ТЕХНІКА ТА МЕТОДИ ЕКСПЕРИМЕНТУ
ENGINEERING AND METHODS OF EXPERIMENT

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THE COMPUTER MODEL OF A NEUTRON FLUXES FORMING SYSTEM ON A LINEAR ELECTRON ACCELERATOR[a]

A computer model of the system for generating neutron fluxes at the output of a linear electron accelerator has been developed in the Geant4 and PhysList QGSP BIC HP programming environment. With the help of the model, a number of virtual experiments on 10^7 primary neutrons were carried out. The dependence of the ratio of the number of neutrons, incident on the detector with a reflector to the number of neutrons without a reflector on the radius of curvature of the hemispherical dome of the reflector is determined, which makes it possible to establish the optimal dimensions of the working area. The energy spectra of neutrons incident on the detector are determined. It has been established that when using a graphite reflector 30 × 30 × 30 cm in size with a radius of curvature of the hemispherical dome of 5 cm, the number of neutrons at the location of the detector increases by 16.9 %, and the neutron background in the accelerator bunker decreases by 2.5 times, which is in good agreement with the real experiment made. Such a decrease in the radiation background, according to sanitary standards, will make it possible to increase the accelerator current by 2.5 times and increase the neutron flux.

Keywords: computer model, accelerator, reflector, neutrons detector, energy spectra.

1. Introduction

To carry out research in the field of fundamental and applied nuclear physics, energy, and nuclear medicine, as well as to create a compact source of thermal and epithermal neutrons based on the linear electron accelerator LUE-30 [1], a neutron flux generation system is being developed. The main purpose of the neutron flux formation system, on the one hand, is to equalize and increase the neutron field in the irradiation zone of the samples under study. On the other hand, the system for generating neutron fluxes will reduce the flux of neutrons and gamma-quanta from the electron-neutron converter to the environment, and thereby improve the radiation background in the bunker and accelerator building. Similar neutron flux generation systems are presented in the works [2, 3]. Our system, in contrast to the neutron flux generation system presented in [2, 3], can produce thermal and epithermal neutrons for various purposes, for example, for nuclear medicine.

The neutron flux generation system will be installed at the output of the linear electron accelerator LUE-30. The linear electron accelerator has the following characteristics: maximum electron energy 30 MeV, maximum current 60 μA, maximum calculated neutron flux, which can be obtained using a tungsten converter 10^{12} to 4 π. The neutron flux generation system will consist of a tungsten 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 can be quickly dismantled so as not to interfere with other studies.

The developed neutron source is based on a well-known principle, which is as follows. The electrons at the accelerator output bombard a high-Z metallic target (for example, tungsten). The resulting gamma bremsstrahlung interacts with the atoms of the same target and as a result of the (γ, n) reaction, a neutron flux is generated. 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 (four tungsten plates 2 mm thick, one after the other). 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 system for the formation of neutron fluxes is shown in Fig. 1.

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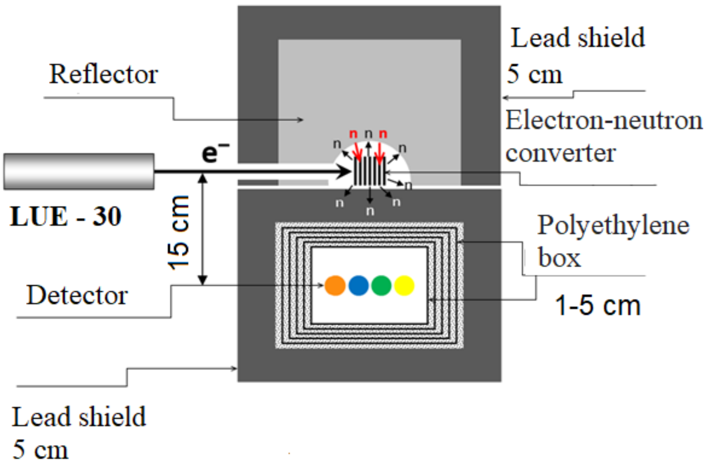

Fig. 1. Scheme of the system for the formation of neutron fluxes.
(See color Figure on the journal website.)

2. Description of the computer model of the system for forming neutron fluxes

In the work, a computer model of the system for generating neutron fluxes at the output of a linear electron accelerator was developed in the Geant4 and PhysList QGSP BIC HP [4] environment. The hadronic part of this physics list consists of elastic, inelastic, capture, and fission processes. Each process is built from a set of cross-section sets and interaction models which provide the detailed physics implementation. The model, instead of tungsten electron-neutron converter, includes a point isotropic neutron source with an energy of 0.9 MeV, a graphite reflector with dimensions of 30 × 30 × 30 cm with a working area in the form of a hemispherical dome, the radius of which varied from 1 to 13 cm, a lead box 5 cm thick, a polyethylene box 5 cm thick, a neutron detector with an area of 1 cm^2. The working zone of the reflector is chosen in the form of a hemisphere, because, as shown in [5, 6], it is optimal for many cases of neutron flux formation systems, in particular, for nuclear reactors. An isotopic source of neutrons was taken to simplify the model. The energy of 0.9 MeV, according to [2], corresponds to the maximum distribution for the tungsten converter. A screenshot of the model is shown in Fig. 2.

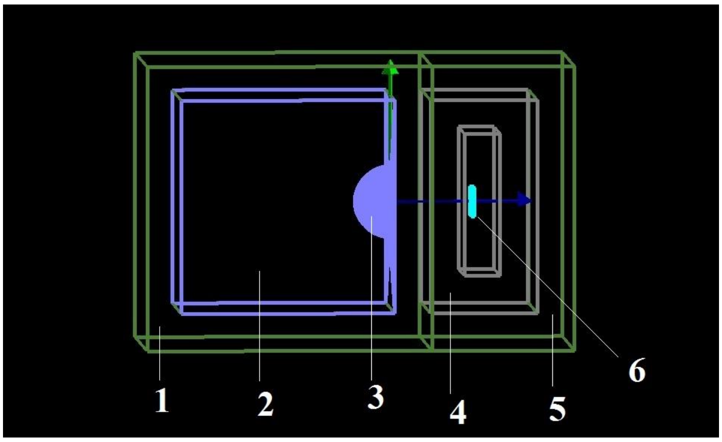

Fig. 2. Computer model of the neutron flux generation. system. *1* - lead reflector shield, *2* - graphite reflector, *3* - neutron source, *4* - polyethylene box, *5* - lead detector shield, *6* - neutron detector.
(See color Figure on the journal website.)

3. Operation with the computer model of the system for forming neutron fluxes

A number of virtual experiments on 10^7 primary neutrons were carried out using a computer model of the system for generating neutron fluxes. Visualization of the computer model is shown in Fig. 3.

It can be seen from Fig. 3 that in the case of a reflector, the number of neutrons falling on the neutron detector increases, and the number of neutrons flying into the hemisphere opposite to the neutron detector and its lead shielding decreases significantly. As can be seen from Fig. 3, these neutrons create the main part of the neutron background in the accelerator bunker, since part of the neutrons flying into the other hemisphere is moderated and retained by the polyethylene box that surrounds the neutron detector.

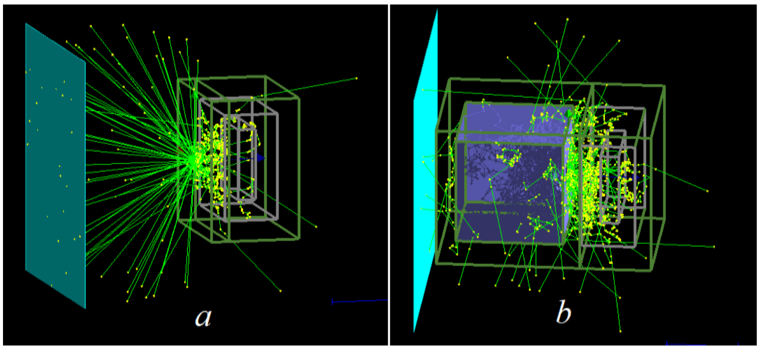

Fig. 3. Computer model of the neutron flux formation system. Visualization of the results obtained for 100 primary particles without a reflector (*a*) and with a reflector dimensions 30 × 30 × 30 cm (*b*). (See color Figure on the journal website.)

A computer experiment showed that when using a graphite reflector with a working zone radius of 5 cm, the number of neutrons at the location of the detector increases by 16.9 %, which is in good agreement with the results of a real experiment carried out earlier [7]. When cement-graphite reflectors were used in the experiment, an additional 15 % breakdown of dye molecules was observed due to an increase in the neutron flux density. In this case, the measurement error did not exceed 10 %. The dependence of the ratio of the number of neutrons with a reflector to the number of neutrons without a reflector falling on the detector on the radius of curvature of the hemispherical dome of the reflector was also determined. It is shown in Fig. 4.

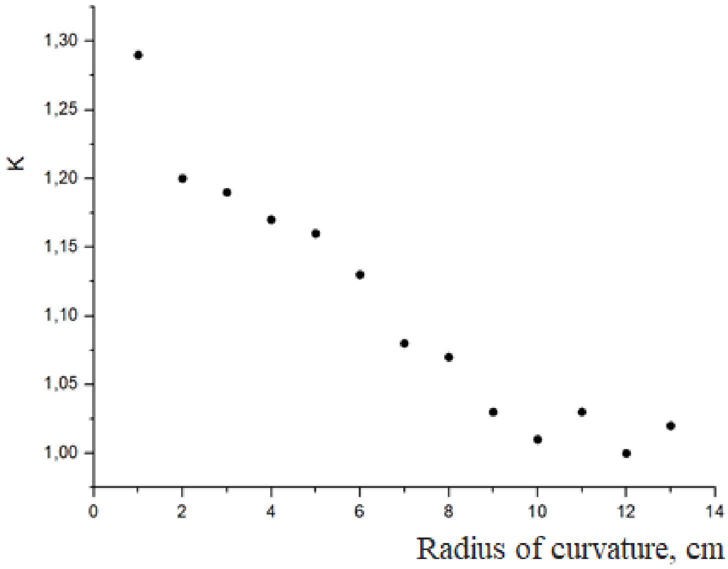

Fig. 4. Dependence of the ratio K – the number of neutrons with a reflector to the number of neutrons without a reflector falling on the detector on the radius of curvature of the hemispherical dome of the reflector.

It can be seen from Fig. 4 that the reflector with a small radius of curvature of the working area up to 3 cm will be the most effective. With an increase in the radius of curvature of the working area, the efficiency of the reflector decreases and is practically absent at values of more than 9 cm. Therefore, for the effective operation of the neutron flux formation system, it is necessary to take into account three factors: the size of the electron beam, the size of the neutron converter, and, accordingly, the size of the working area of the reflector.

Also in the work, the energy spectra and number of neutrons recorded by a neutron detector, are shown in Fig. 5. In the work, the average statistical error was determined as the square root of the number of registered events. The error is shown in green on the diagram.

Calculations have shown that the formation system can significantly reduce the energy of the neutron flux. When passing 5 cm of a polyethylene moderator, a primary monoenergetic beam with an energy of 0.9 MeV turns into a neutron flux with an energy of less than 100 keV (80 % of particles), which can be used for research in the field of nuclear medicine, in particular, for neutron capture therapy.

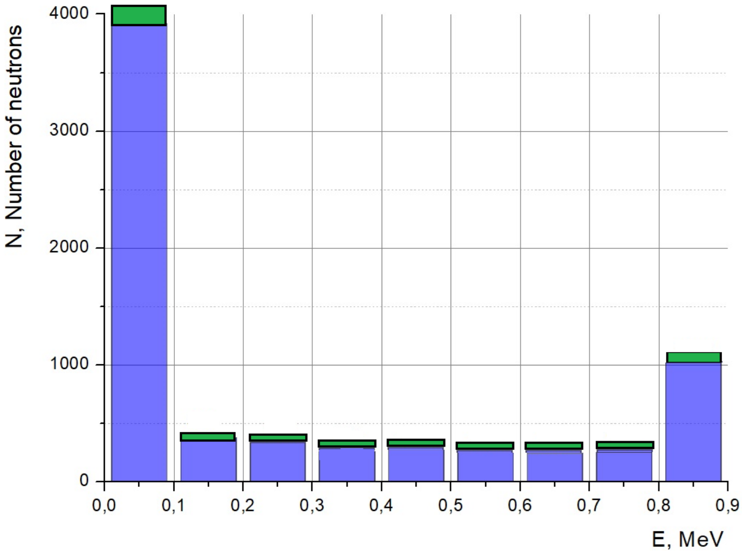

Fig. 5. Energy spectra and number of neutrons recorded by a neutron detector. The initial neutron energy was 0.9 MeV, 10^7 primary particles, 5 cm polyethylene, 5 cm radius of curvature of the working area of the facility. (See color Figure on the journal website.)

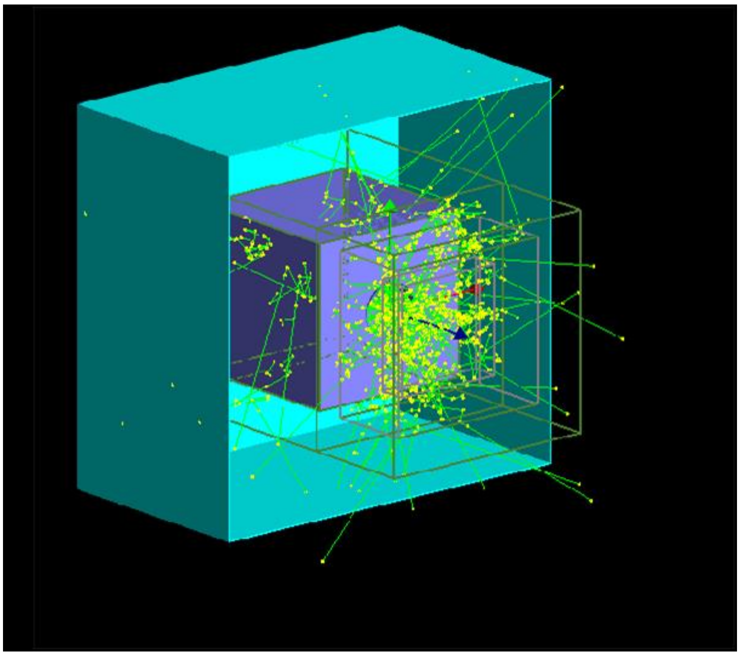

Fig. 6. Neutron flux generation system with a large detector. (See color Figure on the journal website.)

As mentioned earlier, the neutron flux formation system will reduce the neutron flux from the electron-neutron converter to the environment, and thereby improve the radiation background in the bunker and accelerator building. To assess the protective properties of the reflector in the model, a large neutron detector was used, which completely surrounded the reflector, in Fig. 6 it is shown in blue. The conducted studies have shown that when using a graphite reflector 30 × 30 × 30 cm in size, the neutron flux recorded by the detector decreases by 2.5 times compared to the case when the reflector is absent. The system for generating neutron fluxes with a large neutron detector is shown in Fig. 6.

In the work, the energy spectra of neutrons that fall on a large detector, with and without a reflector, were determined. They are shown in Fig. 7.

It can be seen from Fig. 7 that, in addition to reducing the number of neutrons entering the accelerator bunker, the reflector significantly reduces their energy (80 % of the particles have an energy of less than 100 keV), which significantly reduces their penetrating abilities and improves the radiation background. The operation of a linear electron accelerator is regulated by background radiation standards specified in the sanitary passport. Accordingly, reducing the radiation load in the accelerator bunker, due to the use of a system for generating

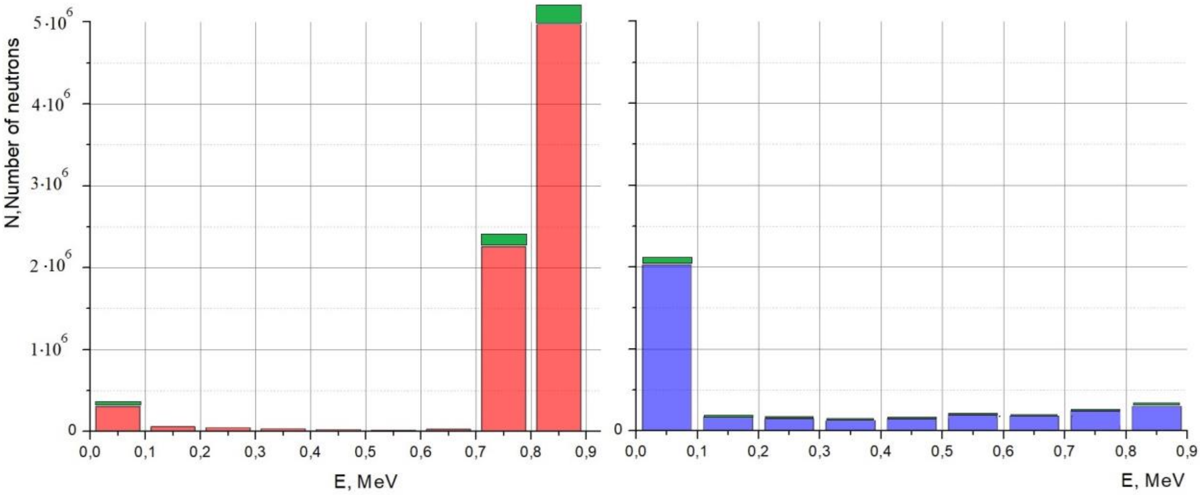

Fig. 7. Energy spectrum of neutrons recorded on a large detector: *left one* without reflector, *right one* with reflector. The initial neutron energy was 0.9 MeV, 10^7 primary particles, 5 cm polyethylene, 5 cm radius of curvature of the working area of the facility. (See color Figure on the journal website.)

neutron fluxes, will make it possible to increase the maximum accelerator current several times and increase the working neutron flux at the site of sample irradiation.

4. Conclusions

In the work a computer model of the neutron flux formation system at the LUE-30 electron accelerator of the NSC KIPT was developed and tested in the Geant4 and PhysList QGSP BIC HP programming environment.

Using the model, a number of computer experiments were carried out, which showed that the efficiency of using a graphite reflector depends on the radius of curvature of its hemispherical dome. The smaller is the radius, the greater is the efficiency. At the same time, it was found that when using a graphite reflector with dimensions of 30 × 30 × 30 cm with a working zone radius of 5 cm, the number of neutrons at the location of the detector increases by 16.9 %, which is in good agreement with the results of a real experiment carried out earlier.

The performed calculations have shown that the generation system can significantly reduce the energy of the neutron flux. When passing 5 cm of a polyethylene moderator a primary monoenergetic beam with an energy of 0.9 MeV turns into a neutron flux with an energy of less than 100 keV (80 % of particles), which can be used for research in the field of nuclear medicine, in particular for neutron capture therapy.

Also, as a result of the calculations, it was found that when using a graphite reflector, the neutron background near it decreases by 2.5 times and the neutron spectrum becomes significantly softer. Reducing the background radiation in the accelerator bunker will make it possible to increase its maximum current and neutron flux in the area where the samples are located several times.

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КОМП'ЮТЕРНА МОДЕЛЬ СИСТЕМИ ФОРМУВАННЯ ПОТОКІВ НЕЙТРОНІВ НА ЛІНІЙНОМУ ПРИСКОРЮВАЧІ ЕЛЕКТРОНІВ

У середовищі Geant4 с фізичним листом QGSP BIC HP розроблено комп'ютерну модель системи формування потоків нейтронів на виході лінійного прискорювача електронів. За допомогою моделі проведено низку віртуальних експериментів на 10^7 первинних нейтронів. Визначено залежність відношення кількості нейтронів, що потрапляють на детектор з відбивачем до кількості нейтронів без відбивача, від радіуса кривизни напівсферичного купола відбивача, що дає можливість встановити оптимальні розміри робочої зони. Визначено енергетичні спектри нейтронів, які потрапляють на детектор. Встановлено, що при використанні графітового відбивача розміром 30 × 30 × 30 см, з радіусом кривизни напівсферичного купола 5 см кількість нейтронів у місці розташування детектора збільшується на 16,9 %, а нейтронний фон у бункері прискорювача зменшується у 2,5 раза, що добре узгоджується з проведеним реальним експериментом. Таке зниження радіаційного фону, згідно із санітарними нормами, дасть можливість збільшити струм прискорювача у 2,5 раза та збільшити потік нейтронів.

Ключові слова: комп'ютерна модель, прискорювач, відбивач, детектор нейтронів, енергетичні спектри.

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