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HIGH FLUX ACCELERATOR-BASED NEUTRON SOURCE

T.A. Bykov[1, 2], *A.A. Ivanov*[1], *D.A. Kasatov*[1, 2], *Ia.A. Kolesnikov*[1, 2], *A.M. Koshkarev*[1, 2], *G.M. Ostreinov*[1, 2], *A.N. Makarov*[1, 2], *I.M. Shchudlo*[1, 2], *E.O. Sokolova*[1, 2], *S.Yu. Taskaev*[1, 2]

[1]Budker Institute of Nuclear Physics, Novosibirsk, Russia
[2]Novosibirsk State University, Novosibirsk, Russia

High-flux neutron sources are relevant to testing materials for thermonuclear facilities and hadron colliders, treating malignant tumors with boron neutron capture therapy, and other applications. An accelerator-based neutron source was proposed and implemented at the Budker Institute of Nuclear Physics in Novosibirsk, Russia. It comprises an originally designed tandem accelerator, a solid lithium target, and a neutron beam shaping assembly. The neutron source has been found capable of producing high neutron fluxes in different energy ranges, from thermal to fast. It is applicable to a wide range of research tasks, including the characterization of neutron detectors, intended for fusion studies, in-depth investigation of the promising $^{11}\text{B}(p, \alpha)\alpha\alpha$ neutronless fusion reaction, etc.

Key words: neutron source, charge particle accelerator, lithium target.

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ИСТОЧНИК БОЛЬШИХ ПОТОКОВ НЕЙТРОНОВ НА ОСНОВЕ УСКОРИТЕЛЯ

Т.А. Быков[1, 2], *А.А. Иванов*[1], *Д.А. Касатов*[1, 2], *Я.А. Колесников*[1, 2], *А.М. Кошкарёв*[1, 2], *Г.М. Остреинов*[1, 2], *А.Н. Макаров*[1, 2], *И.М. Щудло*[1, 2], *Е.О. Соколова*[1, 2], *С.Ю. Таскаев*[1, 2]

[1]Институт ядерной физики им. Г.И. Будкера СО РАН, Новосибирск, Россия
[2]Новосибирский государственный университет, Новосибирск, Россия

Источники больших потоков нейтронов могут найти применение при исследовании материалов для термоядерных установок и адронных коллайдеров, лечении злокачественных опухолей методом бор-нейтронозахватной терапией и для других целей. В новосибирском Институте ядерной физики им. Г.И. Будкера был изобретён и изготовлен такой нейтронный источник на основе ускорителя, включающий впервые разработанный тандемный ускоритель оригинальной конструкции, твёрдую литиевую мишень и систему формирования пучка нейтронов. Было обнаружено, что разработанный нейтронный источник способен генерировать большие потоки нейтронов в различных диапазонах энергий — от тепловых нейтронов до быстрых. Он может быть применяться во многих целях, включая определение характеристик нейтронных детекторов, используемых в термоядерных исследованиях, а также при углублённом изучении перспективной безнейтронной термоядерной реакции $^{11}\text{B}(p, \alpha)\alpha\alpha$.

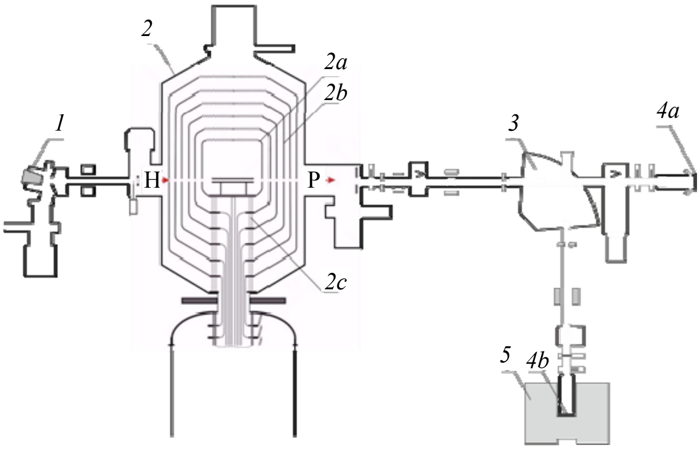
Ключевые слова: нейтронный источник, ускоритель заряженных частиц, литиевая мишень.

INTRODUCTION

A neutron source based on a charged particle accelerator and a lithium target has been proposed and developed for boron neutron capture therapy (BNCT) [1, 2] at the Budker Institute of Nuclear Physics (BINP) in Novosibirsk, Russia. This paper describes the said neutron source and summarizes relevant research. The neutron source applicability for the testing of fusion materials is discussed.

NEUTRON SOURCE

The BINP neutron source comprises a DC vacuum insulation tandem accelerator (VITA), a lithium target, and a neutron beam shaping assembly. A schematic diagram of the neutron source is shown in Fig. 1. The VITA is used to provide a high-current proton/deuteron beam of up to 2.3 MeV. Negative ions injected into the VITA are accelerated by applying a positive potential to the central electrode, then stripped to positive ions, and accelerated again by the same potential. The VITA has a special design that does not include accelerating tubes [3] present in conventional tandem accelerators. Instead, it features intermediate nested electrodes (*2b*), fas-



A cross-sectional view of the neutron source: *1* — negative ion source, *2* — vacuum insulated tandem accelerator (*2a* — high voltage electrode, *2b* — intermediate electrodes, *2c* — feedthrough insulator), *3* — bending magnet, *4* — lithium targets, *5* — neutron beam shaping assembly tened to a feedthrough insulator (*2c*), as shown in Fig. 1. The advantage of this setup is that the ceramic parts of the feedthrough insulator are distanced well away from the ion beam, increasing the high-voltage strength of accelerating gaps given high ion beam current.

After acceleration, the ion beam is directed to the lithium target placed either horizontally (*4a*) or vertically (*4b*) behind the bending magnet. The low and high energy beam lines are equipped with diagnostics, such as retractable Faraday cups, beam current monitors, video cameras, beam profile scanner, stripping target efficiency monitor, and thermocouples installed on the beam apertures along its path. The lithium target (*4*) on a copper substrate is used to generate a neutron flux via the ^{7}Li(p, n)^{7}Be or ^{7}Li(d, n) reactions. The target assembly is water cooled [4].

RESULTS AND DISCUSSION

Proton beam energy varies in the range of 0.6 —2.3 MeV with a high-energy stability of 0.1%. The beam current also varies in a wide range (from 0.5 to 10 mA) with a high current stability (0.4%) [5]. The VITA can generate a deuteron beam with similar characteristics.

A 2 MeV proton beam was used for an *in situ* observation of blister~~s~~ growth in copper and tantalum [6]. The neutron yield behavior generated the ^{7}Li(p, n)^{7}Be reaction was determined as a function of neutron fluence to identify the copper substrate's potential blistering effect on the efficiency of neutron production.

Table 1 shows the yields and energies of reaction products generated by the device.

The yields and energies of reaction products generated by the device

Reaction	Incident ion energy, MeV	Product of reaction	Yield, 10^{11} mC^{-1}	Mean energy, keV	Maximum energy, keV	Ref.
^{7}Li(p, n)^{7}Be	2.0	Neutrons	1.1	75	230	[7]
	2.1		2.13	110	350	
	2.2		3.62	160	460	
	2.3		5.78	230	570	
^{7}Li(d, n)^{8}Be; ^{7}Li(d, n)2^{4}He	2.1		15	5600	15000	[8]
^{7}Li(p, p' γ)^{7}Li	1.85	photons	0.9	478		[9]

In the device, the neutron flux is generated by the ^{7}Li(p, n)^{7}Be threshold reaction. A beam shaping assembly with a magnesium fluoride moderator is applied to convert this flux into a beam of epithermal neutrons with characteristics suitable for clinical testing of BNCT [10].

The device is capable of producing a beam of thermal neutrons with a plexiglas moderator. This beam is employed to irradiate cell cultures and laboratory animals for the boron neutron capture therapy (BNCT) development purposes [11, 12]. It is also used to measure hazardous impurities in boron carbide ceramics and 316L-IG austenitic stainless steel considered for ITER [13].

A beam of monoenergetic neutrons with energies from 10 to 100 keV is produced by kinematic collimation using several-micron-thick lithium foil targets. This beam is suitable for calibrating a dark matter detector [14] and is to be used for boron imaging by prompt gamma-ray spectroscopy.

Fast neutron flux is obtained via the ^{7}Li(d, n) reaction [8]. It is employed to study the activation of B_4C ceramics and SS 316L ITER-grade steel by fast neutrons [15]. It is also intended for the radiation tests of fibers used in ~~of~~ the laser calorimeter calibration system of the CMS electromagnetic detector developed for the High-Luminosity Large Hadron Collider at CERN.

A 478 keV-photon flux is produced by the ^{7}Li(p, p' γ)^{7}Li reaction (inelastic proton scattering by a lithium atomic nucleus) at a proton beam energy below 1.882 MeV, the threshold value for the ^{7}Li(p, n)^{7}Be reaction. This beam is used for *in situ* measuring of the lithium layer thickness [16] and for determining the doses of high-LET radiation [17].

To sum it up, the device is applicable to a wide range of research tasks, including the characterization of neutron detectors designed for fusion studies, in-depth investigation of the promising ^{11}B(p, α)$\alpha\alpha$ neutronless fusion reaction, etc.

CONCLUSION

The accelerator-based neutron source can produce high neutron fluxes in different energy ranges, from thermal to fast, that can be useful in various fields of research, including thermonuclear fusion. The research team has already been involved in~~to~~ neutron activation experiments conducted under the ITER project.

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BUDKER INSTITUTE OF NUCLEAR PHYSICS, 11 Lavrentiev ave., 630090, NOVOSIBIRSK, RUSSIA; NOVOSIBIRSK STATE UNIVERSITY, 1 PIROGOV STR., 630090, NOVOSIBIRSK,, RUSSIA

Bykov T.A., graduate student; timaisabrony@gmail.com
Ivanov A.A., Ph.D., Prof., Head of Laboratory; Budker Institute of Nuclear Physics, A.A.Ivanov@inp.nsk.su
Kasatov D.A., Ph.D., researcher; kasatovd@gmail.com
Kolesnikov Ia.A., graduate student; katyono@mail.ru
Koshkarev A.M., engineer; kent_brockman4@mail.ru
Ostreinov G.M., junior researcher; wtfsnoo@gmail.com
Makarov A.N., Ph.D., senior researcher; alexxmak314@gmail.com
Shchudlo I.M., researcher; cshudlo.i.m@gmail.com
Sokolova E.O., graduate student; buiya@bk.ru
Taskaev S.Yu., Ph.D., chief researcher; taskaev@inp.nsk.su

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