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NUCLEAR EXPERIMENTAL TECHNIQUE

The Luminescence of a Lithium Target under Irradiation with a Proton Beam

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Abstract—The results of measurements of the luminescence spectrum of lithium when it is irradiated with a proton beam with an energy of 2 MeV are presented. The operational diagnostics for monitoring the position of the proton beam on a lithium target, which is used in neutron generation, has been developed and put into operation.

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INTRODUCTION

An accelerator source of epithermal neutrons was proposed and created at the Budker Institute of Nuclear Physics SB RAS [2] for the development of a promising technique for the treatment of malignant tumors, that is, boron neutron capture therapy [1]. Neutrons are generated as a result of the ^{7}Li (p, n)^{7}Be threshold reaction by directing a proton beam with an energy of up to 2.3 MeV and a current of up to 9 mA at a lithium target, obtained in a tandem accelerator with vacuum insulation. In addition to the main purpose, that is, boron neutron capture therapy, the neutron source is used to measure the content of impurities in ceramic samples developed for ITER [3], for measurements of the cross section of the reaction of inelastic scattering of a proton on lithium nucleus and the plan to use it [4] for radiation testing of optical fibers systems of laser calibration of the CMS calorimeter for the operation of the Large Hadron Collider (CERN) in the high luminosity mode.

The need to provide 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 diagnostics for monitoring the position of the proton beam on a lithium target, which is resistant to radiation exposure, into operation.

EXPERIMENTAL SETUP

The diagram of an accelerator source of epithermal neutrons, including a tandem accelerator with vacuum insulation *1* to obtain a stationary proton beam with an energy up to 2.3 MeV and a current up to 9 mA, lithium targets *11*, *16* to generate neutrons as a result of the ^{7}Li (p, n)^{7}Be threshold reaction and neutron beam shaping assembly *12* for the formation of a directed flux of epithermal neutrons is shown in Fig. 1. 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. Thermal evaporating of lithium in a vacuum is carried out on a separate stand.

The proton beam is transported from the accelerator to the target at a distance of 5 m using a corrector *5* and bending magnet *6*. The proton current is measured and controlled by a nondestructive DC current transformer NPCT (*3*) (Bergoz Instrum., France); the degree of stripping of the gas stripping target of the accelerator *14* is controlled by the developed neutral flow sensor [5]; the beam position is controlled by thermocouples inserted inside the cooled diaphragms *2*. The proton beam is swept over the target surface with a magnetic scanner *13*.

The position and size of the proton beam on the lithium target is controlled by thermocouples inserted into the copper disk of the target, and at proton energies below the neutron generation threshold, by a Flir T650sc infrared camera (United States) installed on the nozzle *7* of the bending magnet with a barium fluoride window. Visual control of the position of the proton beam on the target is convenient, but not applicable for neutron generation, since an infrared camera cannot operate in a neutron flux for a long period of time.

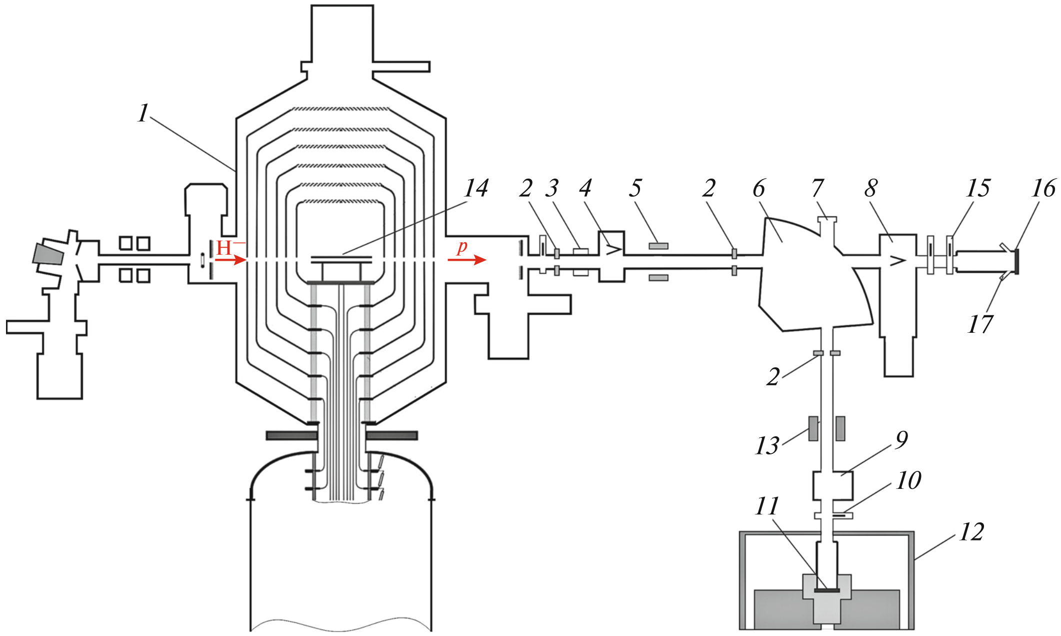

Fig. 1. The experimental setup diagram. *1*, vacuum-insulated tandem accelerator; *2*, cooled diaphragm with an aperture of 26 mm; *3*, nondestructive DC current transformer Bergoz; *4*, diagnostic tank with a retractable Faraday cup; *5*, corrector; *6*, bending magnet; *7*, branch pipe of bending magnet with a window for observing the lithium target; *8*, diagnostic tank with Faraday cup and vacuum pumping; *9*, diagnostic tank with vacuum pumping; *10*, gate valve; *11*, *16*, lithium targets; *12*, beam shaping assembly (BSA); *13*, magnetic scanner; *14*, gas stripping target; *15*, gate valve; *17*, branch pipes with windows for observation.

RESULTS AND DISCUSSION

To develop diagnostics for visual monitoring of the position of the proton beam, a lithium target *16* (see Fig. 1) was placed in the horizontal part of the proton beam transport path behind the bending magnet, which in this case was turned off. A Hikvision (China) video camera is installed on one of the nozzles *17* of the target assembly with barium fluoride glass; on the second pipe, with fused quartz glass, a darkened adapter is located, to which a CCS200 Compact Spectrometer wide-range (200–1000 nm) spectrometer (Thorlabs, United States) is connected through a multimode 1-m-long quartz fiber, with a core diameter of 200 μm and a numerical aperture of 0.22 NA. To protect the accelerator from bremsstrahlung radiation, the spectrometer is placed inside a lead collimator with an outer diameter of 270 mm, a length of 500 mm, and a wall thickness of 50 mm.

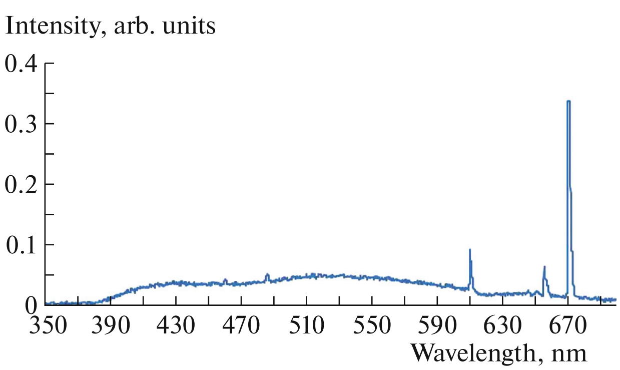

Fig. 2. The luminescence spectrum upon irradiation of lithium with 2 MeV proton beam.

The emission spectrum of the lithium target, as measured with a spectrometer when it is irradiated with a 2 MeV proton beam, is shown in 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 most likely that of the H_α spectral line observed for the hydrogen atom.

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 a lithium target connected to the path through a bellows is irradiated with a proton beam 2 mm in diameter when it 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.

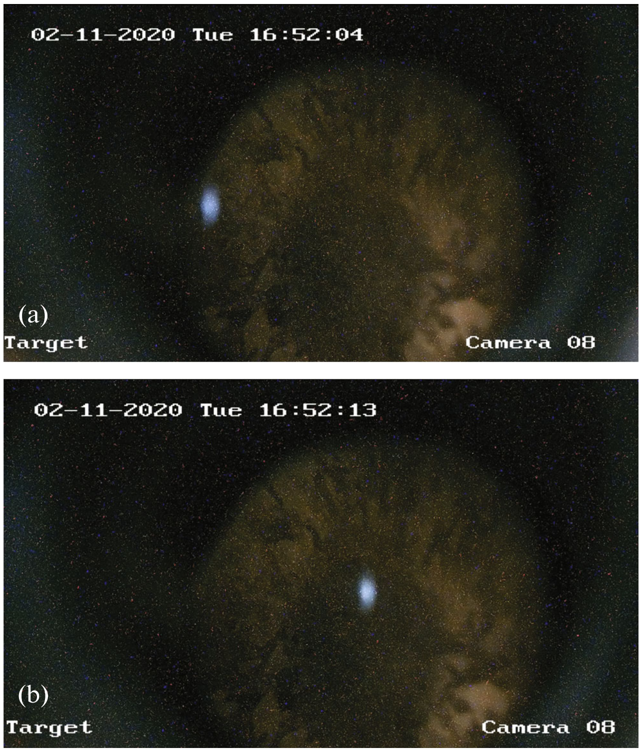

Fig. 3. The glow recorded by Hikvision video camera when a lithium target is irradiated with a proton beam 2 mm in diameter in the direction of protons: (a) to the edge of the target, (b), to the center.

Fig. 4. The luminescence recorded by a Hikvision video camera when a lithium target is irradiated with a proton beam.

Figure 4 shows an image obtained by a Hikvision video camera placed on a vertical pipe (*7* in Fig. 1) of a bending magnet and directed at a lithium target installed in the vertical beam transport path for neutron generation. The bright spot in the center is due to the luminescence of lithium when it is irradiated with protons. This image was obtained with the magnetic scanner turned off, which is designed to scan the proton beam over the target surface. When the scanner is turned on the size of the glowing area increases, as one would expect.

The ability to register luminescence of lithium with a Hikvision video camera allows one to control the position and size of the proton beam on a lithium target, including during neutron generation, due to the chamber's sufficient resistance to the neutron flux. This diagnostics has been put into operation and is used on an ongoing basis to monitor the position and size of the proton beam on a neutron-generating target. It was previously planned to use an infrared camera for this purpose; however, this is possible only when the proton energy is below the neutron generation threshold, since the infrared camera in the neutron flux quickly loses its performance.

Earlier, when studying the blistering of metals during proton implantation [6], we found that the infrared camera shows an overestimated temperature of the metal surface, which, according to the authors, is due to a change in the emissivity of the metal surface upon irradiation with protons. It is now becoming clear that the overestimation of the surface temperature readings is due to luminescence, that is, the nonthermal glow of the target.

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 [7]. The measurements were carried out by mass spectrometry using a bending magnet, inside of which a cooled collimator with a 4 × 20 mm aperture was introduced through a vertical pipe *7* (see Fig. 1). The charged particles that passed through the hole hit a lithium target that is electrically isolated from the facility and generated a current in the circuit, which was measured.

Figure 5 shows that the supply of 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 5b 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. 5c).

CONCLUSIONS

The Budker Institute of Nuclear Physics, SB, RAS operates an epithermal neutron source consisting of a

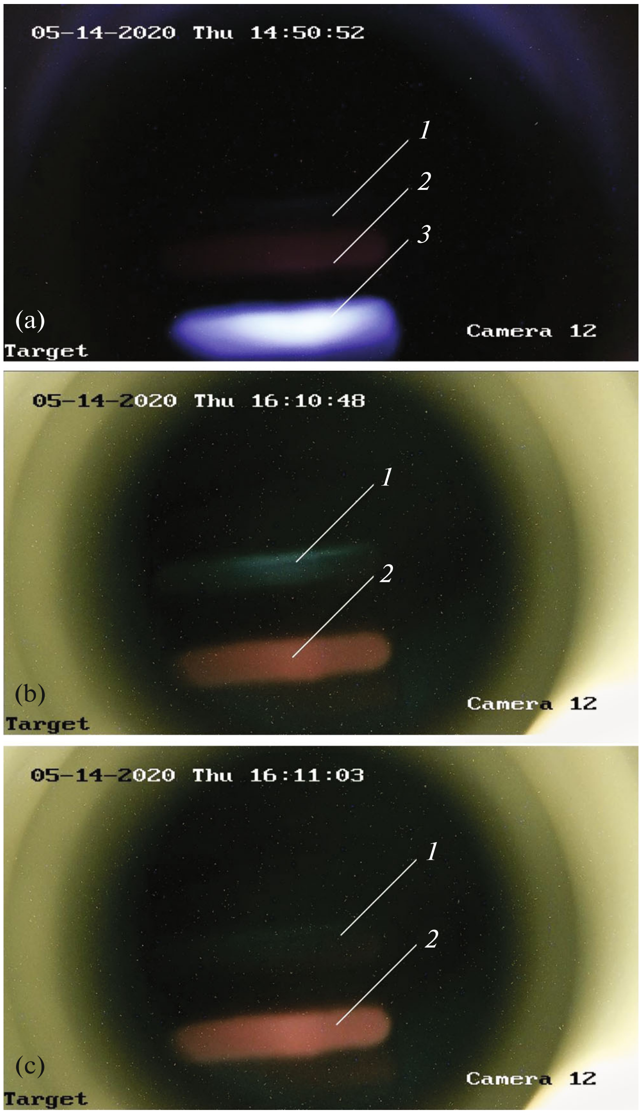

Fig. 5. The glow recorded by a Hikvision video camera when a lithium target is irradiated with the components of a charged particle beam, at a bending magnet current of 14 (a), 68 (b) and 68 A and double gas injection into a stripping target (c). *1*, glow caused by neutrals (hydrogen atoms); *2*, argon ions; *3*, protons.

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 $1s^23d \rightarrow 1s^22p$ electronic transition in the lithium atom, while the 670.7 ± 1 nm line corresponds to the $1s^22p \rightarrow 1s^22s$ transition. Based on the results of the study, an optical diagnostic unit was developed and put into operation for operational monitoring of the position and size of the proton beam on the surface of a lithium target used in the neutron generation mode.

The ability to detect luminescence made it possible to ensure the reliability of measuring the current of the argon ion beam accompanying the proton beam. When studying the blistering of a metal upon implantation of protons with an energy of 2 MeV, luminescence could lead to an overestimation of the surface temperature measured by the infrared camera.

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