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Calculations of Neutron Yield and Gamma Rays Intensity by GEANT4

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Abstract. The possibility of obtaining neutron beams using the extracted proton beam of a cyclotron C18/18 was investigated. The calculation of neutron spectra from protons on ^{9}Be target neutron source was performed by GEANT4 application. An accompanying gamma yield was simulated also. A comparison of the spectra of neutrons and gamma rays to determine the optimal conditions for the effective suppression of gamma background in future experiments was done. The methods of suppression gamma were considered. The absorber material and its optimal thickness were determined by GEANT4 calculations.

Keywords: GEANT4, cyclotron C18/18, proton beam, neutron yield, gamma rays

1. Introduction

The work is dedicated to the formation of neutron beams based on the external proton beam of cyclotron C18/18 from IBA. The cyclotron C18/18 produces proton beam with energy 18 MeV and current of up to 100 μA. The obtained neutron beams will be used for investigation the neutron-induced reactions as well as for applied problems.

The modified C18/18 has a special vacuum tube for passing protons through it. Before bombarding the target, proton beam pass through the 500 μm foil from Al which is installed for keeping the vacuum inside the tube. After passing through the Al foil protons lose part of the energy from 18 MeV to 14.8 MeV. In Table 1 are listed ^{9}Be (p,xn) reactions, which thresholds less than 14.8 MeV.

Reaction	Q-value, MeV	Reaction threshold, MeV
$p + {}^{9}Be \rightarrow {}^{9}B + n$	-1.8504	2.0572
$p + {}^{9}Be \rightarrow {}^{9}B + n + \gamma$	-1.8855	2.057
$p + {}^{9}Be \rightarrow {}^{8}Be + p + n$	-1.6645	1.8507
$p + {}^{9}Be \rightarrow {}^{8}Be + p + n + \gamma$	-1.7011	1.8507
$p + {}^{9}Be \rightarrow {}^{5}Li + \alpha + n + \gamma$	-3.5377	3.9333
$p + {}^{9}Be \rightarrow 2\alpha + p + n$	-1.5727	1.74859

Table 1. ^{9}Be (p,xn) reactions which thresholds are less than 14.8 MeV

2. GEANT4 model of the experiment

The neutron spectra, neutron/gamma yield ratio as a function of target thickness, absorber material and its thicknesses are received by using the GEANT4 [3].

GEANT4 (for **Geometry and Tracking**) is a platform for the simulation of the passage of particles through matter, using Monte Carlo methods. It is the successor of the GEANT series of software toolkits developed by CERN, and the first to use object oriented programming (in C++). Its development, maintenance and user support are taken care by the international Geant4 Collaboration. Application areas include high energy physics and nuclear experiments, medical, accelerator and space physics studies. A number of research projects around the world use the software.

GEANT4 includes facilities for handling geometry, tracking, detector response, run management, visualization and user interface. For many physics simulations, this means less time needs to be spent on the low-level details and researchers can start immediately on the more important aspects of the simulation.

Following is a summary of each of the facilities listed above:

- Geometry is an analysis of the physical layout of the experiment, including detectors, absorbers, etc., and considering how this layout will affect the path of particles in the experiment.
- Tracking is simulating the passage of a particle through matter. This involves considering possible interactions and decay processes.
- Detector response is recording when a particle passes through the volume of a detector and approximating how a real detector would respond.
- Run management is recording the details of each run (a set of events), as well as setting up the experiment in different configurations between runs.

GEANT4 offers a number of options for visualization, including OpenGL, and a familiar user interface, based on Tcsh.

In the model created for the experiment used physics lists are EmStandard for electromagnetic processes and G4HadronPhysicsQGSP_BERT_HP for hadronic processes.

In the GEANT4 simulation was taken into account the arrangement of future experiment. The target with radius 5mm must be installed after the vacuum tube at 3cm distance. Proton beam with radius of the target must be passed through the 3cm air then hit the target. Installed virtual sensitive detector has a shape of tube with 2.5 cm radius and 20 cm length.

3. Gamma rays attenuation

Neutrons will be detected using time-of-flight method using the neutron detector located at the distance 2 m.

The neutron flux output dependence on the thickness of the ^{9}Be target was calculated by the program GEANT4.

First of all the optimal thickness of the target for obtaining higher yields of neutrons was determined. The simulation by GEANT4 of the obtaining energy spectra of neutrons for 2.5 mm thickness of Be target at proton beam energy 14.8 MeV was performed. The thickness of the beryllium 2.5 mm corresponds to the thickness of the stopping of protons with an energy of 14.8 MeV in Be. Using the target thicker than 2.5 mm is not productive, because in this case the emitted neutrons will be absorbed.

While doing calculations took into account that the Be target is located at a distance of 3 cm from beam line in the air.

Therefore, as an optimal thickness of the target ^{9}Be to produce neutron beams, thickness of 2.5 mm on the base of GEANT4 simulation was chosen, for which further calculations were performed.

However, there is a significant problem for detecting neutrons caused by the high intensity accompanying gamma rays. As shown in Figure 2, the total number of gamma rays exceeds the total number of neutrons. This excess is about 1.83.

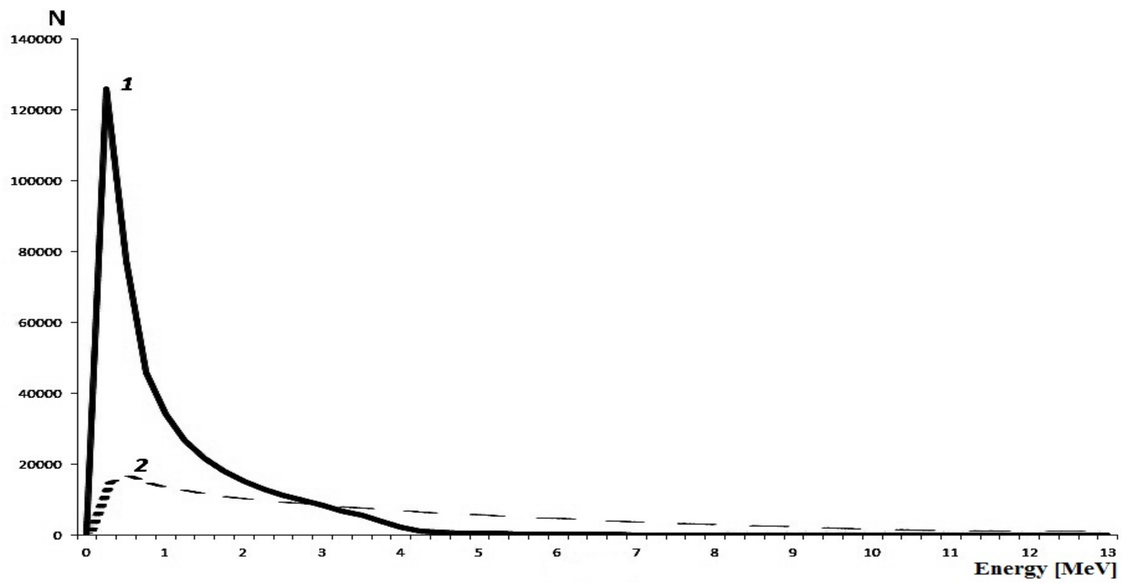


Figure 2. The energy spectra of gamma rays (1) and neutrons (2) after 3 cm air and 2.5 cm Be

For decreasing intensity of gamma rays in [4] is considered the installing sheets from different materials. Figure 3 shows that lead sheet decreases gamma rays better than other material.

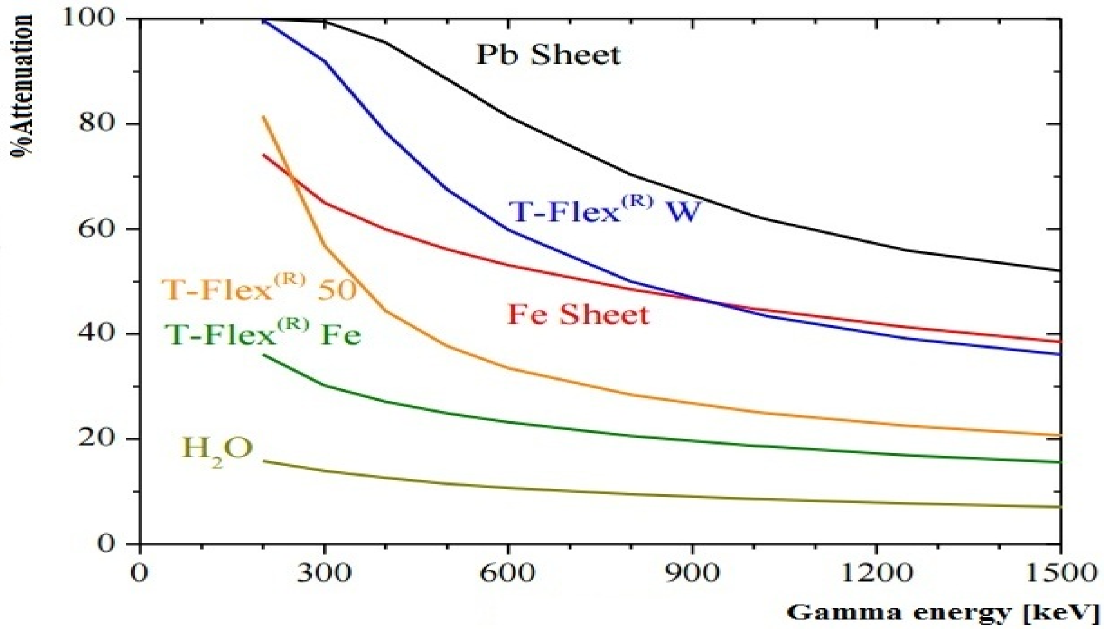


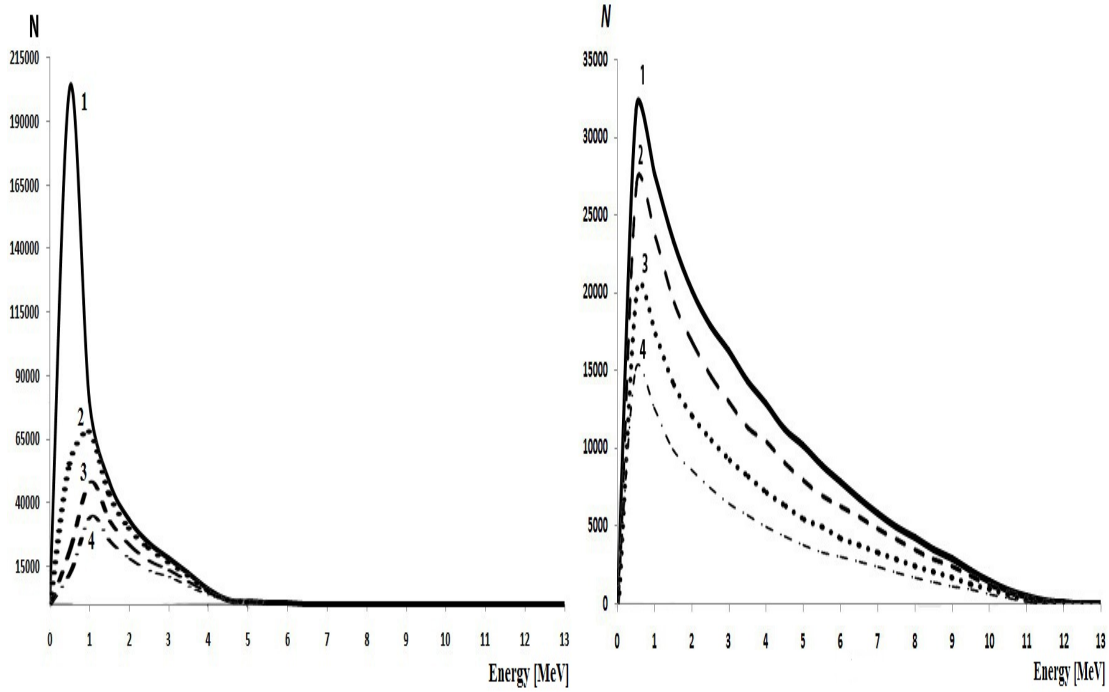
Figure 3. Attenuation of gamma radiation versus gamma energy for half inch (1.27 cm) thicknesses of selected shielding types [2]

In order to select the optimum thickness of the lead sheet, the GEANT4 simulation of passage neutrons and gamma obtained was performed. Neutrons and gamma tracking through lead sheets for 0.5cm, 1.27 cm and 2 cm thicknesses.

In Figures 4a and 4b are presented GEANT4 calculations of the energy spectra of gamma rays and neutrons respectively without lead sheet and with lead sheet of thicknesses 0.5 cm, 1.27 cm and 2 cm. Figure 5 (a-d) clearly shows that increasing the thickness of lead sheet results in a decrease of the gamma rays with respect to the neutron yield. In Figure 6 the neutron-gamma ratio dependence on the lead sheet thickness installed after the 2.5 mm Be target is depicted. Table 2 lists the summary results neutrons/gamma rays ratio for 2.5 mm Be target.

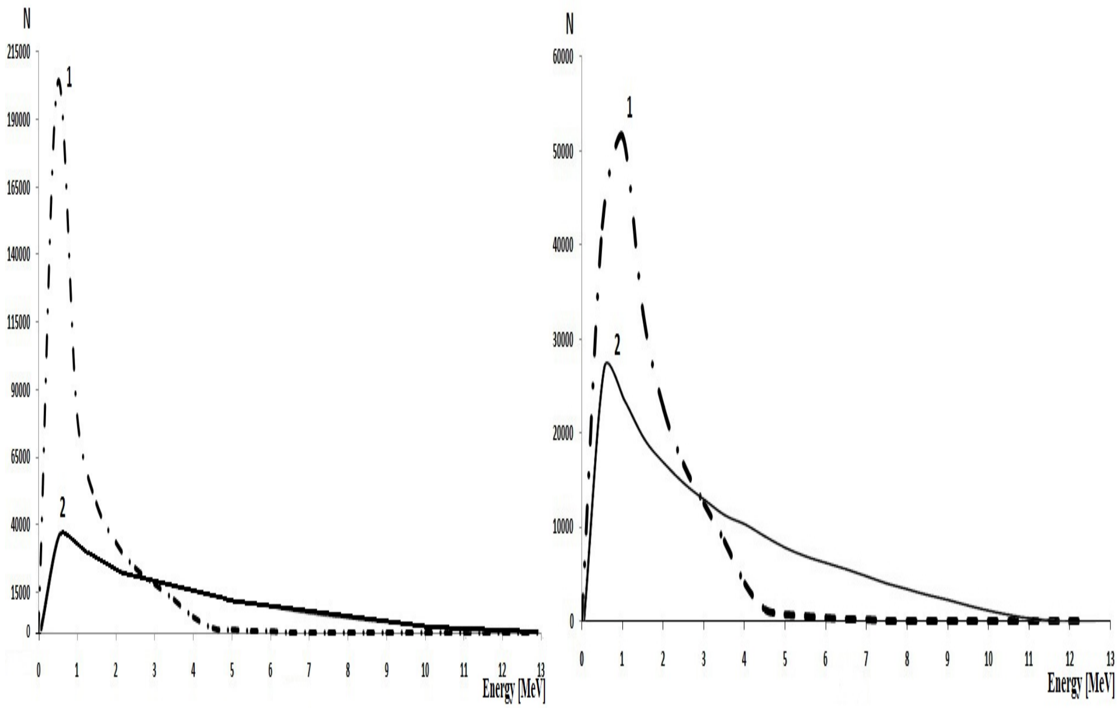
Thickness of lead (cm)	0	0.5	1.27	2
$N_{neutrons}/N_{gamma}$	0.55	0.99	1.35	1.67

Table 2. Neutron/gamma ratio for different thicknesses of lead sheets installed after 2.5 mm Be target



a) **b)**

Figure 4. Energy spectra of gamma rays (a) and neutrons (b) for 2.5mm Be target. 1) without Pb, 2) 0.5cm Pb, 3) 1.27 cm Pb, 4) 2 cm Pb



a) **b)**

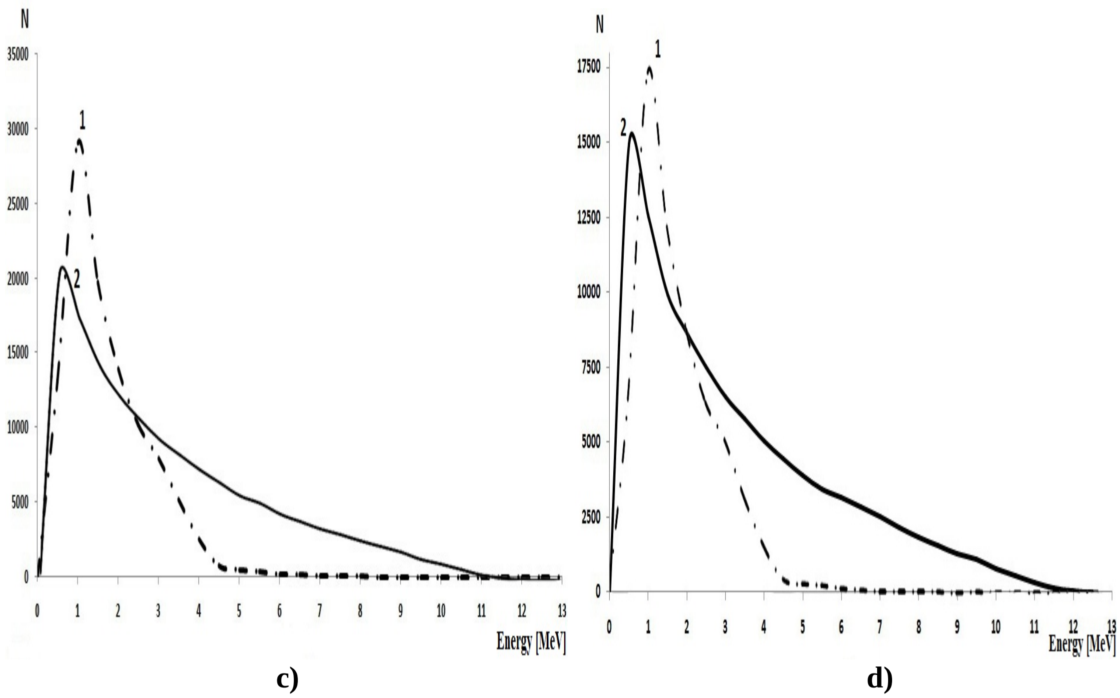


Figure 5. Energy spectra of gamma rays (1) and neutrons (2) for 2.5mm Be target. a) without Pb, b) 0.5 cm Pb, c) 1.27 cm Pb, d) 2 cm Pb

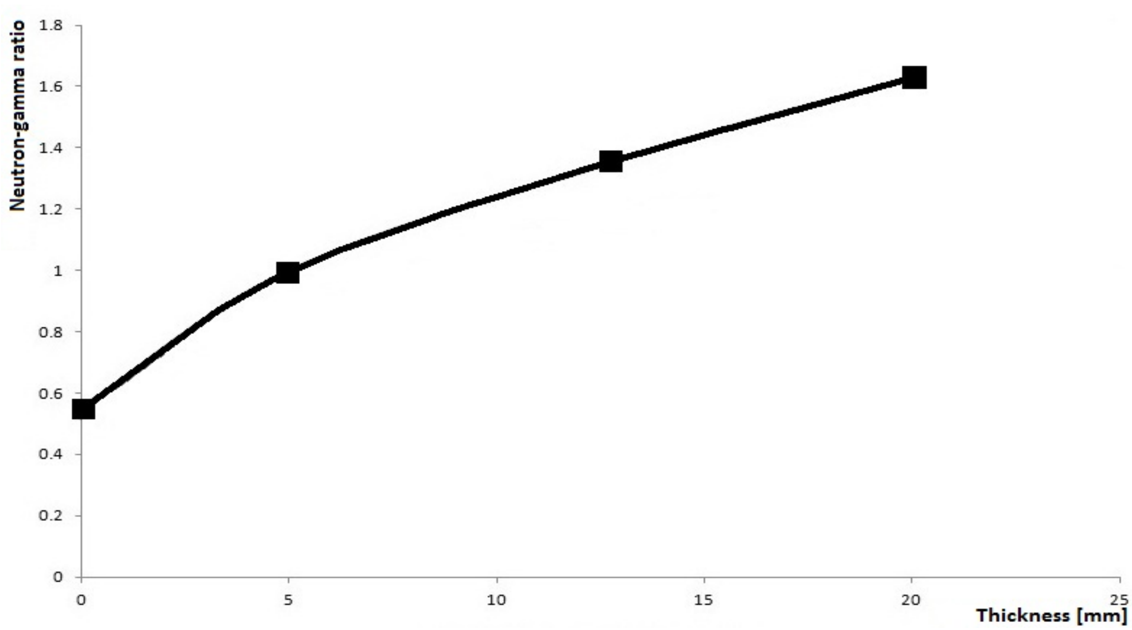


Figure 6. Neutron/gamma ratio for different thicknesses of lead installed after 2.5 mm Be

In the simulation by GEANT4 the virtual neutron detector is located at 2 m distance after the target as it is planned in the future experiment using time-of-flight method. In Figure 7 is presented the simulated energy spectra of neutrons in detector at the distance of 2 m from the target without lead sheet and with lead sheet of different thicknesses.

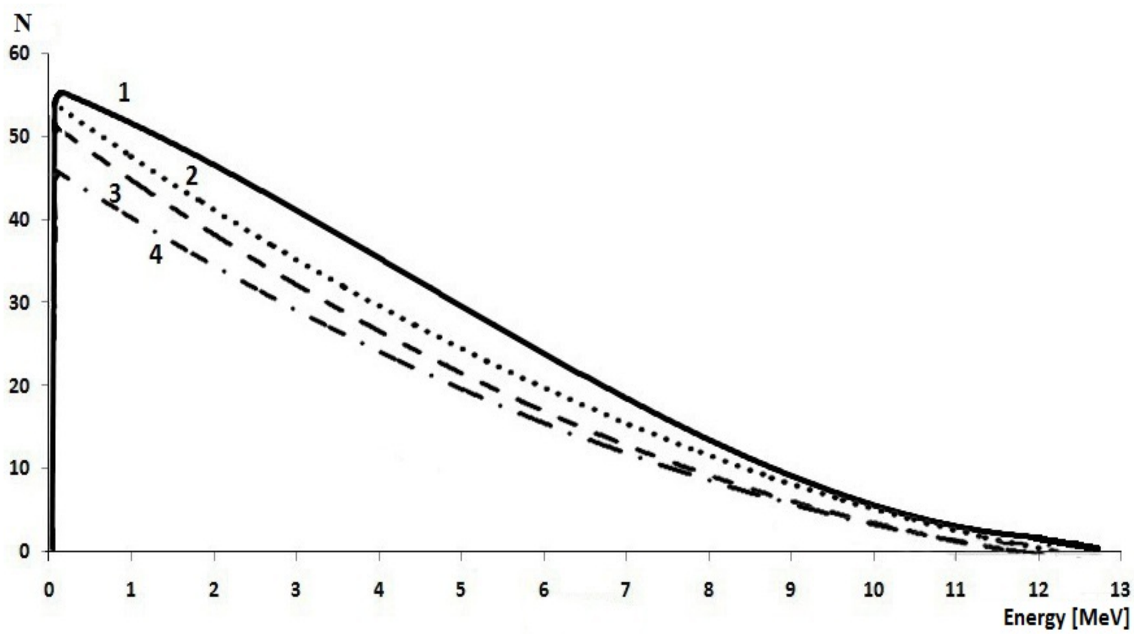
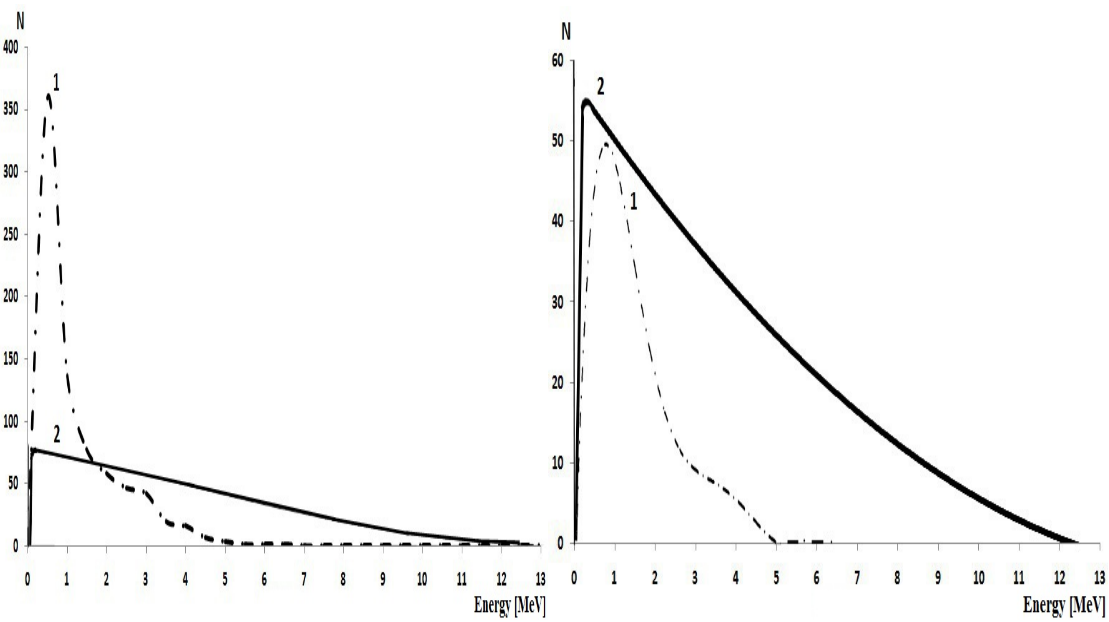
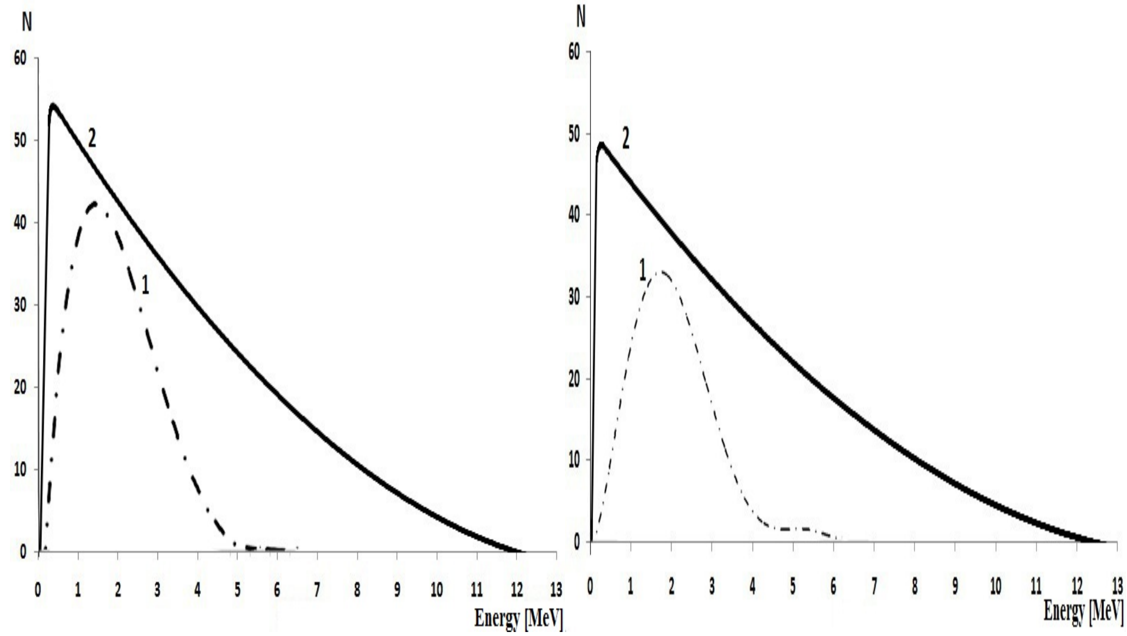


Figure 7. Energy spectra of neutrons in detector at 2 m distance for 2.5mm Be target.
1) without Pb, 2) 0.5cm Pb, 3) 1.27 cm Pb , 4) 2 cm Pb

In Figure 8 are presented the simulated by GEANT4 energy spectra of neutrons and gamma rays at 2 m distance. Table 3 shows the ratio of neutrons and gamma rays in the location of neutron detector.



a) **b)**



c) **d)**

Figure 8. Energy spectra of gamma rays (1) and neutrons (2) in detector at 2 m distance for 2.5 mm Be target. a) without Pb, b) 0.5cm Pb, c) 1.27 cm Pb, d) 2 cm Pb

Increasing the thickness of lead sheets causes a decrease of yield of gamma rays and the relative growth of the neutron yield. Without installing a layer of lead sheet yield of gamma is greater than the neutron yield (Figure 8a). Further increasing of the lead sheet thickness (Figure 8a, 8b) leads to that the neutron yield exceeds the yield of gamma rays. At the same time gamma rays with energies above 6 MeV (Figure 8, b-d) is completely absorbed. When the thickness of the lead sheet is 2 cm the excess of neutron yield over gamma rays significantly (Figure 8d).

Thickness of lead (cm)	0	0.5	1.27	2
$N_{neutron}/N_{gamma}$	0.84	1.64	2.56	3.33

Table 3.Neutron/gamma ratio at 2 m distance for different thicknesses of lead sheet installed after 2.5 mm Be target

4. Summary

Monte - Carlo simulation with the GEANT4 toolkit of energy distribution of the secondary neutrons and gamma rays after thick (2.5mm) Be target for 14.8 MeV proton energies was performed. The optimum thickness of the beryllium target to get the maximum yield of neutrons is 2.5 mm. The energy distribution of neutrons and gamma rays after lead sheets with thicknesses 0.5cm, 1.27cm and 2 cm, installed after the Be target was calculated.

The effective option for getting more neutrons at 2 m distance after the target system (Be target with lead sheet) is the using 2.5 mm Be target and 1.27 cm lead sheet. In this case, intensity of gamma rays will be less than the yield of neutrons in the energy range up to 13MeV.

In the future, we plan to design using GEANT4 and create a beam shaping assembly consisting of the moderator and reflector for the formation of low-energy neutron beams for scientific and applied problems.

Acknowledgments

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