https://doi.org/10.46813/2022-141-073

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

*S.P. Gokov[1], V.M. Horbach[2], S.A. Kalenik[1], Yu.G. Kazarinov[1,2], V.V. Kantemirov[1], V.I. Kasilov[1], S.S. Kochetov[1], O.A. Lyukhtan[2], A.V. Tverdohvalov[1], V.V. Tsiats'ko[1], E.V. Tsiats'ko[1]*

*[1]National Science Center "Kharkov Institute of Physics and Technology", Kharkiv, Ukraine;*
*[2]V.N. Karazin Kharkiv National University, Kharkiv, Ukraine*
*E-mail: gokovsp@kipt.kharkov.ua*

A system for the formation of neutron fluxes, consisting of a neutron converter, a neutron reflector and a lead protection, has been developed and partially manufactured. Test tubes with an aqueous solution of the organic dye methyl orange with the addition of 4% boric acid were used as detectors of the generated neutron fluxes, which is associated with the impossibility of using gas-discharge neutron counters in the accelerator bunker due to the impact of pulsed electrical noise and gamma-ray flashes. Testing of the neutron flux formation system showed that the neutron flux at the location of the detectors increased by 15%, while the neutron background in the accelerator bunker decreased by 3 times. The conducted studies have shown the effectiveness of using a chemical dosimeter under conditions of intense pulsed neutron fluxes.

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 experiments on the interaction of neutron fluxes with various materials, as well as to create a compact source of thermal and epithermal neutrons based on the linear electron accelerator LUE-30 [1], a system for the formation of neutron fluxes was developed and partially manufactured. 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 neutron flux formation system allows to 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.

## DESCRIPTION OF THE NEUTRON FLUX FORMATION SYSTEM

The neutron flux formation system consists of an electron-neutron converter, a neutron reflector and protection against the accompanying gamma background around the reflector. As part of this work, cement-graphite neutron reflectors with a working area in the form of a hemisphere, ideal for a nuclear reactor, and a cylinder, used in the design of nuclear reactors, were calculated and manufactured [2, 3]. The diagram of the neutron flux generation system with a reflector with a working area in the form of a hemisphere at the LUE-30 accelerator is shown in Fig. 1.

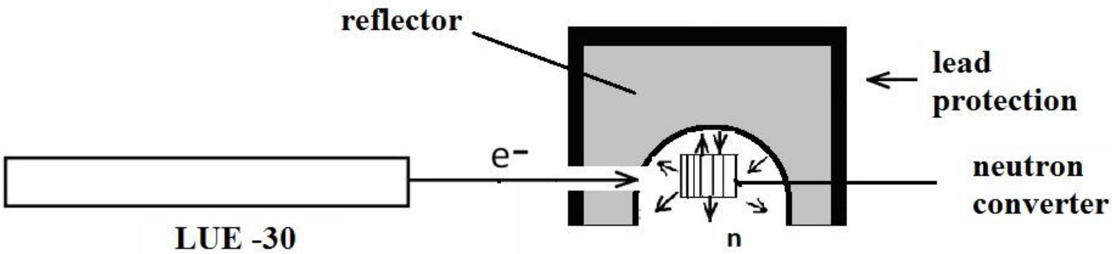


*Fig. 1. Scheme of the system for generating neutron fluxes with a reflector with a working area in the form of a hemisphere on the LUE-30 accelerator*

A neutron reflector is a medium that, due to its good moderating properties, allows:

- to reduce the leakage of neutrons from the irradiation zone and thereby improve the radiation background;
- slightly align and increase the neutron field in the irradiation zone.

It follows from the above that the main requirement for the reflector material is that it must be a good neutron moderator, that is, it must have a sufficiently large ability to slowdown and the lowest possible absorption of moderated and thermal neutrons [2, 3].

We have manufactured two neutron reflectors: with spherical and cylindrical working areas from a cement-graphite mixture in the ratio: 30% cement, 70% graphite. This composition is due to the above properties of the material for the reflectors and the mechanical strength of the entire structure. The dimensions of the reflectors were 300x300x200 mm, the radius of the hemisphere was 50 mm, and the cylinder diameter was 100 mm.

The electron-neutron converter, which consisted of four tungsten plates 2 mm thick, was fastened with a steel rod inside the working area of the reflectors. A hole 30 mm in diameter was drilled in the side part of the reflector to pass the electron beam from the accelerator to the electron-neutron converter. A photograph of the manufactured reflector from a cement-graphite mixture is shown in Fig. 2.

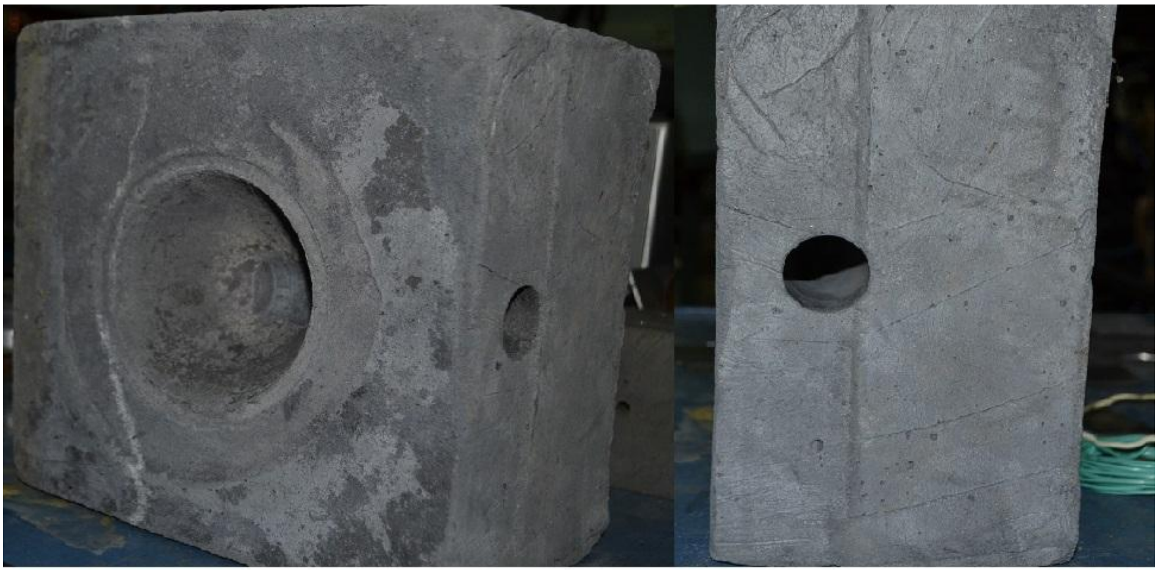

*Fig. 2. Photo of a reflector made from a cement-graphite mixture with a working area in the form of a hemisphere. On the left is a view of the working area, on the right is a hole for passing the beam*

When performing this work, a reflector with an electron-neutron converter inside was placed on the axis of the electron beam of the LUE-30 accelerator. Outside, the reflector was lined with lead bricks.

A photo of the reflector with lead shielding on the axis of the LUE-30 accelerator is shown in Fig. 3.

*Fig. 3. Photo of a reflector with lead shielding on the axis of the LUE-30 accelerator*

## TESTING THE NEUTRON FLUX FORMATION SYSTEM

The work was carried out at the NSC KIPT on a linear electron accelerator LUE-30. An electron beam with the energy of 15 MeV and an average current of 20 μA was output from the accelerator to an electron-neutron converter located inside the system for generating neutron fluxes. Irradiation was carried out for 1 hour, which corresponds to a total neutron flux of $10^{11}$ n/cm$^2$ at the location of the detectors (calculated using the Geant4 program [5]).

Test tubes with an aqueous solution of the organic dye methyl orange with the addition of 4% boric acid [4], which were installed inside the lead protection, were used as detectors of the formed neutron fluxes. The scheme of the experiment is shown in Fig. 4.

This is due to the fact that under the radiation conditions of the LUE-30 bunker, when the accelerator is operating at short distances from the electron-neutron converter, it is impossible to use gas-discharge neutron counters due to the influence of pulsed electrical noise and gamma-ray flashes.

Test tubes with an aqueous solution of the organic dye methyl orange with boric acid were installed inside the lead shield with a 5 cm thick polyethylene heater at a distance of 15 cm from the electron-neutron converter.

We carried out three experiments: test tubes with a solution were irradiated only in the presence of a converter without a reflector, with a reflector with a working area in the form of a hemisphere, and with a reflector with a working area in the form of a cylinder. Absorption spectra were obtained for all irradiated samples using an SF-46 spectrophotometer. The degree of discoloration of the solutions was used to determine the total flux of thermal neutrons passing through the irradiated object.

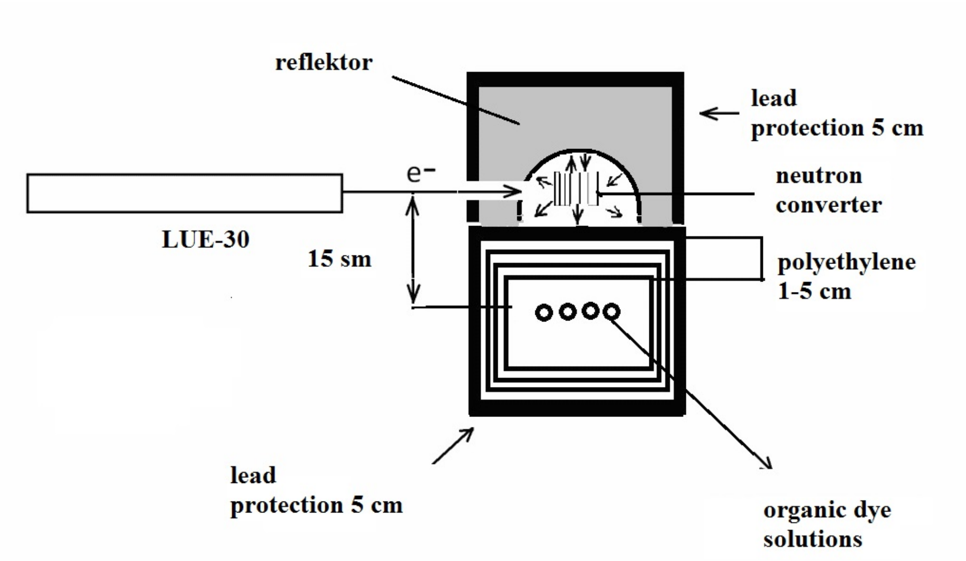


*Fig. 4. Scheme of the experiment*

The main absorption spectra of irradiated and non-irradiated solutions of methyl orange dye with boric acid are shown in Fig. 5

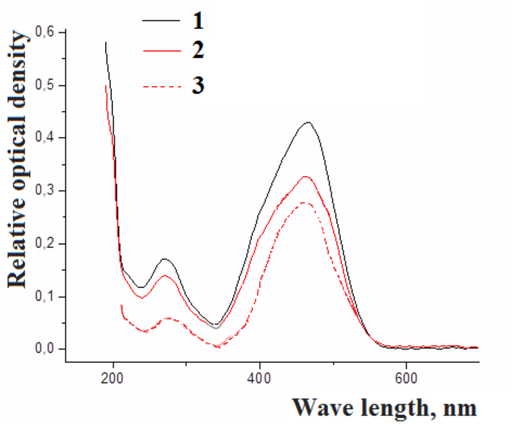


*Fig. 5. Main absorption spectra of irradiated and non-irradiated aqueous solution dye methyl orange with 4% boric acid: 1 – non irradiated dye solution with boric acid; 2 – dye solution with boric acid irradiated without reflector; 3 – dye solution with boric acid irradiated with reflector*

It can be seen from Fig. 5 that when the samples studied without a reflector are irradiated with a neutron flux, the absorption spectrum of an aqueous solution of the methyl orange dye "sags" by 25 percent relative to the non-irradiated solution. This indicates a 25% breakdown of dye molecules in solution due to the interaction of thermal and epithermal neutron fluxes with $^{10}B$, which is contained in boric acid [4]. 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. It was found in the work that the results obtained for our experiment are practically independent of the shape of the working area of the reflector. The spherical or cylindrical shape of the working area of the reflector led to the same additional breakdown of the dye molecules in the solution, i.e. to the same increase in the density of the neutron flux at the place of irradiation of the samples.

In this work, the neutron background was also monitored in the bunker and the LUE-30 accelerator building. The neutron background inside the bunker at a distance of 9 m from the electron-neutron converter and within the accelerator building was monitored using a certified MKS-01 instrument. At the same time, it was found that the neutron background when using the neutron flux formation system decreases by 3 times. This will significantly improve the radiation situation during the operation of the LUE-30 accelerator for neutron programs and save the technical resource of the accelerator itself, due to the possibility of increasing the neutron flux density in the experiment and reducing the operating time of the equipment.

## CONCLUSIONS

In the work, a system for the formation of neutron fluxes at the electron accelerator LUE-30 of the NSC KIPT was developed and tested.

The neutron fluxes obtained using the formation system were recorded using chemical dosimeters (test tubes with an aqueous solution of the organic dye methyl orange with the addition of 4% boric acid). This is due to the fact that under the radiation conditions of the LUE-30 bunker, when the accelerator is operating at short distances from the electron-neutron converter, it is impossible to use gas-discharge neutron counters due to the influence of pulsed electrical noise and gamma-ray flashes.

An analysis of the obtained absorption spectra of aqueous solutions showed that the use of cement-graphite mixture reflectors in the system for generating neutron fluxes makes it possible to increase the neutron flux at the location of the irradiated samples by 15%, while the neutron background in the bunker and in certain places of the accelerator building decreases by 3 times.

It was also found that the results obtained in our experiment do not actually depend on the shape of the working area of the reflector.

The presence of a system for the formation of neutron fluxes in the future will significantly improve the radiation situation during the operation of the LUE-30 accelerator for neutron programs and save the technical resource of the accelerator itself.

The conducted studies have shown the effectiveness of using a chemical dosimeter under conditions of intense neutron pulsed fluxes in the presence of significant pulsed electrical noise and gamma-ray flashes.

## REFERENCES


1. V. Kasilov, S. Gokov, S. Kalenik, S. Kochetov, L. Saliy, V. Tsyats'ko, E. Tsyats'ko, and O. Shopen. Concept of Neutron Source Creation for Nuclear Medicine on the Basis of Linear Electron Accelerator // *East European Journal of Physics*. 2021, v. 4, p. 160-163.
2. А.Н. Климов *Ядерная физика и ядерные реакторы*. М.: "Атомиздат", 1985, 384 с.
3. В.Е. Левин. *Ядерная физика и ядерные реакторы***.** 4-е изд. М.: "Атомиздат", 1979, 288 с.
4. S.P. Gokov, Yu.G. Kazarinov, S.A. Kalenik, V.Y. Kasilov, T.V. Malykhina, Ye.V. Rudychev, and V.V. Tsiats'ko. Research of interaction processes of fast and thermal neutrons with so-lution of organic dye methyl orange // *East European Journal of Physics*. 2021, v. 4, p. 130-134.
5. Geant4 Collaboration, Physics Reference Manual, http://cern.ch/geant4-userdoc/UsersGuides/ PhysicsList-Guide/fo/PhysicsList Guide.pdf.



*Article received 08.09.2022*


## РОЗРОБКА ТА ТЕСТУВАННЯ СИСТЕМИ ФОРМУВАННЯ ПОТОКІВ НЕЙТРОНІВ НА ЛІНІЙНОМУ ПРИСКОРЮВАЧІ ЕЛЕКТРОНІВ


***С.П. Гоков, В.М. Горбач, С.О. Каленик, Ю.Г. Казарінов, В.В. Кантеміров, В.Й. Касілов, С.С. Кочетов, О.А. Люхтан, А.В. Твердохвалов, В.В. Цяцько, Є.В. Цяцько***



Розроблена та частково виготовлена система формування нейтронних потоків, яка складається з нейтронного конвертера, відбивача нейтронів та свинцевого захисту. В якості детекторів сформованих потоків нейтронів використовувалися пробірки з водним розчином органічного барвнику метиловий помаранчевий з додаванням 4% борної кислоти, що пов'язано з неможливістю використання газорозрядних лічильників нейтронів у бункері прискорювача через вплив імпульсних електричних перешкод і гамма-спалахів. Тестування системи формування потоку нейтронів показало, що потік нейтронів у місці розташування детекторів збільшився на 15%, а нейтронний фон у бункері прискорювача зменшився в 3 рази. Проведені дослідження показали ефективність використання хімічного дозиметра в умовах інтенсивних імпульсних потоків нейтронів.