https://doi.org/10.46813/2023-148-168

DEVELOPMENT AND TESTING OF A COMPUTER MODEL OF A SYSTEM FOR FORMING NEUTRON FLUXES ON A LINEAR ELECTRON ACCELERATOR

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A computer model of the system for forming neutron fluxes at the output of a linear electron accelerator has been developed in the Geant4 programming environment. The system for forming neutron fluxes consists of a monoenergetic neutron source, a graphite reflector, a polyethylene moderator, lead protection and detector. With the help of the model, a number of virtual experiments on 10^7 primary neutrons were carried out for the energy range of the neutron source from 0.1 to 1.1 MeV. The dependence of the ratio of the number of neutrons falling on the detector with a reflector to the number of neutrons without a reflector is determined, on the energy of the neutron source. Energy spectra of neutrons falling on the detector are determined. It was established that the graphite reflector not only increases the number of particles falling on the detector, but also moderated the energy spectrum of neutrons. The neutron background in the accelerator bunker when using a reflector decreases from 2 to 7 times, depending on the energy of the neutron source.

PACS: 61.72.Cc, 61.80.Hg, 78.20.Ci, 87.80.+s, 87.90.+y, 07.05.Tp, 78.70.–g

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.

The neutron flux generation system 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 (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.

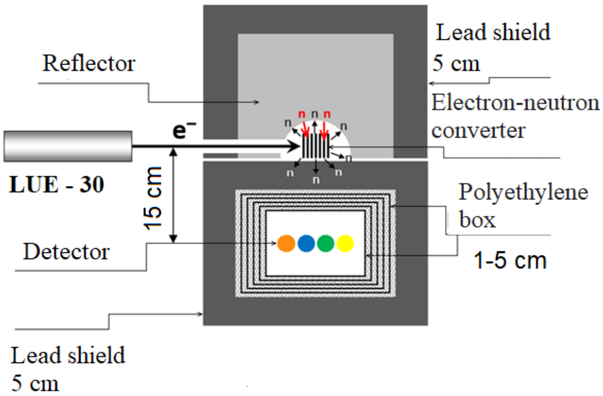

Fig. 1. Scheme of the system for the formation of neutron fluxes

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 [2] environment. The model includes a point isotropic neutron source with an energy in the range of 0.1…1.1 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 was 5 cm, a lead box 5 cm thick, a polyethylene box 5 cm thick, a neutron detector with an area of 100 см^2. This energy range of the neutron source was taken because it is close to the energy spectrum of a tungsten neutron converter. The working zone of the reflector is chosen in the form of a hemisphere, because, as shown in [3, 4], it is optimal for many cases of neutron flux formation systems, in particular, for nuclear reactors. The radius of the working zone of the neutron converter was taken to be 5 cm, because it is optimal for our system for generating neutron fluxes and was used in a real experiment [5]. A screenshot of the model is shown in Fig. 2.

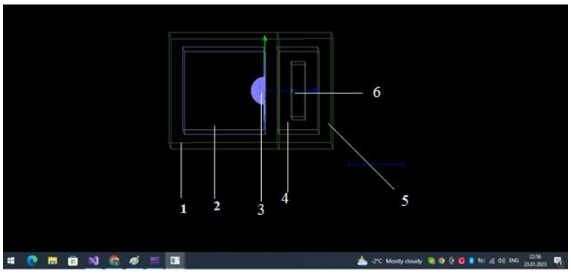

Fig. 2. Computer model of the neutron flux generation system: 1 – Lead reflector shield; 2 – Graphite reflector; 3 – Neutron source; 4 – Polyethylene box; 5 – Lead detector shield; 6 – Neutron detector

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,a,b.

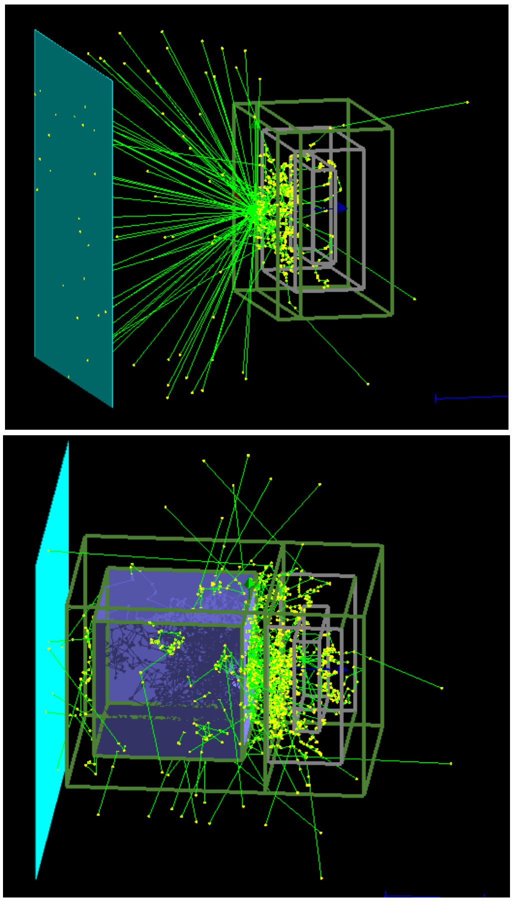

Fig. 3. Computer model of the neutron flux formation system. Visualization of the obtained results for 100 primary particles without a reflector (a); visualization of the results obtained for 100 primary particles with a reflector dimensions 30×30×30 cm (b)

It can be seen from Fig. 3,a,b 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,a,b, 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.

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 (reflection coefficient) on the energy of neutron source in the range of 0.1...1.1 MeV was determined. It is shown in Fig. 4.

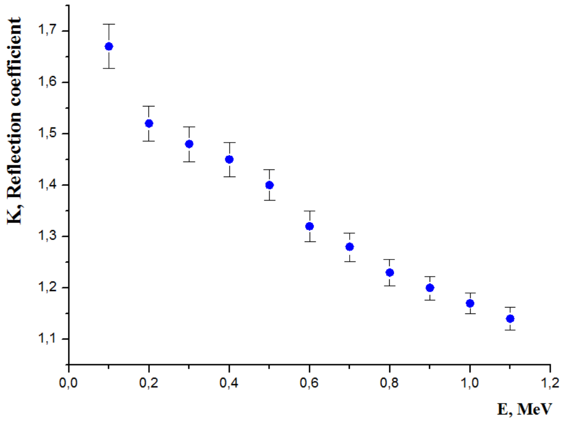

Fig. 4. Dependence of the reflection coefficient on the energy of neutron source

In the work, the average statistical error was determined as the square root of the number of registered events. The error is shown on the Fig. 4. It can be seen from Fig. 4 that the efficiency of the graphite reflector decreases with increasing energy of the neutron source. This is due to the peculiarities of diffuse neutron scattering on matter.

Also in the work the total number of neutrons that falling on the detector with an area of 100^2 cm were determined. The dependence of the total number of neutrons that falling on the detector on the energy of the source is shown in Fig. 5.

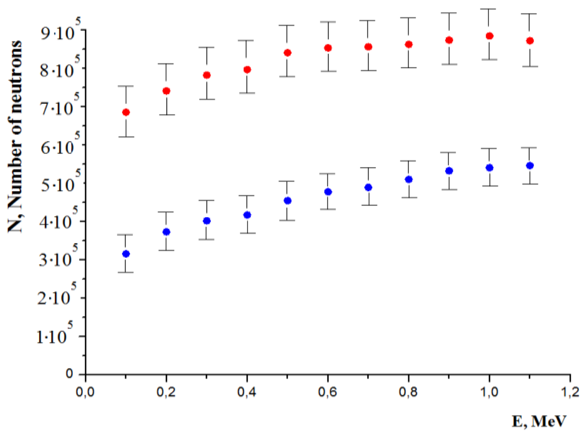

Fig. 5. Dependence of the total number of neutrons that falling on the detector *on the energy of neutron source*

It can be seen from Fig. 5 the total number of neutrons that falling on the detector increases with increasing energy of the neutron source. This is due to an increase in the penetrating ability of neutrons as their energy increases.The energy spectra of neutrons falling on the detector were determined. The energy spectra of neutrons for source energies of 0.6 and 1.1 MeV, are shown in Figs. 6, 7.

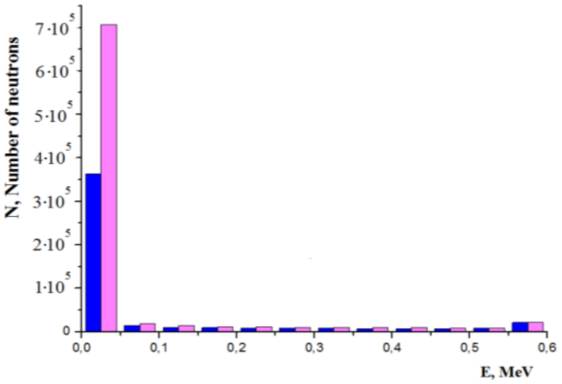

Fig. 6. Energy spectra of neutrons recorded by a neutron detector. The initial neutron energy was 0.6 MeV, 10^7 primary particles, 5 cm polyethylene

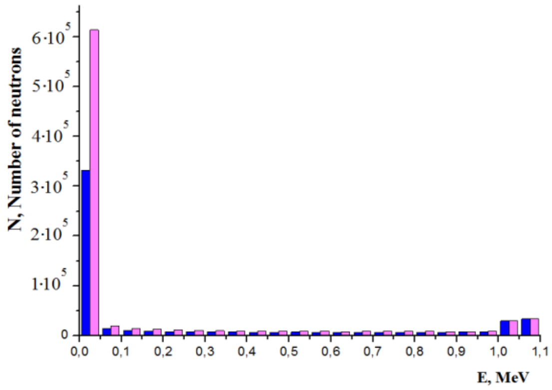

Fig. 7. Energy spectra of neutrons recorded by a neutron detector. The initial neutron energy was 1.1 MeV, 10^7 primary particles, 5 cm polyethylene

The number of neutrons without a reflector is shown in blue. The number of neutrons with a reflector is shown in magenta. It can be seen from Figs. 6, 7 that the reflector not only increases the number of neutrons that falling on the detector, but also moderated their spectrum.

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 in the range of 0.2...1.1 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.

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. 8 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 from 2 to 7 times depending on the energy of the neutron source compared to the case when the reflector is absent. When lower the neutron energy, the more their flux is weakened

The system for generating neutron fluxes with a large neutron detector is shown in Fig. 8.

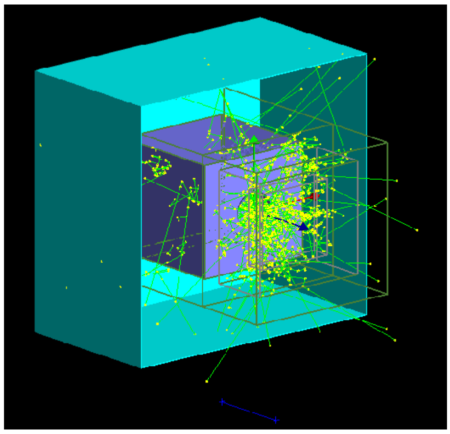

Fig. 8. Neutron flux generation system with a large detector

In the work, the energy spectra of neutrons that falling on a large detector, with and without a reflector, were determined. They are shown in Fig. 9 for initial neutron energy 0.9 MeV.

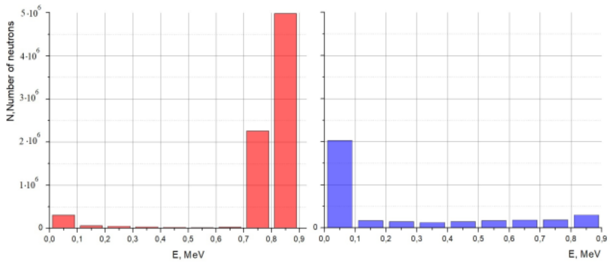

Fig. 9. Energy spectrum of neutrons recorded on the detector for initial neutron energy 0.9 MeV. Left one without reflector, right one with reflector

It can be seen from Fig. 9 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. All this will make it possible to increase the limiting current of the accelerator electron beam by several times while maintaining the same radiation load and to optimize its operation.

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 programming environment.

The system for forming neutron fluxes consists of a monoenergetic neutron source, a graphite reflector, a polyethylene moderator, lead protection and detector. With the help of the model, a number of virtual experiments on 10^7 primary neutrons were carried out for the energy range of the neutron source from 0.1 to 1.1 MeV. The computer experiments showed that the efficiency of using a graphite reflector depends on the energy of neutron source. The smaller is the energy, the greater is the efficiency.

It can be seen from modeling results the total number of neutrons that falling on the detector increases with increasing energy of the neutron source. This is due to an increase in the penetrating ability of neutrons as their energy increases.

The performed 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 in the range of 0.2…1.1 MeV turns into a neutron flux with an energy of less than 100 keV (80% of particles).

Also, as a result of the calculations, it was found that when using a graphite reflector, the neutron background in the accelerator bunker decreases from 2 to 7 times depending on the energy of the neutron source and the neutron spectrum becomes significantly moderated. This will make it possible to increase the limiting current of the electron beam during experiments while maintaining the same radiation load and save the technical resource of the accelerator.

REFERENCES

1. V. Kasilov, S. Gokov, S. Kalenik, S. Kochetov, et al. Concept of Neutron Source Creation for Nuclear Medicine on the Basis of Linear Electron Accelerator // *East European Journal of Physics*. 2021, № 4, p. 160-163.
2. geant4-userdoc.web.cern.ch/UsersGuides/ ForApplicationDeveloper/BackupVersions/V10.6c/fo/ BookForApplicationDevelopers.pdf.
3. A.N. Klimov. *Nuclear physics and nuclear reactors*. M.: "Atomizdat", 1985, 384 p.
4. V.E. Levin. *Nuclear physics and nuclear reactors*. 4-e izd. M.: "Atomizdat", 1979, 288 p.
5. S.P. Gokov, V.M. Horbach, S.A. Kalenik, et al. Development and Testing of a System for Forming Neutron Fluxes on a Linear Electron Accelerator // *Problems of Atomic Science and Technology.* 2022, № 5, p. 73-76.

Article received 03.08.2023

РОЗРОБКА ТА ТЕСТУВАННЯ КОМП'ЮТЕРНОЇ МОДЕЛІ СИСТЕМИ ФОРМУВАННЯ ПОТОКІВ НЕЙТРОНІВ НА ЛІНІЙНОМУ ПРИСКОРЮВАЧІ ЕЛЕКТРОНІВ

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У середовищі Geant4 розроблено комп'ютерну модель системи формування потоків нейтронів на виході лінійного прискорювача електронів. Система формування складається з моноенергетичного джерела нейтронів, графітового відбивача, поліетиленового отеплювача, свинцевого захисту та детектора. За допомогою моделі проведено низку віртуальних експериментів на 10^7 первинних нейтронів для діапазону енергій нейтронного джерела 0,1…1,1 МеВ. Визначено залежність відношення кількості нейтронів, які потрапляють на детектор, з відбивачем до кількості нейтронів без відбивача від енергії джерела нейтронів. Визначено енергетичні спектри нейтронів, які потрапляють на детектор. Встановлено, що графітовий відбивач не тільки збільшує кількість частинок, які потрапляють на детектор, але і отеплює енергетичний спектр нейтронів. Нейтронний фон у бункері прискорювача при використанні відбивача зменшується від 2 до 7 разів у залежності від енергії нейтронного джерела.