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THE STUDY OF GAMMA RADIATION PARAMETERS ON THE COMPUTER MODEL OF THE NEUTRON SOURCE ON THE LINEAR ELECTRON ACCELERATOR

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In the Geant4 software, with the help of the computer model of the neutron source at the output of the linear electron accelerator, the main characteristics of gamma radiation were determined at the location of the irradiated samples and outside on top of the lead shielding on the large detector. We conducted several computer experiments on 10^7 primary electrons with an energy of 25 MeV. The analysis of the obtained data showed that the graphite neutron reflector is also an effective reflector of low-energy gamma quanta ($E_\gamma < 1$ MeV), its presence increased the flow of gamma quanta of these energies at the small detector by 30%. At the same time, lead protection reduced the gamma background on the samples and in the bunker by more than 20 times. The performed calculations proved that lead shielding with a thickness of 5 cm is sufficiently effective for conducting experiments on neutron programs at primary electron energies of 25 MeV.

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INTRODUCTION

To carry out research in the field of fundamental and applied nuclear physics, energy and nuclear medicine, a significant number of experiments are needed to study the effect of radiation on the properties of materials. Currently, there is a great need for facilities that can be used as neutron and gamma radiation sources to create radiation conditions that are adequate to the operating conditions of the materials and devices under study as a part of detector systems. For this purpose, we have developed a compact neutron source based on the LUE-30 linear electron accelerator [1, 2].

The LUE-30 linear electron accelerator has the following characteristics: the beam energy varies in the range of 7…30 MeV, the average current is – 1…60 μA. The developed neutron source is based on the well-known principle, which is as follows. Electrons leaving the accelerator bombard a metal target with a high Z (for example, tungsten). The resulting gamma bremsstrahlung radiation interacts with the atoms of the same target and as a result of reactions (γ, n) a flow of neutrons is generated. It is known that to obtain the maximum yield of neutrons, the thickness of the target should be at least 5 radiation lengths. For tungsten, the radiation length is 0.17 cm for an electron energy of 25 MeV. Therefore, we chose the thickness of the W-target equal to 0.8 cm. The target consists of 4 tungsten plates with a thickness of 2 mm and a transverse size of 20x20 mm. The distance between the plates is 1 mm.

The neutron source will be installed at the output of the linear electron accelerator LUE-30. It will consist of an electron-neutron converter, a neutron reflector, lead shielding from the accompanying gamma background around the reflector, a neutron detector, lead shielding around the detector, and a polyethylene box to obtain neutron fluxes of various energies. The system is quite compact, it will consist of several parts, its linear dimensions will not exceed 60 cm, so if necessary (experiment) it can be mounted within a few hours. After conducting experiments using neutron fluxes, this system is quickly dismantled so as not to interfere with other studies.

The electron beam from the linear accelerator is led through a hole in the lead shield and a graphite reflector to a total absorption electron-neutron converter. The generated neutron flux, partially reflected, partially absorbed by the reflector, passes through the lead shield, is insulated with a polyethylene box, and is recorded by a neutron detector. The scheme of the neutron source presented in Fig. 1.

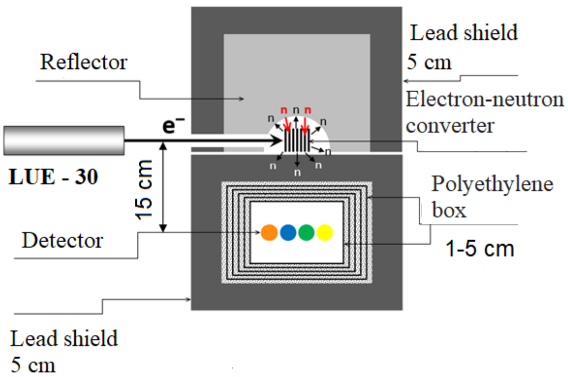

Fig. 1. The scheme of the neutron source *on the linear accelerator*

The characteristics of neutron fluxes that can be obtained using the neutron source we developed were described earlier [1, 2]. The purpose of this work is to study, using a computer model in a programming environment Geant4 [3], the main characteristics of gamma radiation arising during the operation of a neutron source at the LUE-30 linear electron accelerator.

This study is necessary both for the correct conduct of experiments using neutron irradiation, and for determining the necessary conditions for the safe operation of a neutron source.

DESCRIPTION OF THE COMPUTER MODEL OF THE NEUTRON SOURCE

In the works, a computer model of a neutron source at the output of a linear electron accelerator in the Geant4 environment was developed using PhysList QGSP_BERT_HP. The hadronic part of this physical writing consists of elastic, inelastic processes, capture and separation processes. Each process consists of a set of sections and interaction models that provide a detailed physical implementation. As it was said above, the neutron-producing target of the neutron source consists of 4 tungsten plates with a thickness of 2 mm and a transverse size of 20x20 mm. The distance between the 1 mm plates was 1 mm for effective cooling of the entire assembly. The screenshot of the neutron-producing target model is shown in Fig. 2.

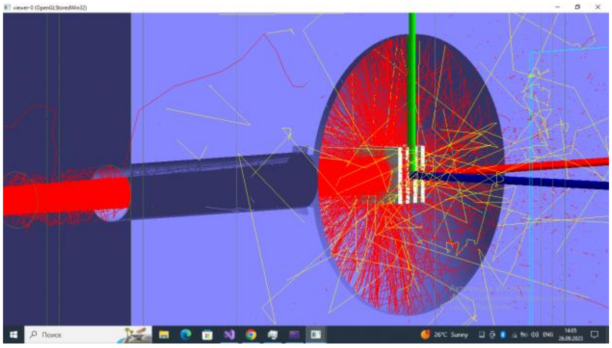

Fig. 2. The Computer model of the neutron-producing target

The red color shows a beam of electrons passing from the accelerator through the lead shield and a hole in the reflector to the neutron-producing target.

When modeling in GEANT4, the parameters of the incident electron beam (energy spectrum, spatial distribution) were consistent with experimental data. The performed modeling proved that the neutron yield at an electron energy of 25 MeV is $5 \cdot 10^{-3}$ N_n/N_e. Neutron sources based on the interaction of gamma radiation with a nucleus are characterized by a neutron energy spectrum with the most probable energy of 0.6 MeV and an average of 1.8 MeV. The resulting spectrum of neutrons from a neutron-producing target is shown in Fig. 3.

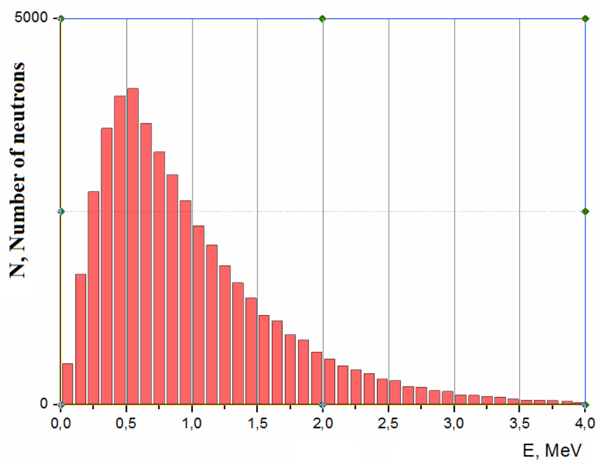

Fig. 3. Energy spectrum of a neutron source

OPERATION WITH THE COMPUTER MODEL OF THE NEUTRON SOURSE

In the work, with the help of a computer model of a neutron source at the output of a linear electron accelerator, the main characteristics of gamma radiation from a neutron-producing target in the primary electron energy range of 5…30 MeV were determined. Spectra of gamma quanta for primary electron energies of 5, 10, 15, 20, 25, and 30 MeV obtained with the help of a 4π detector installed around tungsten plates are presented in Fig. 4. Modeling was carried out for 10^7 primary electrons.

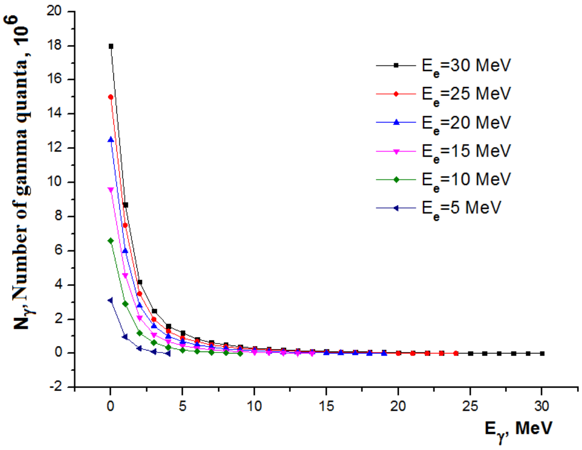

Fig. 4. Energy spectra of gamma quanta for electron beam energies 5, 10, 15, 20, 25, 30 MeV

Fig. 4 shows that as the energy of the primary electron beam increases, first of all, the number of generated gamma quanta increases (especially with low energies of 1…2 MeV). Also, for a small part of the particles, the energy increases to values corresponding to the energy of the electron beam.

For all energies presented in the work, the value of the total yield of gamma quanta $K=N_\gamma/N_e$ per one incident electron was calculated. In Fig. 5 the dependence of the gamma quanta yield K on the energy of the electron beam is presented.

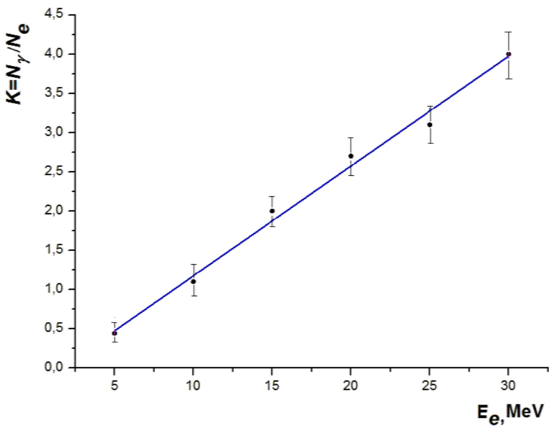

Fig. 5. The dependence of the gamma quanta yield K on the energy of the electron beam

It can be seen from Fig. 5 that the dependence of the coefficient K is well approximated by a straight line. From Fig. 5 it can be seen that in the energy range of operation of the LUE-30 accelerator, the number of gamma rays that are generated increases 10 times. In the work, the average statistical error was determined as the square root of the number of registered events. The modeling error is also shown in Fig. 5.

As is known, the operation of a linear electron accelerator is regulated by background radiation standards specified in the sanitary passport. The maximum operating mode is determined by measuring the fluxes of gamma rays and neutrons at control points when the accelerator beam hits a tungsten target without lead protection. Taking into account the obtained energy spectra and dependencies, we were able to evaluate additional safe operating modes of the accelerator, which do not exceed the mode specified in the sanitary passport.

As is known, bremsstrahlung gamma quanta do not propagate isotropically from a tungsten target, but have a preferred direction along the beam axis in the direction of electron motion.

To determine the inhomogeneity of gamma quanta fluxes in different directions, the 2π detector was installed on the axis of the electron beam. The print screen of a computer model of the neutron source with the 2π detector is shown in Fig. 6.

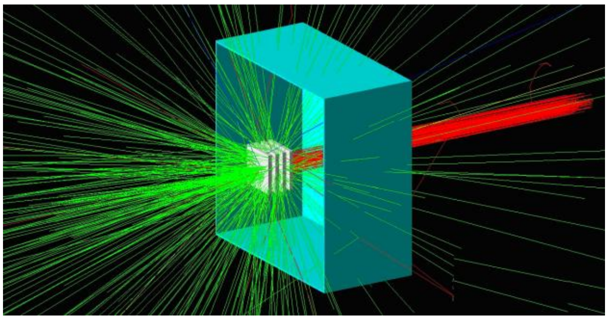

Fig. 6. The Computer model of the neutron source with 2π detector

In Fig. 6 shows in red an electron beam that hits a neutron-producing target consisting of 4 tungsten plates. The 2π detector is shown in blue, the gamma quanta flux is shown in green.

It can be seen from Fig. 6 that the flux density of gamma quanta into the hemisphere forward along the motion of the electron beam is significantly greater than into the rear hemisphere. The energy spectra of gamma quanta and their number in the front and rear hemisphere were determined by the motion of the beam for electron energies of 5, 10, 15, 20, 25, 30 MeV using the 2π detector.

The characteristic energy spectra in the front and rear hemispheres for the electron energy of 20 MeV shows in Fig. 7.

From Fig. 7 we can see, that not only a larger number of gamma rays flies into the front hemisphere along with the movement of the electron beam, but their energy is greater than in the rear hemisphere. In this case, the total number of gamma rays that fall into the front hemisphere is 3 times greater than into the rear hemisphere.

This fact must also be taken into account when calculating the radiation protection of a neutron source at the output of an electron accelerator.

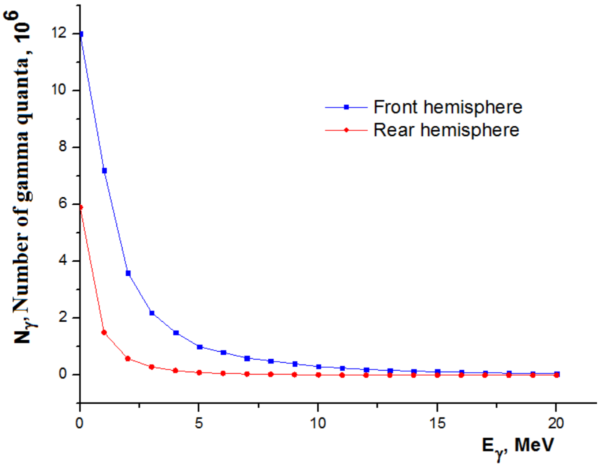

Fig. 7. Energy spectra of gamma quanta in the front and rear hemisphere *for 20 MeV electron beam energy*

In the Geant4 software, with the help of the computer model of the neutron source at the output of the linear electron accelerator, the main characteristics of gamma radiation were determined at the location of the irradiated samples on the small detector with an area of 100 cm^2 and outside on top of the lead shielding on a large detector. We conducted several computer experiments on 10^7 primary electrons with an energy of 25 MeV. The following system configurations were considered: 1. Tungsten plates without graphite reflector and lead protection. 2. With reflector, without lead protection 3. With graphite reflector and lead protection. The samples were both with and without lead protection. For all the considered configurations, energy spectra of gamma quanta were obtained that fall on a small detector at the location of the samples and a large detector (accelerator bunker, environment).

The energy spectra of gamma quanta for electron beam 25 MeV energy, small detector 100 cm^2 are presented in Fig. 8.

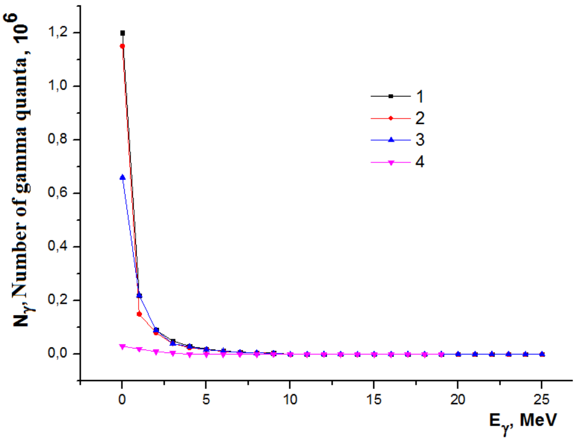

Fig. 8. The energy spectra of gamma quanta for electron beam 25 MeV energy, for small detector 100 cm^2

Number 1 indicates the energy spectrum of gamma quanta on a small detector without lead protection in the presence of a graphite reflector and lead protection around it. Number 2 indicates the energy spectrum of gamma rays on a small detector in the presence of only a reflector around the neutron-producing target. The number 3 indicates the energy spectrum of gamma quanta on a small detector in the presence of only a neutron-producing target. The number 4 indicates the energy spectrum on the small detector of the entire neutron source assembly Fig. 1.

The analysis of the obtained data showed that the graphite neutron reflector is also an effective reflector of low-energy gamma quanta ($E_\gamma \leq$ 1MeV), its presence increased the flow of gamma quanta of these energies at the small detector by 30%. In general, the configuration with a graphite reflector and lead shielding around it increases the flux of gamma quanta to the irradiated samples by more than 40%. At the same time, lead protection reduced the gamma background on the samples by more than 20 times.

The energy spectra of gamma quanta for electron beam 25 MeV energy on the big detector around the neutron-producing target without lead protection (number 1) and with protection (number 2) are presented in Fig. 9.

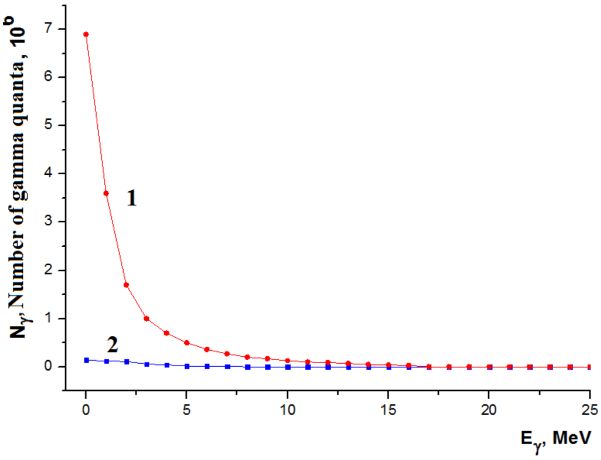

Fig. 9. The energy spectra of gamma quanta for electron beam 25 MeV energy, for big detector

From Fig. 9 it is clear that in the presence of lead protection around the graphite reflector, the flux of gamma quanta into the environment also decreases significantly (more than 20 times) The performed calculations proved that lead shielding with a thickness of 5 cm is sufficiently effective for conducting experiments on neutron programs at primary electron energies of 25 MeV at the linear electron accelerator LUE-30.

CONCLUSIONS

In the Geant4 software, with the help of the computer model of the neutron source at the output of the linear electron accelerator, the main characteristics of gamma radiation were determined on the neutron-producing target, at the location of the irradiated samples and outside on top of the lead shielding on a large detector.

We conducted several computer experiments on 10^7 primary electrons with an energy of 25 MeV. The following system configurations were considered: 1. Tungsten plates without graphite reflector and lead protection. 2. With reflector, without lead protection 3. With graphite reflector and lead protection. The samples were both with and without lead protection. For all the considered configurations, energy spectra of gamma quanta were obtained that fall on a small detector at the location of the samples and a large detector (accelerator bunker, environment).

The analysis of the obtained data showed that the graphite neutron reflector is also an effective reflector of low-energy gamma quanta ($E_\gamma \leq 1$ MeV), its presence increased the flow of gamma quanta of these energies at the small detector by 30%. In general, the configuration with a graphite reflector and lead shielding around it increases the flux of gamma quanta to the irradiated samples by more than 40%. At the same time, lead protection reduced the gamma background on the samples and in the bunker by more than 20 times.

The performed calculations proved that lead shielding with a thickness of 5 cm is sufficiently effective for conducting experiments on neutron programs at primary electron energies of 25 MeV at the linear electron accelerator LUE-30.

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ДОСЛІДЖЕННЯ ПАРАМЕТРІВ ГАММА-ВИПРОМІНЮВАННЯ НА КОМП'ЮТЕРНІЙ МОДЕЛІ ДЖЕРЕЛА НЕЙТРОНІВ НА ЛІНІЙНОМУ ПРИСКОРЮВАЧІ ЕЛЕКТРОНІВ

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У програмному середовищі Geant4 за допомогою комп'ютерної моделі джерела нейтронів на виході лінійного прискорювача електронів були визначені основні характеристики гамма-випромінювання у місті розташування зразків, що опромінюються, та зовні, поверх свинцевого захисту на великому детекторі. Ми провели декілька комп'ютерних експериментів на 10^7 первинних електронів з енергією 25 МеВ. Аналіз отриманих даних довів, що графітовий відбивач нейтронів також є ефективним відбивачем низькоенергетичних гамма-квантів ($E_\gamma < 1$ МеВ), тільки його присутність збільшувала потік гамма-квантів цих енергій на малому детекторі на 30%. При цьому свинцевий захист зменшував гамма-фон на зразках і в бункері більш ніж у 20 разів. Проведені розрахунки довели, що свинцевий захист товщиною 5 см є досить ефективним для проведення експериментів за нейтронними програмами при енергіях первинних електронів 25 МеВ.