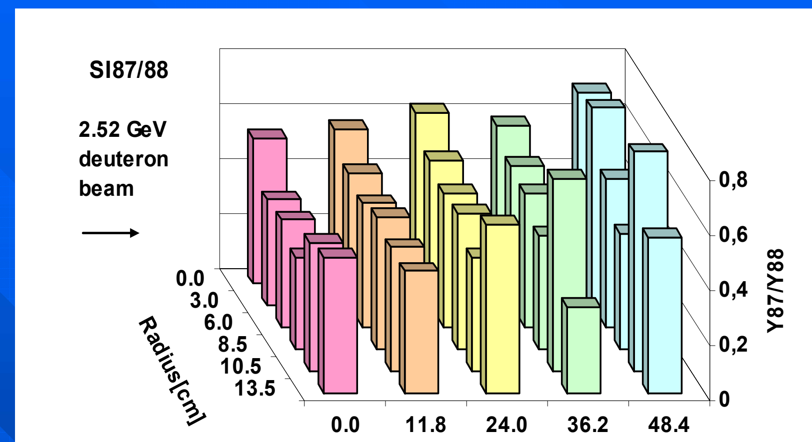
Spectral Index (SI)

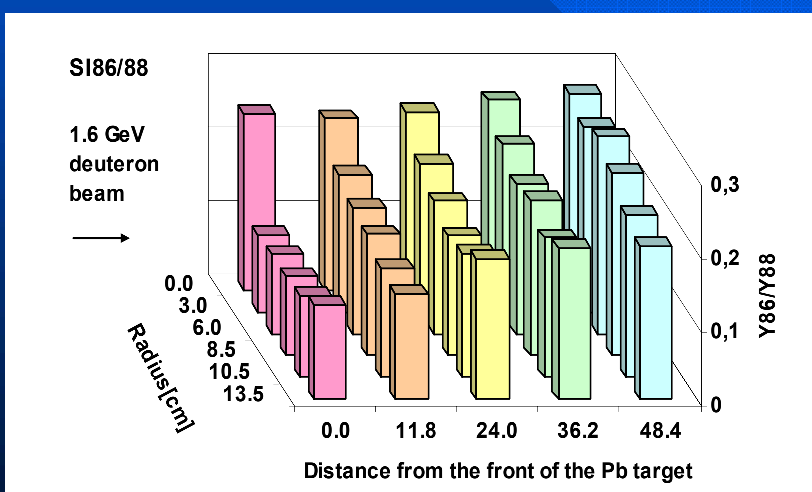
$$SI_{87/88} = \frac{I_{87}}{I_{88}} = \frac{\int_{E_{87}}^{\infty} \varphi(E)\sigma_{87}(E)dE}{\int_{E_{88}}^{\infty} \varphi(E)\sigma_{88}(E)dE}$$

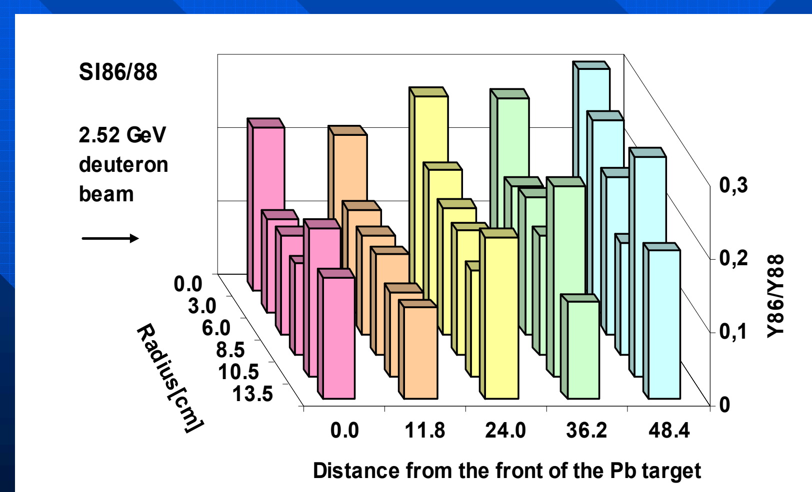
E_{87},E_{88} – reaction threshold energies [MeV]

Spectral Index $SI_{87/88}$ and $SI_{86/88}$ spatial distribution comparison between the experiments



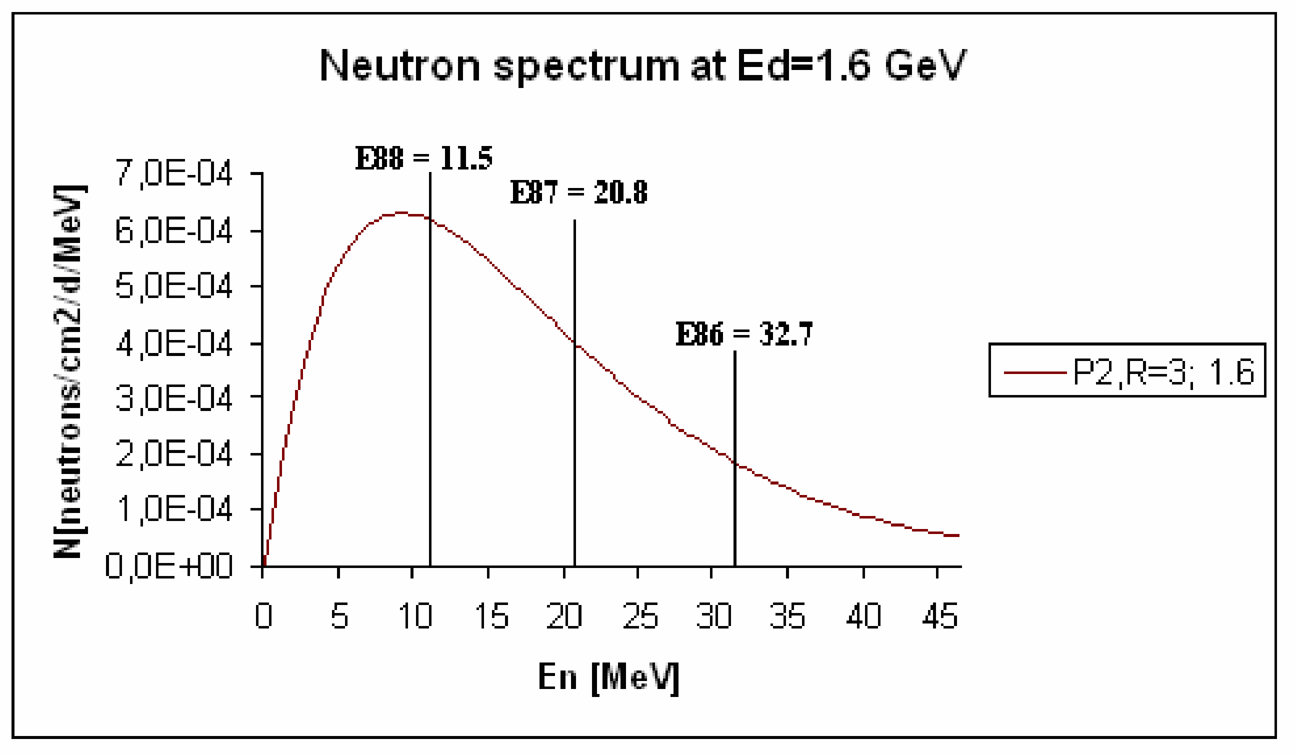






3. Neutron Fields - Use spectral indexes

First results



4. Conclusions

1. Y-89 is a very good threshold detector for neutron distribution measurement
2. Comparison axial distributions shows that with increase of energy per nucleon of the beam particle the maximum of isotope production move deeper into lead target. 1.6 GeV maxima are on Plane 2 while 2.52 GeV maxima are in between of Plane 2 and Plane 3 (axial position 24.2 cm). MCMPX calculation don't show this efect.

- It was assumed that the main contribution to value B error came from statistical error, ΔN_1 Now we postulate that main contribution going from numer of deuteron infrastruktury the beem. (minimum 10% probably about 20-30 %)
- Threshold reaction channels are wery easy and fast method to calculate neutron flux.
- Spectral indexes Y87/Y88 and Y86/Y88 show the contribution of the neutrons above the threshold in fast (above 11.5 MeV – Y89(n,2n)Y88 reaction threshold energy) neutron spectrum.
- We need good cross-section.

References:

[1] M.I. Krivopustov et al., JINR Preprint R1-2000-168, Dubna, 2000// Kerntechnik 2003, 68, p.p. 48-55// JINR-Preprint E1-2004-79, Dubna, 2004 (in print NIM).

[2] M. Bielewicz, M. Szuta, A. Wojciechowski, E. Strugalska-Gola et al. On the Experiment of Neutron Spectrum Investigation on U/Pb-Assembly Using 0.7 GeV Proton Beam from the JINR Nuclotron (Dubna) – Relativistic Nuclear Physics and Quantum Chromodynamics Proceedings of the XVII International Baldin Seminar on High Energy Physics Problems, Dubna, September 27 – October 2, 2004, Vol. II, p.p 125-132.

3] J.Frana, Program DEIMOS32 for Gamma Ray Spectra Evaluation. Journal of Radioanalytical and Nuclear Chemistry, Vol. 257, pp. 583-587, 2003.

[4] F.Krizek, V. Wagner, J. Adam et al.. The Study of Spallation Reactions, Neutron Production and Transport in a Thick Lead and an Uranium Blanket During 1.5 GeV Proton Irradiation. Czech. Jour. Of Phys., Vol.56, p. 243, 2006

Thank you for the cooperation