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PULSED NEUTRON SOURCE AT THE MULTIFUNCTIONAL ACCELERATOR COMPLEX OF THE NATIONAL SCIENCE CENTER "KIPT"

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The results of modeling the interaction of a pulsed electron beam from a linear accelerator of the multifunctional acceleration complex of the National Science Center "Kharkiv Institute of Physics and Technology" with a target made of wolfram are presented. The optimal target parameters for using the time-of-flight method in neutron experiments have been selected.

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INTRODUCTION

Along with the widespread use of various sources of electrons, protons, and photons in physical research, neutron beams make it possible to obtain a range of important information about the nature of phenomena that can be studied thanks to the unique characteristics of neutrons. The interaction of neutrons with atoms is relatively weak, which allows neutrons to penetrate deep into matter-this is their significant advantage over X-rays and gamma rays, as well as beams of charged particles.

Free neutrons are formed as a result of nuclear processes in nuclei and the interaction of nuclei with incoming particles. The paper [1] provides the characteristics of the most intense neutron sources that are actively used in the world for experimental research.

Pulse neutron sources based on proton and electron accelerators deserve special attention.

In a spallation neutron source, high-energy protons collide with a heavy metal target (e.g., lead, tungsten, mercury, or uranium). Under the impact of this collision, approximately 20 to 30 neutrons per proton are evaporated from the target nucleus.

As of 2022, the most powerful neutron source in the world is the Spallation Neutron Source in Oak Ridge, Tennessee, USA [2, 3].

The average neutron flux density obtained in proton accelerators is lower than in reactors, but when accumulators are used to reduce the proton pulse duration, the pulsed neutron flux value is high, which is particularly important when using the fly-through technique in experiments.

Another possibility for obtaining neutrons is photonuclear reactions of the type (γ, n) and (γ, 2n). The cross section of these reactions has a so-called giant resonance for heavy nuclei at an energy of γ-quanta of about 15 MeV. Since the yield of bremsstrahlung γ-quanta is proportional to the charge of the nucleus and the energy of the primary electrons, accelerators with energies above 30 MeV must be used to obtain the largest number of neutrons [4].

One of the most intense neutron sources built on these principles is nELBE [5, 6], which is based on the ELBE superconducting accelerator in Rossendorf (Germany). This neutron source was created to study reactions caused by fast neutrons, which are relevant for future nuclear transmutation and nuclear waste management facilities. Neutrons in the energy range from 10 keV to 10 MeV are used for experiments. The average intensity of the neutron beam in a lead target for electrons with energy E_e = 40 MeV and beam current I_e =1 mA is $2.7 \cdot 10^{13}$ n/s [5]. Due to the short electron pulse of 5 ps, the characteristics of the neutron beam from this source are comparable to those of the most intense pulsed neutron sources [7].

Let us consider what pulsed neutron fluxes can be obtained using a linear electron accelerator, which is the basis of the recirculator being designed at the National Science Center "Kharkiv Institute of Physics and Technology" [8].

PULSED NEUTRON SOURCE

As a result of the interaction of the electron beam with the converter, photonucleus reactions of the (γ, n) and (γ, 2n) types generate neutron fluxes with a continuous energy spectrum. For neutron experiments, a time-of-flight technique is used, the diagram of which is shown in Fig. 1 [9].

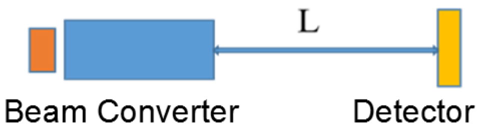

Fig. 1. Time-of-flight methodology scheme

An electron cluster flies into the converter, generating gamma-quanta and neutrons, which scatter isotropically around the target. The neutron beam travels a distance L and is detected by a detector. From the relationship linking the energy of neutrons E and the time of their flight to the detector t [9], we can see that this dependence allows us to unambiguously obtain the value of E by measuring the flight time:

$$t = L/v = L/\sqrt{2E/m},$$

where v is the neutron velocity.

This relationship is valid provided that the neutron pulse length is small compared to the flight time. Thus, it is possible to measure the energy of a neutron from a continuous source.

If the flight time is measured in microseconds, the flight length in meters, and the neutron energy in electron volts, we have the relationship between the basic quantities in the form [9]:

$$t/L=72,3/\sqrt{E}.$$

The accuracy of energy measurement using the flight time method depends on the uncertainty of the flight time Δt and the spread ΔL in the flight length value. As a rule, the uncertainty in the flight length value is significantly less than the uncertainty in the flight time [9]. In this case, the following relationship applies [9]:

$$\Delta E=2\,E\,\Delta t/\,t.$$

To determine the neutron flux at a distance of 10 m from the converter, a simulation was performed of the interaction of a 205.5 MeV electron beam with a tungsten converter.

The MCNPX program was used for the simulation [10].

The diameter of the cylindrical electron beam was 1.25 mm [11]. The length of the electron bunch (rms) was 5 ps (0.15 cm), and the charge in the bunch (pC) was 300 ($1.875\cdot10^{12}$ electrons) [12].

The converter had a cylindrical shape with a diameter of D and a length of N centimeters.

The dependence of the average neutron density generated by a single electron during the interaction of an electron beam and the number of neutrons emitted from targets with diameters of 10, 5, and 1 cm from the length of the converter is shown in Figs. 2–8.

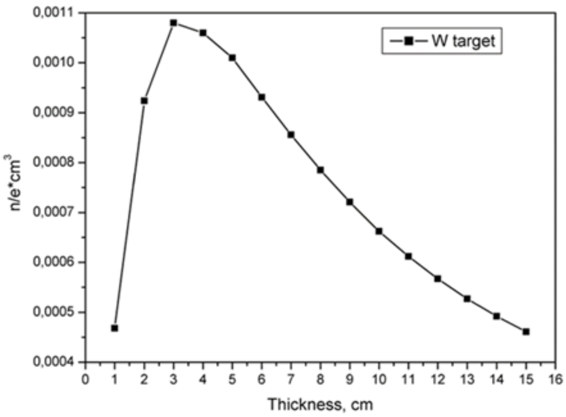

Fig. 2. Density of neutron flux generated in a target with a diameter of D=10 cm

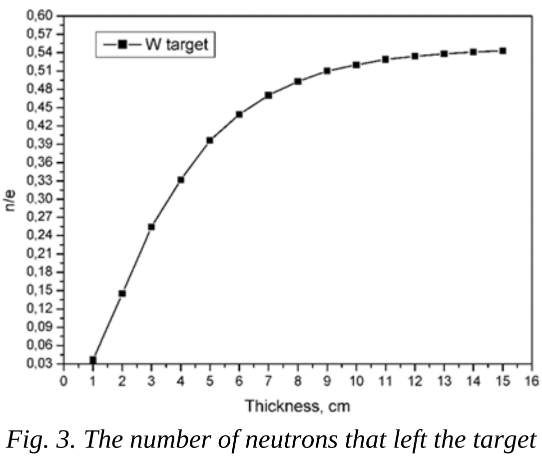

Fig. 3. The number of neutrons that left the target with a diameter of D=10 cm

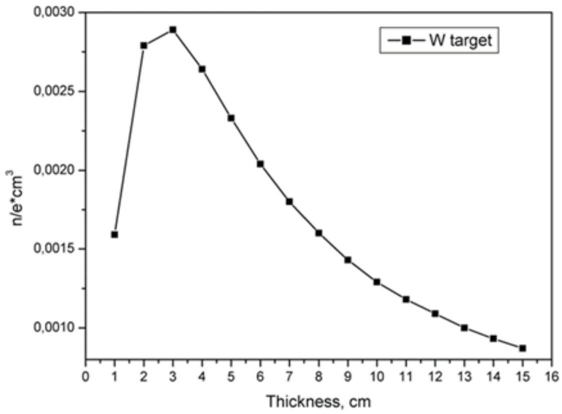

Fig. 4. Density of neutron flux generated in a target with a diameter of D=5 cm

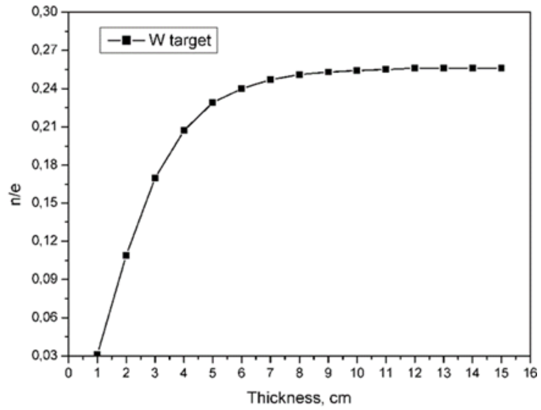

Fig. 5. The number of neutrons that left the target with a diameter of D=5 cm

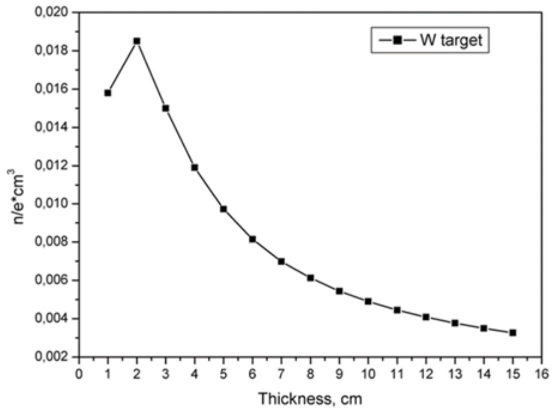

Fig. 6. Neutron flux density generated in a target with a diameter of D=1 cm

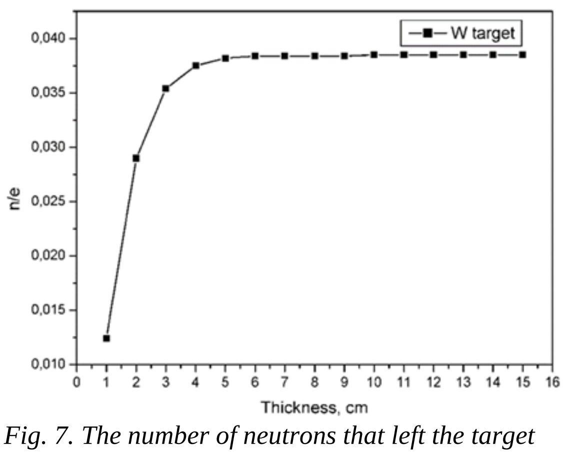

Fig. 7. The number of neutrons that left the target with a diameter of D=1 cm

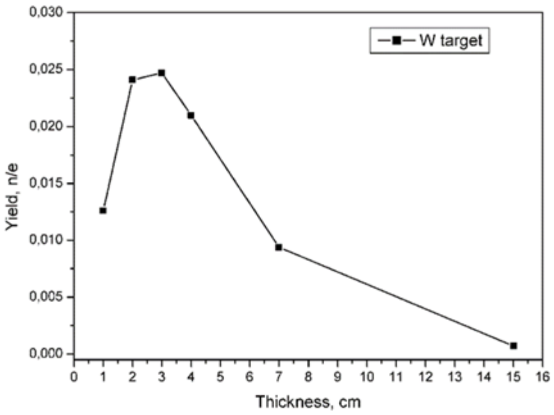

Fig. 8. Neutron emission from the end of the target with a diameter of D=10 cm

As can be seen from the figures, in terms of obtaining the optimal number of neutrons relative to the target parameters, a converter length of about 3 cm is best.

Reducing the target diameter to 5 cm will improve the time parameters of the neutron beam. Calculations show that the intensity of the neutron beam at 10 m from the converter will decrease by no more than 20 percent.

The neutron spectrum that can be obtained using a converter with these parameters is shown in Fig. 9. The neutron spectrum registration point is an area of 1 cm² at a distance of 10 m from the end of the target, the medium is a vacuum.

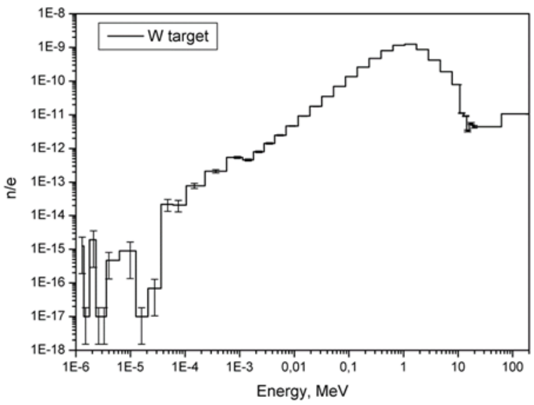

Fig. 9. Neutron spectrum

The total number of neutrons that can be registered at this point will be $5.804 \cdot 10^{-09}$ n/el.

The accuracy of neutron energy measurement in the geometry under consideration will be about $8 \cdot 10^{-3}$ for neutrons with an energy of 10 MeV.

CONCLUSIONS

The modeling results obtained can be used in the development of an experimental channel for the multifunctional acceleration complex of the National Science Center "Kharkiv Institute of Physics and Technology" for studying the interaction of neutrons with amorphous and single-crystal structures using the time-of-flight technique.

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ІМПУЛЬСНЕ ДЖЕРЕЛО НЕЙТРОНІВ НА БАГАТОФУНКЦІОНАЛЬНОМУ ПРИСКОРЮВАЛЬНОМУ КОМПЛЕКСІ ННЦ ХФТІ

П.І. Гладких, І.С. Гук, Г.Д. Коваленко, С.І. Прохорець, Є.В. Рудичев

Наведено результати моделювання взаємодії імпульсного електронного пучка лінійного прискорювача багатофункціонального прискорювального комплексу ННЦ ХФТІ з мішенню, виготовленою з вольфраму. Вибрано оптимальні параметри мішені для використання часопролітної методики експериментів із нейтронами.