High Energy Neutron Flux Density Meassurment

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THE MEASUREMENTS OF THE HIGH ENERGY EVAPORATED NEUTRONS BY MEANS OF ^{89}Y THRESHOLD REACTION ACTIVATION METHOD.

Outline

1. Motivation
2. ADS experiments with two types of beams.
3. Average Fast Neutron Flux Density (10-100 MeV)
4. Theoretical calculation.
5. Conclusions

This work is a preliminary step to study of radioactive waste utilization problems (transmutation) of

E&T RAW collaboration.

1. Motivation

- Up to now we were concentrated on measurement of neutron flux distribution in the deeply subcritical assembly QUINTA versus axis and radius of the assembly for the neutron energy above 10 MeV applying the proton and deuteron beam of energy from 1 GeV to 8 GeV extracted from the NUCLOTRON accelerator.

- Recently we have applied proton beam of energy 0.66 GeV extracted from the PHASOTRON accelerator. Nuclear data handling of the experiment session turned our attention to the neutron flux density measured on five foil plates in terms of three different neutron energy: 11.5 – 20.8 MeV, 20.8 - 32.7MeV and 32.7 – 100 MeV. This that the neutron density flux for the range of neutron energy 20.8 - 32.7 MeV is higher than for the range of neutron energy 11.5 – 20.8 MeV was not expected feature of the measurement. This unexpected feature of measurement is presented in Fig.1

1. Motivation

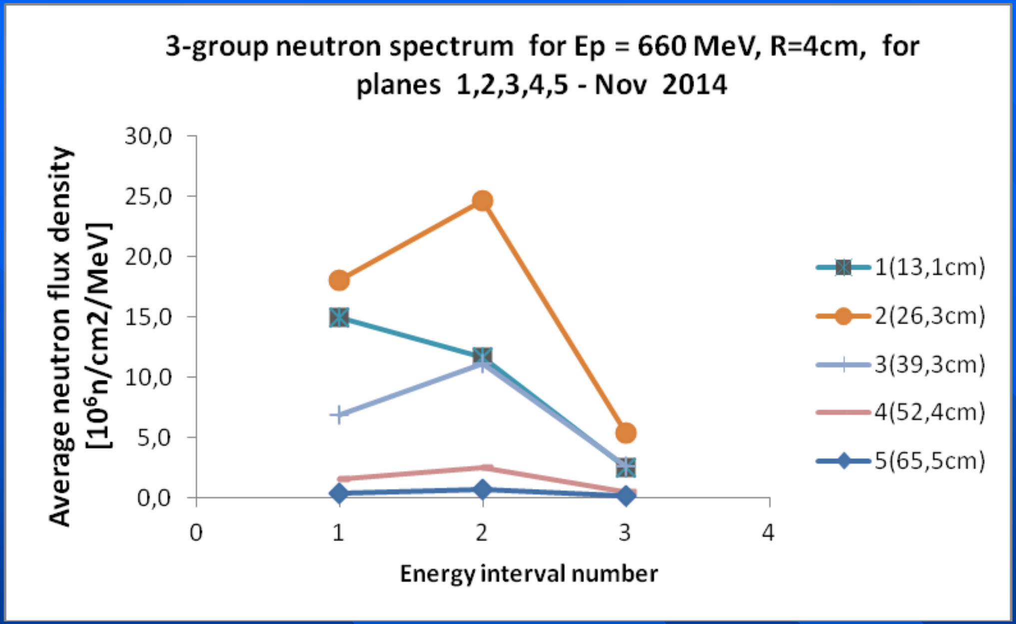


Fig. 1. Average neutron flux density versus three different energy range: 1-> (11,5-20,8 MeV), 2-> (20,8-32 MeV), 3-> (32-100MeV) for R=4 cm and five planes (number of successive planes 1,2, 3, 4 and 5) ; proton beam energy 0.66 GeV; Experiment: Nov 2014.

1. Motivation

- Repeating in the same way data handling for the other planes as in collecting these in one figure it can be noticed that the same effect is observed for the planes 2 – 5 but except the plane 1 which describes the average neutron flux density in the first section where process of spallation begins.

- That is why, that we have found this unexpected feature of average neutron flux in the experiment with the proton beam of energy 0.66 GeV, we have decided to make overview of our experiments performed earlier for the deuteron beam of energy 1 – 8 GeV.

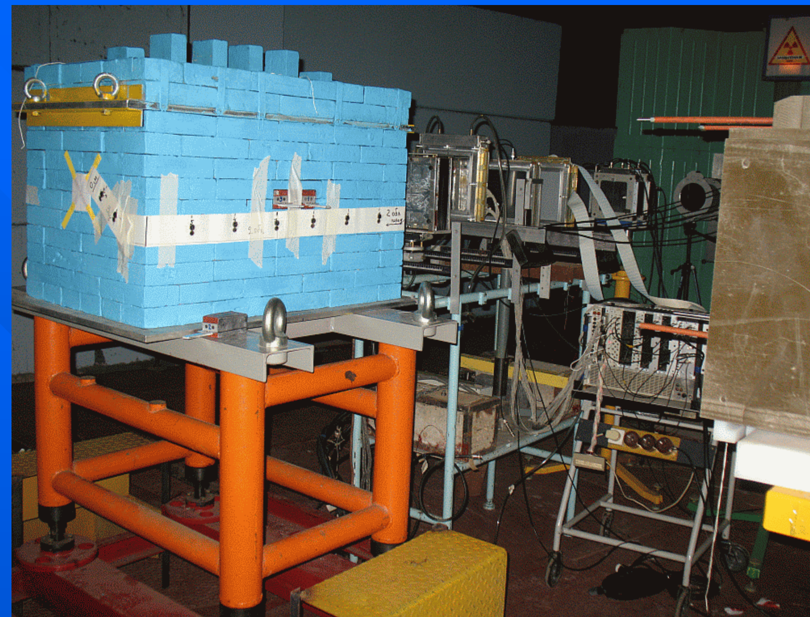
2. **ADS** experiments with two types of beams

Accelerators (Nuclotron – Dubna Russia)

Used accelerator (JINR Dubna):

- **Nuclotron (VBLHE) – wide spectrum of possible energies E_p = 500 MeV to 8 GeV, strong focusing, $10^{12} - 10^{13}$ protons per hour**
- **Phasotron -- one possibile energy E_p = 660 MeV but about 10^{15} protons per hour**

1. QUINTA assembly in and without ofthe lead shield

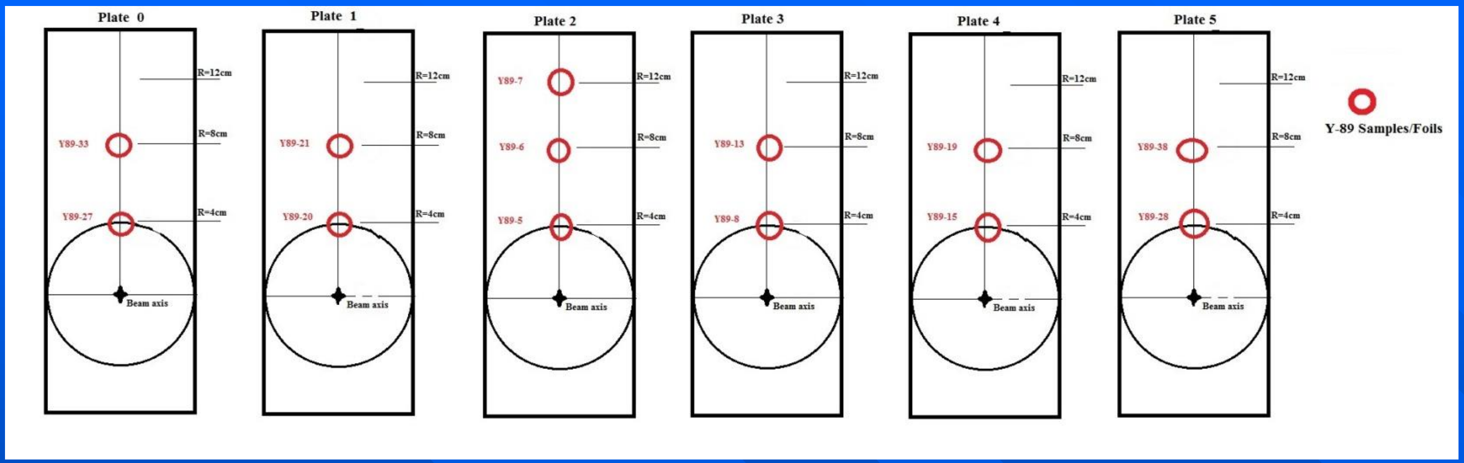


The Quinta sometimes is surrounded by lead bricks 100 mm thick on all six sides of total weight 1780 kg. Shield work as a neutron reflector and as a biological shielding for γ-rays. In the front is a square window 150x150 mm.

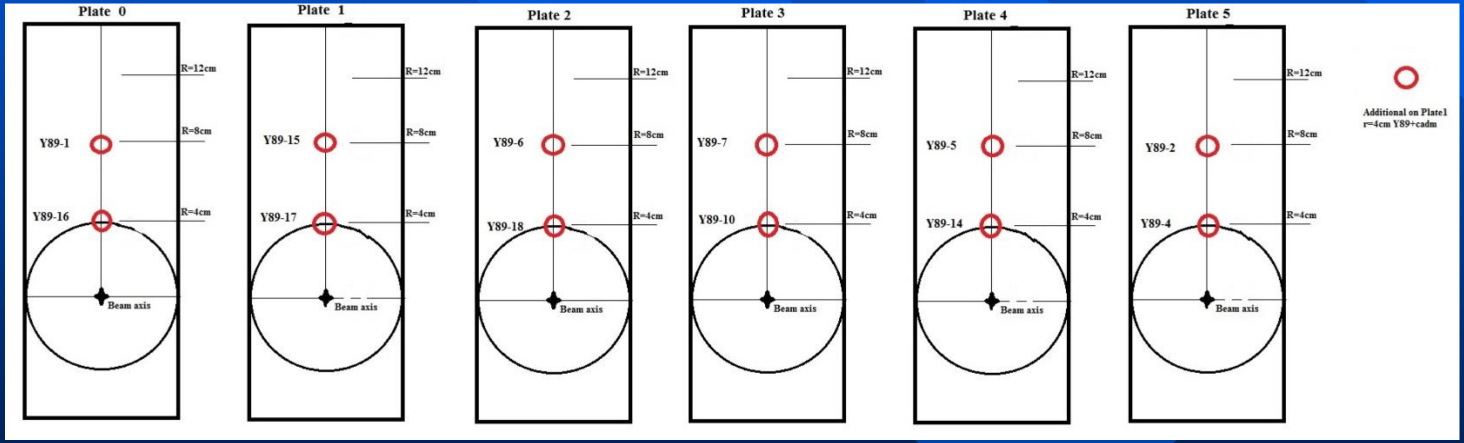
The Quinta assembly, consists of a total of 512 kg of natural uranium. It is composed of five sections, 114 mm long and separated by a 17 mm air gap. The uranium cylindrical rods, 36 mm in diameter, 104 mm in length and 1.72 kg in mass. The first section contains only 54 rods and the removal of the central 7 rods is to create a beam window next sections have 61 uranium roads. This beam window is 80 mm in diameter and serves to reduce the loss of backward emitted/scattered neutrons. The front and back of each section are bounded by aluminum plates 350 x 350 x 5 mm.

2. ADS experiments with two types of beams

Arrangement of the 89Y detectors on the detector plates in the QUINTA Assembly



2014.XI



2011.III

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

2. QUINTA experiments with two types of beams (part 1)

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	4 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 lead shield			Model U/U + Pb shield	
Activation Detectors:	Yttrium 89 – disc shape, h ≅1-2 mm, d = 10 mm				

2. QUINTA experiments with two types of beams (part 3)

Accelerator:	JINR Cyklotron		
Time:	8 Nov 2014	4 Dec 2015	20 Jun 2017
Beam:	Proton	Proton	Proton
Energy:	0,66 GeV	0,66 GeV	0,66 GeV
Irrad. Time:	20 580 s	~20000 s	~18000 s
Collected beem particles:	$8{,}64 \cdot 10^{14}$	$\sim 2 \cdot 10^{15}$	$\sim 2 \cdot 10^{15}$
Target "QUINTA":	Model U/U + Pb shield		Model U/U without Pb shield
Activation Detectors:	Yttrium 89 – disc shape, h ≅1-2 mm, d = 10 mm		

3. Average Fast Neutron Flux Density (10-100 MeV) Overview of our experiments performed in 2011 and 2014 (beam energy 0.66, 2, 4 and 6 GeV).

- Such a behavior of average neutron flux density versus three different energy range can be explained to some extend by dependence of micro cross section in the considered neutron energy range shown in Fig.2.
- The threshold neutron energies of yttrium (n,xn) reactions determine the considered energy ranges.
- In the first energy range 11,5-20,8 MeV the area under the cross section curve of $Y^{89}(n,2n)Y^{88}$ is smaller than in the second energy range of the same reaction. Moreover there is also the area under the curve of $Y^{89}(n,3n)Y^{87}$. Since the measured amount of neutrons is proportional to the area under the cross section curves the results in Fig.1 is understandable.

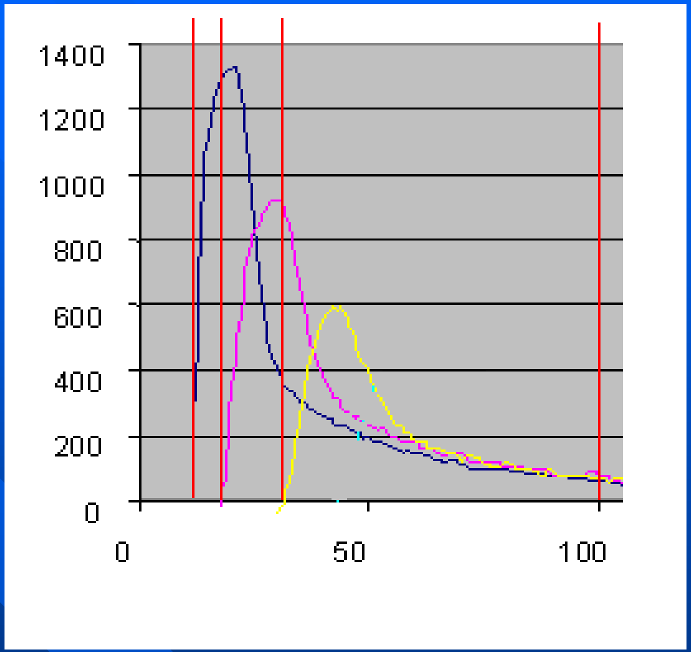


Fig. 2. Cross-sections of the three yttrium (n,xn) reactions – threshold energies: E1 = 11,5 MeV Y88, E2 = 20,8 MeV Y87, E3 = 32,7 MeV Y86

3. Average Fast Neutron Flux Density (10-100 MeV)

Experiment performed in 2014 (beam energy 0.66GeV).

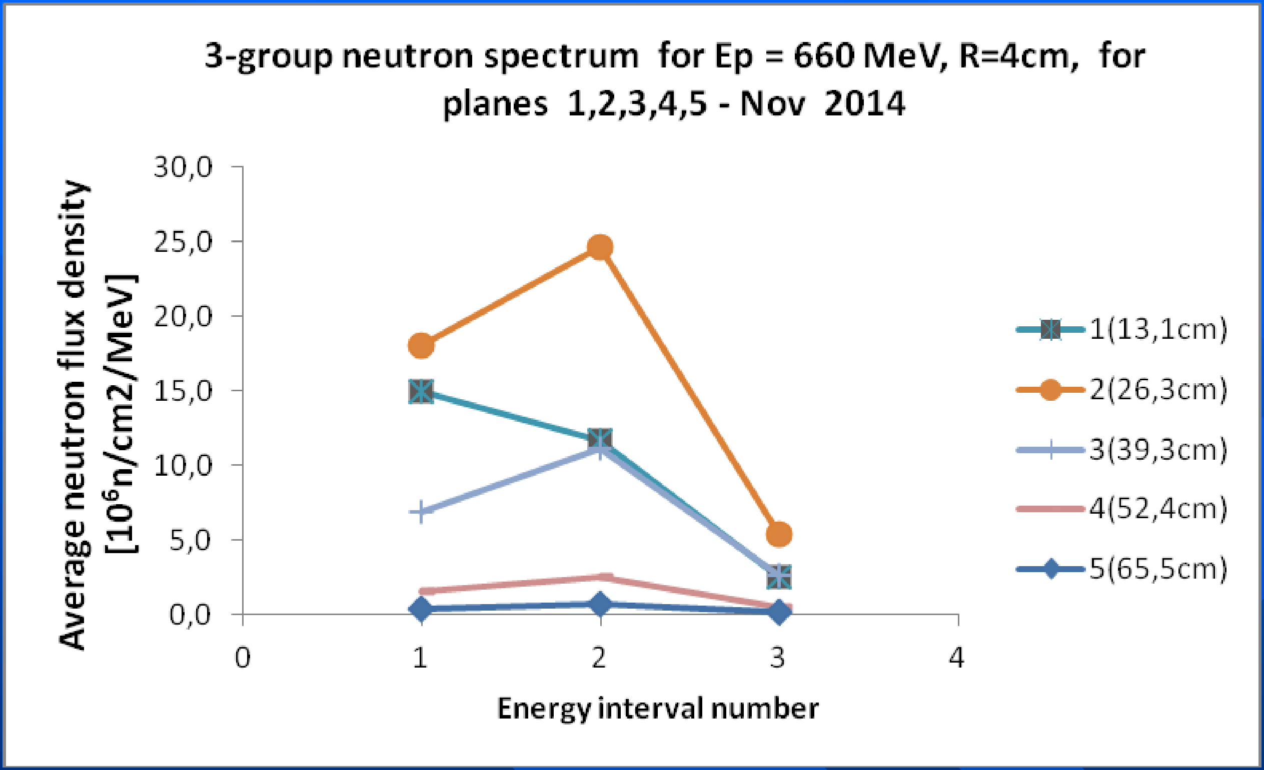


Fig.3. Average neutron flux density versus three different energy range: 1-> (11,5-20,8 MeV), 2-> (20,8-32 MeV), 3-> (32-100MeV) for R=4 cm and five planes (number of successive planes 1,2, 3, 4 and 5) ; proton beam energy 0.66 GeV; Experiment: Nov 2014.

3. Average Fast Neutron Flux Density (10-100 MeV)
Overview of our experiments performed in 2011 (beam energy 2 GeV).

Repeating in the same way data handling as in Fig.3 , for deuteron beam of energy 2 GeV it can be noticed (see Fig. 4) that the same effect is observed for the planes 2, 4 and 5 but except the plane 1 and 3 which describes the average neutron flux density in the first section and third section.

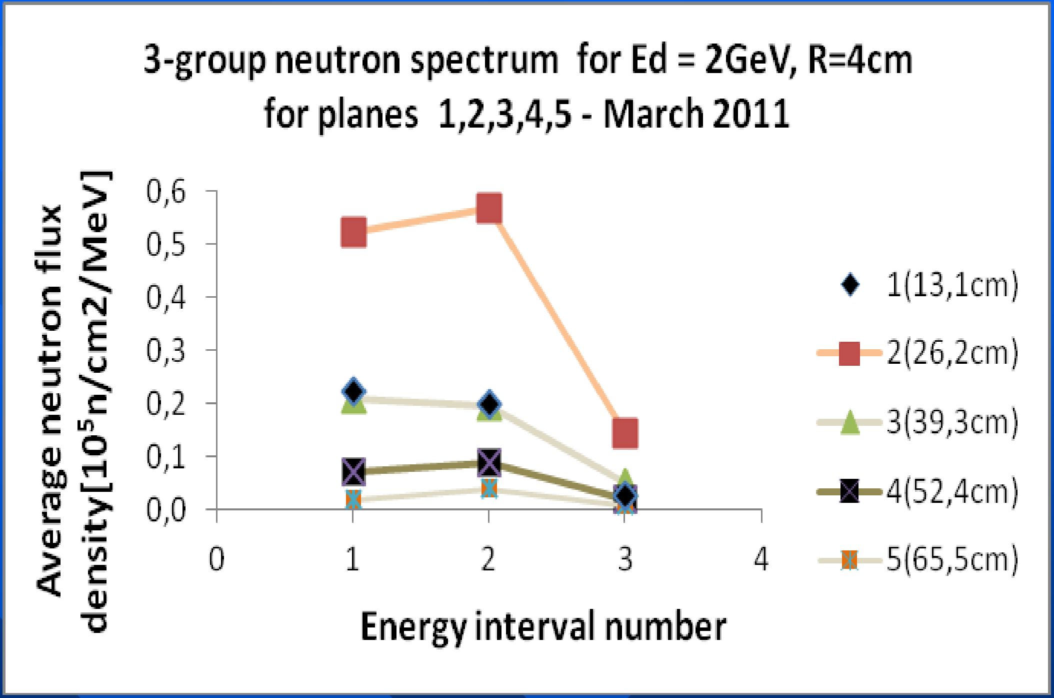


Fig. 4. Average neutron flux density versus three different energy range: 1- (11,5-20,8 MeV), 2- (20,8-32 MeV), 3- (32-100MeV) for R=4 cm and five planes (number of successive planes 1,2, 3, 4 and 5) ; deuteron beam energy 2 GeV; Experiment: III 2011

3. Average Fast Neutron Flux Density (10-100 MeV)
Experiment performed in 2011 (beam energy 4 GeV).

- However the average neutron flux density versus three different energy range: 1- (11,5-20,8 MeV), 2- (20,8-32 MeV), 3-(32-100MeV) for R=4 cm and five planes for deuteron beam of energy 4GeV behaves according to expectation (see Fig.5). In this case the explanation as for the experimental data in Figs 1,2 is not sufficient.

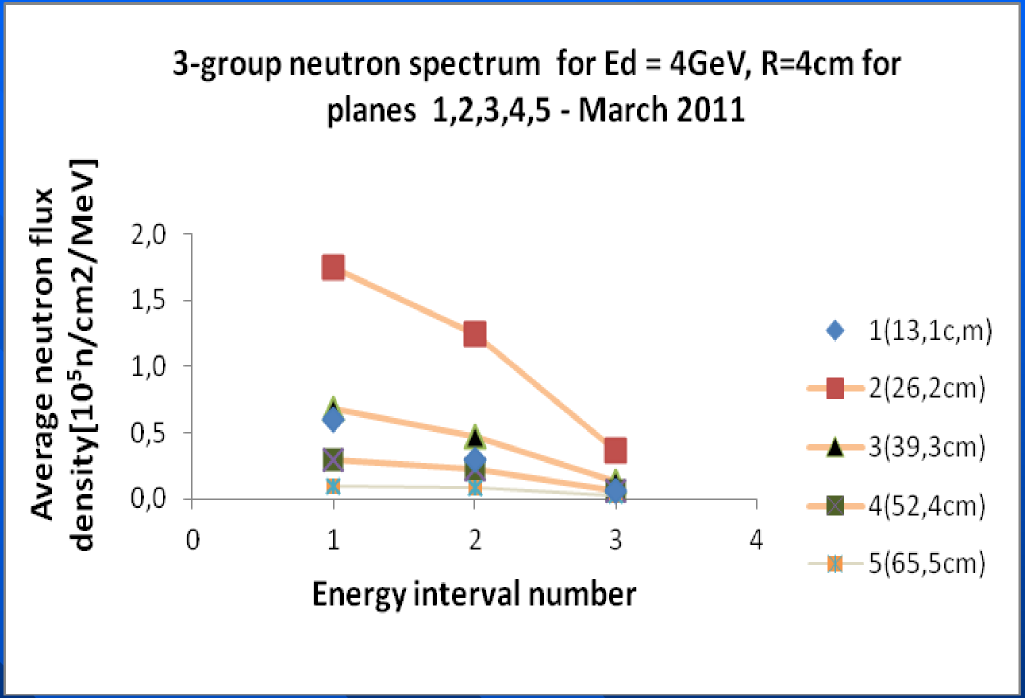


Fig.5. Average neutron flux density versus three different energy range: 1-> (11,5-20,8 MeV), 2-> (20,8-32 MeV), 3-> (32-100MeV) for R=4 cm and five planes (number of successive planes 1,2, 3, 4 and 5) ; deuteron beam energy 4 GeV; Experiment: III 2011

3. Average Fast Neutron Flux Density (10-100 MeV)
Experiment performed in 2011 (beam energy 6 GeV).

- However the average neutron flux density versus three different energy range: 1- (11,5-20,8 MeV), 2- (20,8-32 MeV), 3- (32-100MeV) for R=4 cm and five planes for deuteron beam of energy 6GeV behaves according to expectation (see Fig.6). In this case the explanation as for the experimental data in Figs 1,2 is not sufficient.

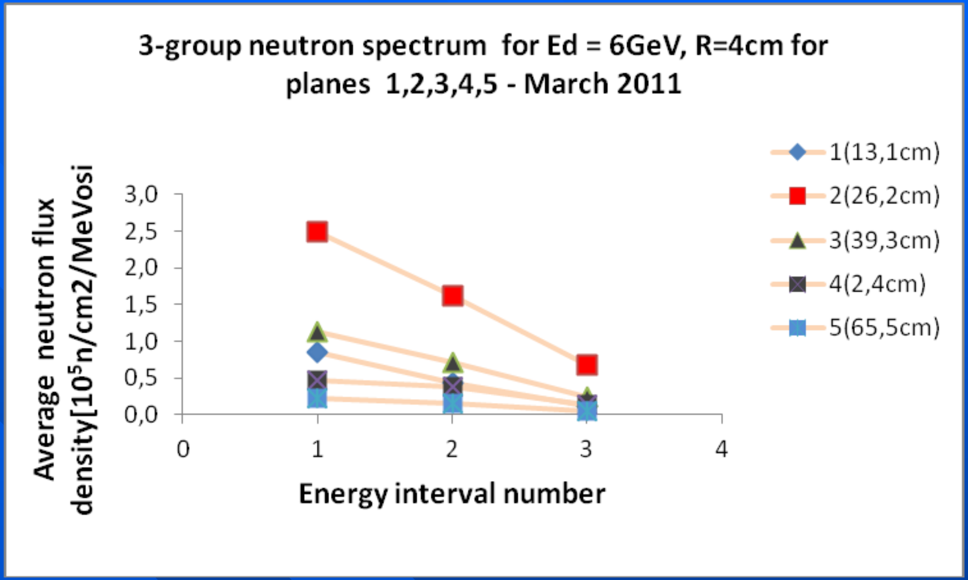


Fig.6. Average neutron flux density versus three different energy range: 1-> (11,5-20,8 MeV), 2-> (20,8-32 MeV), 3-> (32-100MeV) for R=4 cm and five planes (number of succesive planes 1,2, 3, 4 and 5) ; deuteron beam energy 6 GeV; Experiment: III 2011

4. Theoretical calculation.

- Calculations by help of Monte Carlo method [2] show that in the energy range (20,8-32 MeV) the neutron fluence is higher than in the range 11,5-20,8 MeV (see Fig.7) for energy of deuteron beam equal to 1 GeV.

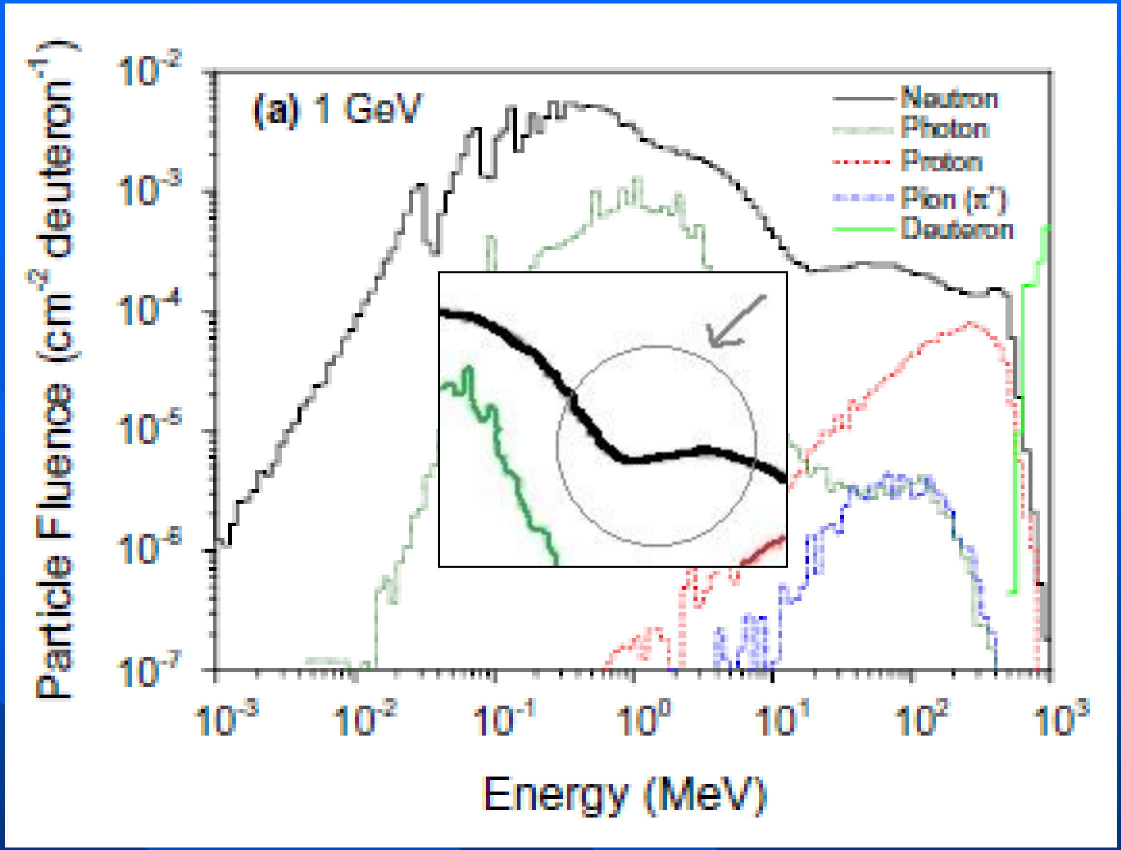
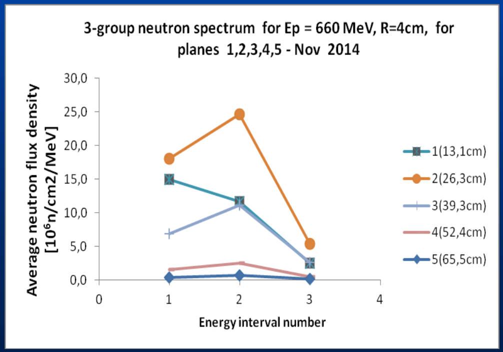
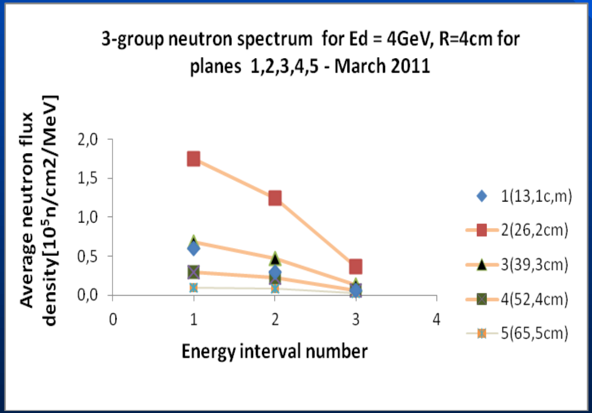


Fig. 7 Neutron spectrum in function of energy (black solid line) for deuteron beam of energy 1 GeV. [2] Asquith N.L., Hashemi-Nezhad S.R., Tyutyunnikov S. at al (2014)



4. Theoretical calculation.

- Only calculations by help of Monte Carlo method [2] show that in the three energy ranges (11,5-20,8 MeV, 20,8-32 MeV and 32-100 MeV) the neutron fluence is continuously decreasing with neutron energy for energy of deuteron beam equal to 4 GeV (see Fig. 8)



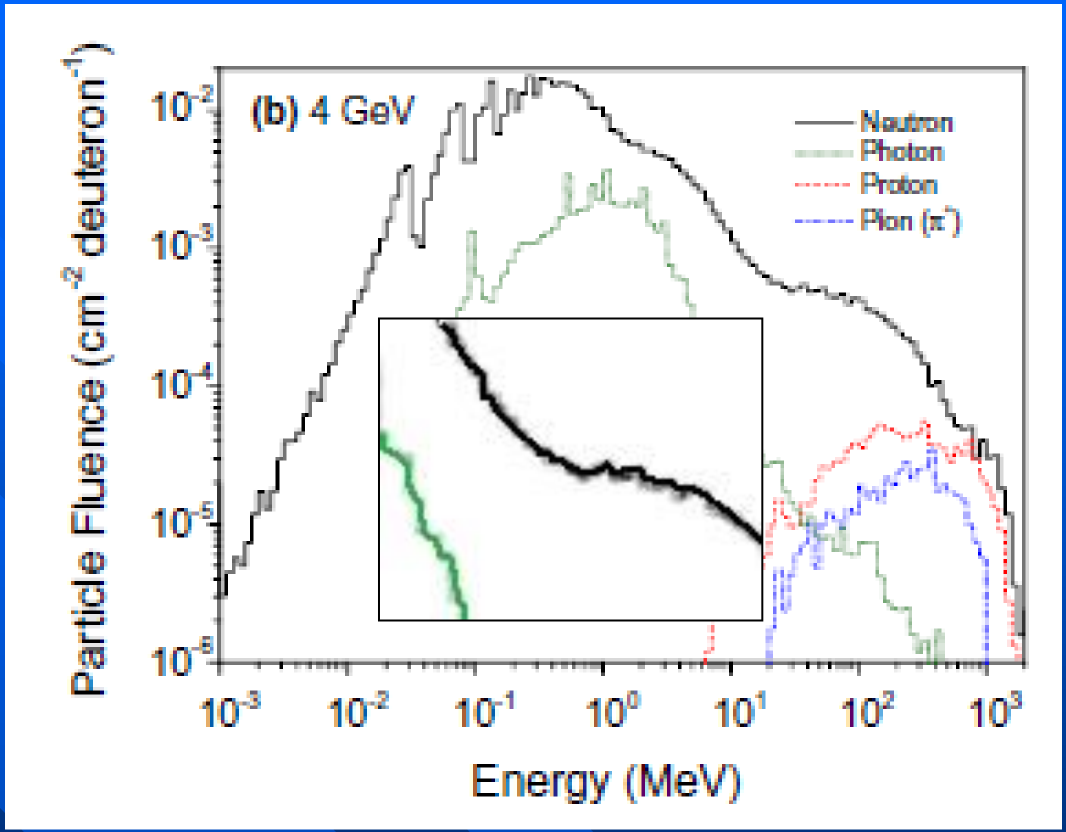


Fig. 8. Neutron spectrum in function of energy (black solid line) for deuteron beam of energy 4 GeV [2] Asquith N.L., Hashemi-Nezhad S.R., Tyutyunnikov S. at al (2014)

4. Theoretical calculation.

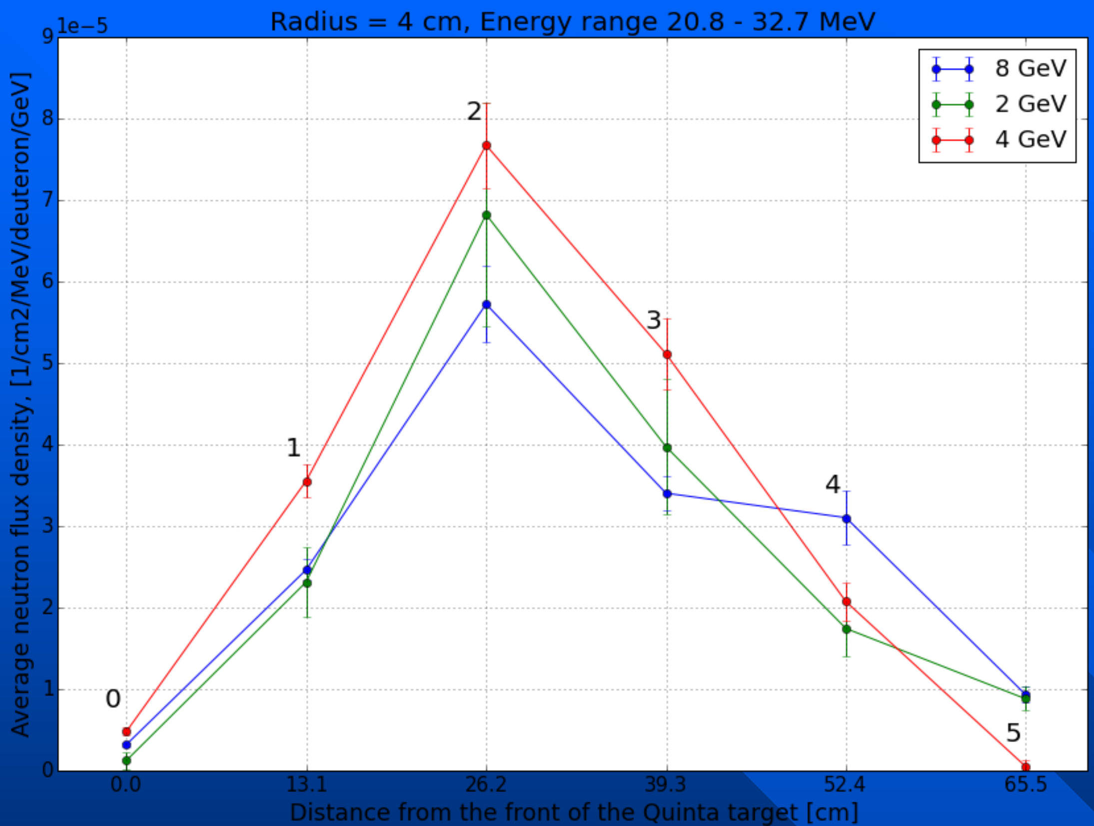


Fig. 3. Average neutron flux density per deuteron and its energy in function of the Quinta target axis at R= 4 cm for three deuteron energies (2-top line, 4 middle line, 8-bottom line at position “2”-26.2cm) GeV, in the neutron energy range (20.8 – 32.7 MeV). Errors range < 20%.

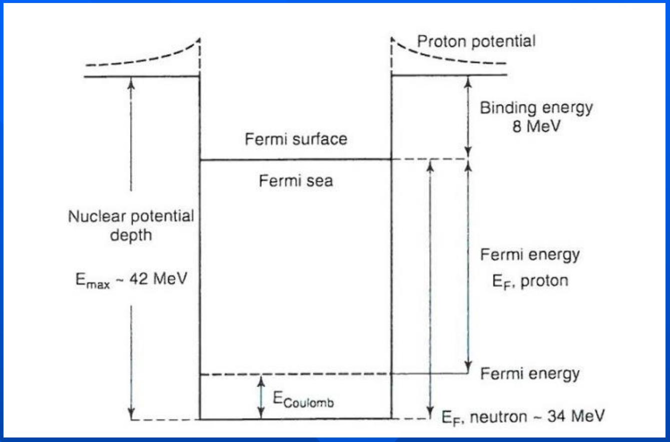


Fig. 4 Example for potential well for protons and neutrons [15] D. Filges, F. Goldenbaum, Handbook of Spallation Research, Wiley-Vch (2009)

5. Conclusions

- This short analysis carried above let us to infer that neutron flux density in the range above 10 MeV should be our concern in the future experimental research.
- Theoretical analysis carried out by authors [2] using MC method explain to some extant our experimental observation.
- The presented above tendencies are vague and need to be checked in next experiments because we don't clearly see this effect in all our experimental results.
- Though the measured amount of neutrons proportional to the area under the cross section curves in the energy range 11.5 – 20.8 MeV explain the results for proton or deuteron beams in the range of 0.66 and 2 GeV, however it does not explain the behavior of average neutron flux for higher energy than 2 GeV of different beams.
- The measurement of high neutron flux density and explanation of the results are still needed to be developed by additional experiments and calculation.

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Thank you for the cooperation