DIAGOSTICS OF THE PROTON BEAM POSITION USING THE LUMINESCENCE OF A LITHIUM NEUTRON-GENERATING TARGET*

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Abstract

A compact accelerator-based neutron source [1] has been proposed and created at the Budker Institute of Nuclear Physics in Novosibirsk, Russia. An original design tandem accelerator is used to provide a proton beam. The neutron flux is generated as a result of the ^{7}Li (*p, n*) ^{7}Be threshold reaction using the solid lithium target. A beam shaping assembly is applied to convert this flux into a beam of epithermal neutrons with characteristics suitable for BNCT (boron neutron capture therapy) [2]. In addition to the main purpose the neutron source is used to measure the content of impurities in ceramic samples developed for ITER [3], for measurement of the cross section of the reaction of inelastic scattering of a proton on a lithium nucleus. The neutron source is planned to be used for radiation testing of optical fibers of the laser calorimeter calibration system of the CMS [4] for the High Luminosity Large Hadron Collider (CERN). The need to provide the long-term stable generation of neutrons requires the development of diagnostic techniques that display relevant information from various subsystems of the neutron source in real time. We have developed and put into operation diagnostics for monitoring the position of the proton beam on a lithium target, which is also resistant to radiation exposure.

EXPERIMENTAL SETUP

An accelerator-based source of epithermal neutrons (Fig. 1) consists of an ion source *1a*, tandem accelerator with vacuum insulation *1* to obtain a stationary proton beam with an energy of up to 2.3 MeV and a current of up to 9 mA, lithium target *3* to generate neutrons as a result of the ^{7}Li (*p, n*) ^{7}Be threshold reaction. The lithium target is a copper disk, on which a thin lithium layer (usually 60 μm) is deposited from the side of the proton beam, and spiral channels for water cooling occur on the back side. The lithium targets may be installed in various positions: *A* after the bending magnet, *B* inside the irradiation room, *C* with movable system, *D* along the proton beam, *E* along the proton beam in the separate bunker, inside the beam shaping assembly (optionally).

To develop diagnostics for visual monitoring of the position of the proton beam, a lithium target was placed in the position *C* behind the bending magnet, which in this case was turned off. A Hikvision (China) video camera was installed on one of the branch pipe of the target assembly with barium fluoride glass; on the second branch pipe, with fused quartz glass, a darkened adapter was located, to which a CCS200 Compact Spectrometer (Thorlabs, United States) with the wide range (200–1000 nm) was connected through a multimode 5-m-long quartz fiber, with a core diameter of 200 μm and a numerical aperture of 0.22 NA. The spectrometer and PC were placed in the separate bunker to protect the spectrometer from bremsstrahlung radiation and neutrons.

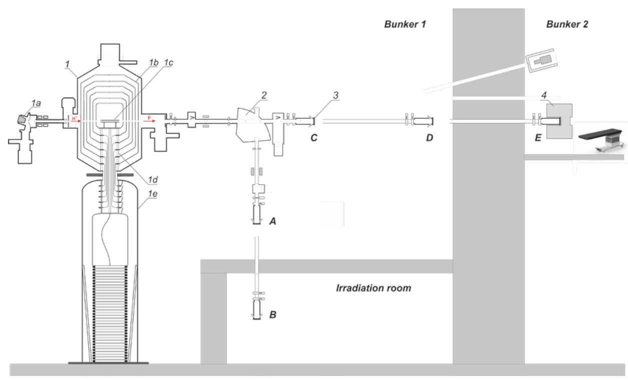

Figure 1: Compact accelerator-based neutron source: *1* – tandem accelerator with vacuum insulation; *2* – bending magnet; *3* – lithium neutron-generating target; *4* – beam shaping assembly.

RESULTS AND DISCUSSION

The emission spectrum of the lithium target was measured with a spectrometer when it was irradiated with a 2 MeV proton beam (see Fig. 2). The 610.3 ± 0.5 nm emission line corresponds to the $1s^2 3d \rightarrow 1s^2 2p$ electronic transition in the lithium atom, while the 670.7 ± 1 nm line corresponds to the $1s^2 2p \rightarrow 1s^2 2s$ transition in the lithium atom, and the 656.3 ± 1 nm line is the H_α spectral line observed for the hydrogen atom.

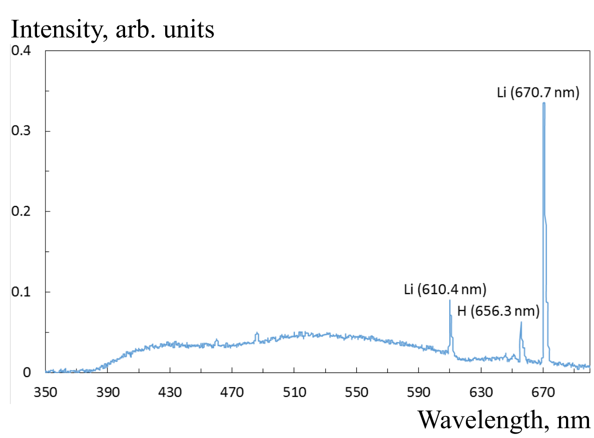

Figure 2: The luminescence spectrum of the lithium target.

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The luminescence of lithium under the action of high-energy protons is clearly recorded by the video camera. Thus, Fig. 3 shows the images obtained with a Hikvision video camera when the lithium target is connected in *C* position (Fig. 1) through a bellows. The lithium target is irradiated with a proton beam of 2 mm in diameter and is moved using a Bohua actuator (China). The images clearly show a glow in the form of a light oval spot. The shape of the spot is due to the fact that the video camera views the target at an angle of 45°. Visualization of the proton beam on the target was used to measure the spatial distribution of the thickness of the lithium layer by recording the intensity of radiation of 478 keV gamma quanta emitted during inelastic scattering of protons on lithium nuclei [5].

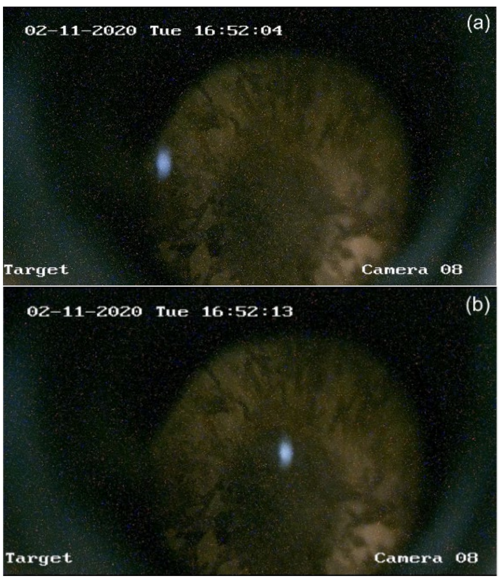

Figure 3: The glow recorded by Hikvision video camera when a lithium target is irradiated with a proton beam 2 mm in diameter in the direction of protons: (a) to the edge of the lithium target, (b) to the center.

The registration of luminescence made it possible to increase the reliability of the results of measuring the current of an argon ion beam that contributes to the flux of secondary charged particles in the accelerator [6]. The measurements were carried out by mass spectrometry using a bending magnet, inside which a cooled collimator with a 4 × 20 mm aperture was introduced through a vertical pipe (see Fig. 1). The charged particles which passed through the hole hit a lithium target which is electrically isolated from the facility and generated a current in the circuit, which was measured.

Figure 4 shows that the supply of a current to the bending magnet leads to the separation of the beam components: if the neutrals (hydrogen atoms) remain in place, then the argon ions and protons are displaced downward. At a certain current of the bending magnet, the proton beam will hit the collimator below the slit, the argon ions will pass through the slit, and their current can be measured. The measured current was so small, at the level of measurement accuracy, that if it were not for the visualization of the argon beam on the lithium target, it could be mistakenly considered zero. Figure 4b shows that only neutrals and argon ions pass through the slit and enter the target. With an increase in the gas injection into the stripping target, the glow intensity caused by argon ions increases, which should be expected, while the intensity of neutrals, that is, hydrogen atoms, on the contrary, decreases, which should also be expected (Fig. 4c).

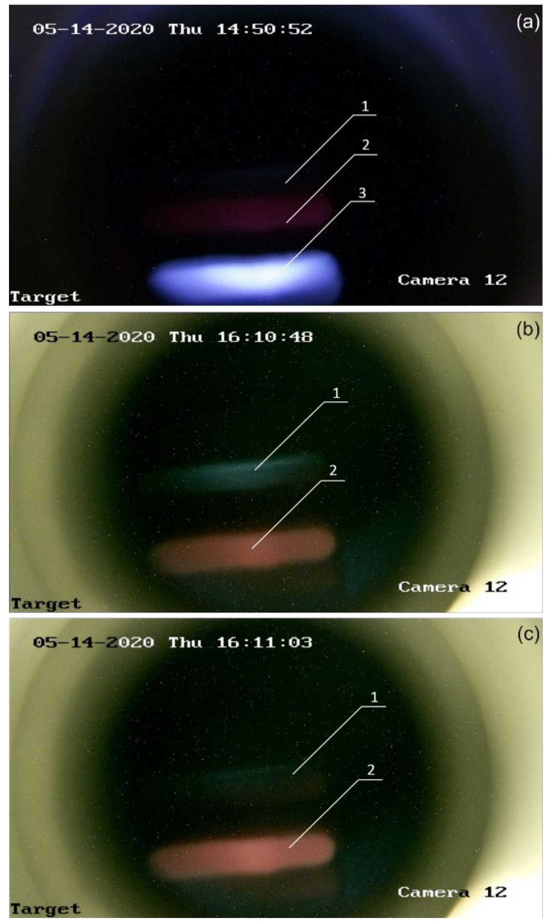

Figure 4: The glow recorded by a Hikvision video camera when a lithium target is irradiated with the components of a charged particle beam, at a bending magnet current of 14 A (a), 68 A (b) and 68 A and double gas injection into a stripping target (c). *1*, glow caused by neutrals (hydrogen atoms); *2*, argon ions; *3*, protons.

CONCLUSION

The accelerator-based epithermal neutron source operates at the Budker Institute of Nuclear Physics. It consists of a vacuum-insulated tandem accelerator for producing a proton beam and a lithium target for generating neutrons as a result of the ^{7}Li (*p, n*) ^{7}Be threshold reaction. The luminescence of lithium was recorded when the target was irradiated with protons using a video camera and a spectrometer. The registered radiation intensity of 610.3 ± 0.5 nm corresponds to the $1s^2 3d \rightarrow 1s^2 2p$ electronic transition in the lithium atom, while the 670.7 ± 1 nm line corresponds to the $1s^2 2p \rightarrow 1s^2 2s$ transition. Based on the results of the study, an optical diagnostic was developed and put into operation for operational monitoring of the position and the size of the proton beam on the surface of a lithium target used in the neutron generation mode.

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