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PHYSICS AND TECHNIQUE OF ACCELERATORS

Automation of Physical Experiments on the Accelerating Neutron Source

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Abstract—A neutron source based on a tandem accelerator with vacuum insulation and a lithium target has been created at the Budker Institute of Nuclear Physics, Siberian Branch, Russian Academy of Sciences. This report provides an overview of the diagnostic tools used at the facility, such as determining the position and size of a beam of negative hydrogen ions using a wire scanner and video cameras, automating experiments on measuring the phase portrait of a proton beam with energies up to 2 MeV using a wire scanner, determining the position and the size of the proton beam on the surface of the lithium target using built-in thermocouples in real time, and automating measurements of the spatial distribution of the absorbed dose components in the water phantom.

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INTRODUCTION

An accelerator source of neutrons is in operation at the Budker Institute of Nuclear Physics, Siberian Branch, Russian Academy of Sciences, in Novosibirsk [1] This neutron source became the prototype of a medical facility for boron neutron capture therapy (BNCT). The neutron source is also used for biological and physical research, for the development of BNCT techniques, and for other applications.

This neutron source is an electrostatic proton accelerator. The source of negative hydrogen ions (Fig. 1a) forms a beam with an energy of 28 keV and a current of 5 mA, which is then focused and enters the accelerator tank (Fig. 1b), where it is accelerated to an energy of 1 MeV. In the center of the accelerator, the beam is recharged by argon gas (Fig. 1c) and a beam of protons with an Energy of 2 MeV is formed at the output of the accelerator. Neutron generation occurs as a result of dropping a proton beam onto a neutron generating target (Fig. 1f) coated with a thin layer of lithium. Neutrons are generated as a result of the threshold reaction 7Li(p, n)7Be.

The position and parameters of the beam are controlled by various diagnostic tools at all stages. Their integration into the overall automation system ensures the reliable operation of the plant.

DETERMINING BEAM POSITION USING A WIRE SCANNER

A D-Pace OWS-30 wire scanner is used to determine the position of a beam of negative ions with an energy of 28 keV (Fig. 1a) in the low-energy path (Fig. 2). It is a rod with two tungsten wires 0.5 mm in diameter. The wires are fixed on the rod in such a way that, when the rod is rotated, the wires would cross the measurement plane orthogonally to each other.

When the wires pass through the beam, the current is measured, which includes the current of negative hydrogen ions and the electron emission current. Blocking of the electron emission from the wires is carried out by installed blocking rings, to which a potential of minus 300 V is applied [2].

The software displays the current profile depending on the angle of the rod. Additional software for the analysis of measurements has been developed. It implements algorithms for finding the total beam current and its position and dimensions.

USING OPTICAL VIDEO CAMERAS TO DETERMINE THE POSITION OF THE BEAM

The use of a gas stripping target at the center of the accelerator worsens the vacuum conditions. Such (2×10^{-3} Pa) vacuum conditions will make it possible to see the glow of the residual gas using conventional CCD video cameras. Two such video cameras are mounted on nozzles that remove the inlet diaphragm of the accelerator from the vertical and horizontal directions. The diameter of the input diaphragm is 20 mm.

Software was developed that receives an image from two cameras and determines the position of the luminous spot in the input aperture with respect to two

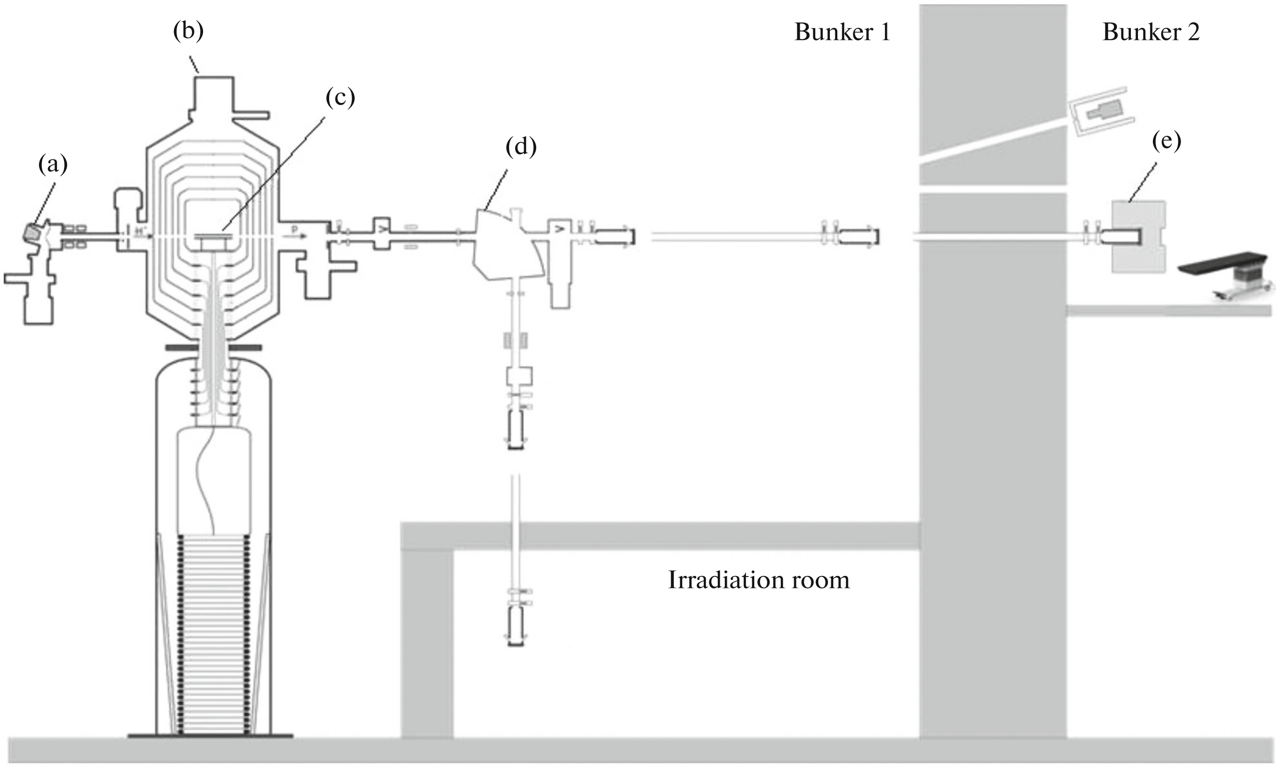

Fig. 1. General view of the accelerator: (a) source of negative hydrogen ions, (b) accelerator tank, (c) argon exchange tube, (d) bending magnet, and (e) beam formation system with a lithium target.

axes. The scale of the axes is set from the known diameter of the inlet diaphragm.

The use of cameras and the developed software makes it possible to control the position of the beam in real time.

PHASE PORTRAIT OF A PROTON BEAM

The phase portrait of the proton beam was measured using a wire scanner and additional software [3]. For this, a cooled movable diaphragm with a diameter of 1 mm is installed in the diagnostic chamber in front of the rotary magnet (Fig. 1d), and the wire scanner is installed behind the rotary magnet. The wire scanner is placed so that one wire measures the current horizontally and the other vertically.

At the beginning, by changing the position of the diaphragm, a position is found at which the maximum current on the lithium target is measured. Further, one coordinate is left fixed, the other is moved in 1-mm increments, and the current profile is measured. The same is repeated for the second coordinate.

After the software processing of all measurements, a phase portrait of the beam is constructed and the beam emittance is determined.

BEAM POSITION CONTROL ON A LITHIUM TARGET

Nine thermocouples are built into the lithium target: four horizontally, four vertically, and one in the middle at the point of intersection of the axes. Using the least squares method, the Gaussian function for two axes was inscribed in the temperature values; then an image of a two-dimensional Gaussian was constructed. The position of the maximum was fixed and recorded in time. This makes it possible to control the

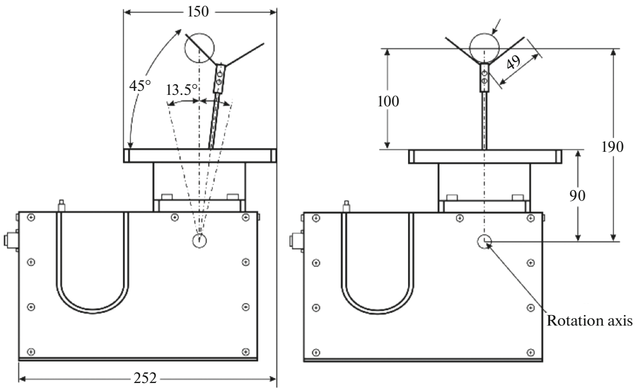

Fig. 2. Scheme of a wire scanner.

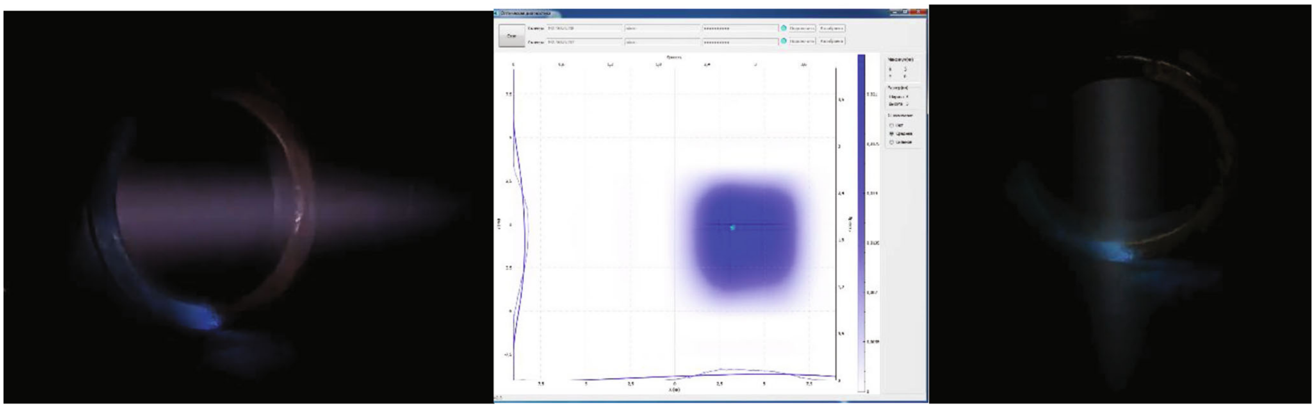

Fig. 3. Accelerator inlet diaphragm from two angles and software.

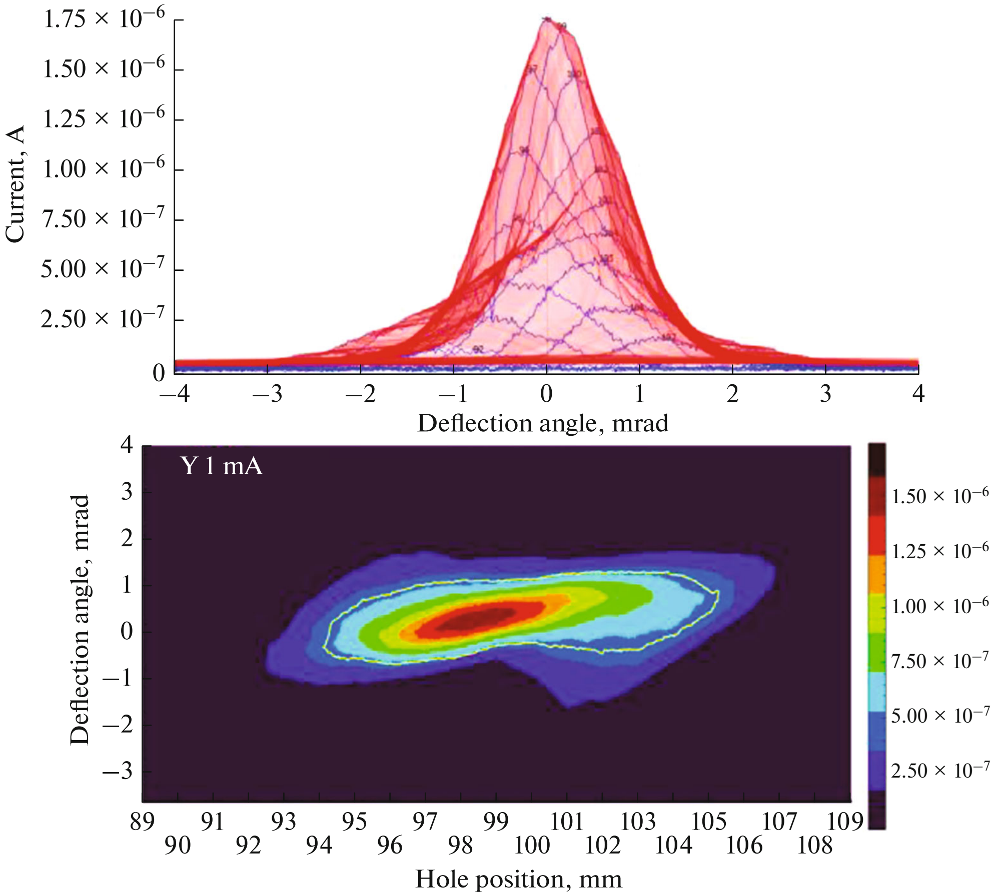

Fig. 4. Result of processing measurements for a 2 MeV 1 mA proton beam.

position of the beam on the lithium target with respect to temperature.

SPATIAL DOSE DISTRIBUTION IN THE WATER PHANTOM

Neutron generation was carried out in two bunkers on a lithium target installed in the beam formation system (Fig. 1f). The proton energy was 2.07 MeV. A water phantom was placed in front of the beam forming system. The water phantom is equipped with a movable carriage that can move throughout the entire volume of the phantom. A boron neutron sensor is fixed to the movable carriage [4]. To automate the measurement process, software was developed to control the movable phantom carriage. This software

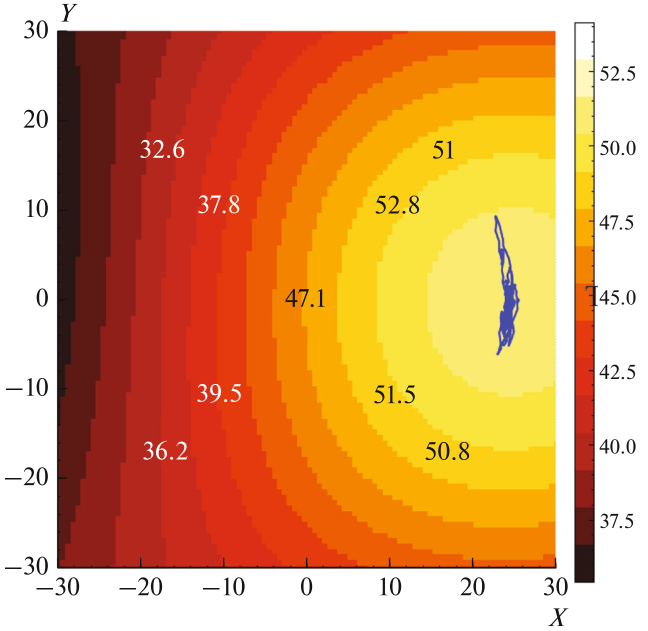

Fig. 5. Image of a two-dimensional Gaussian function represented in temperature values.

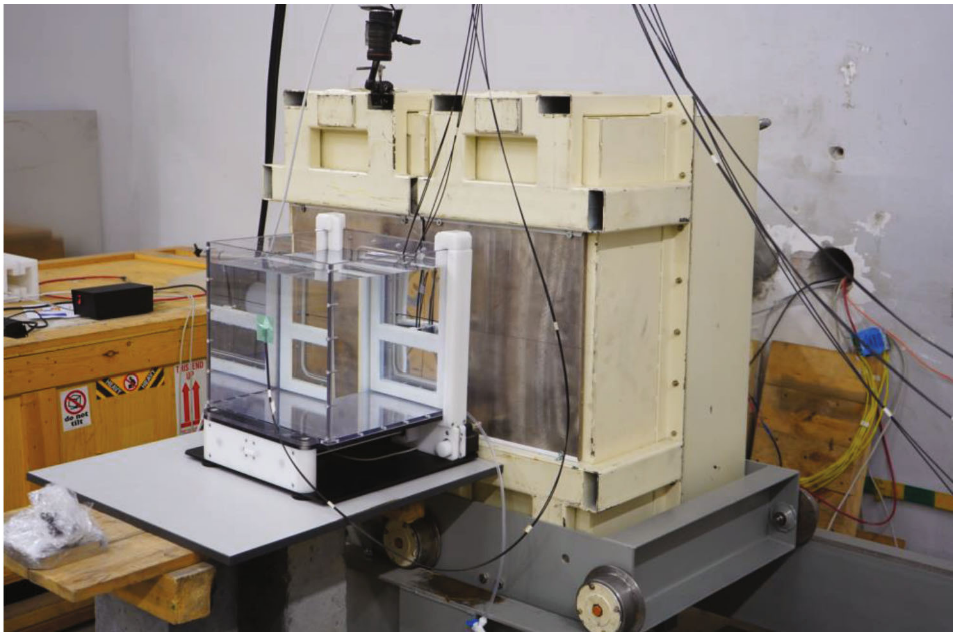

Fig. 6. Photo of the beam-forming system with a water phantom.

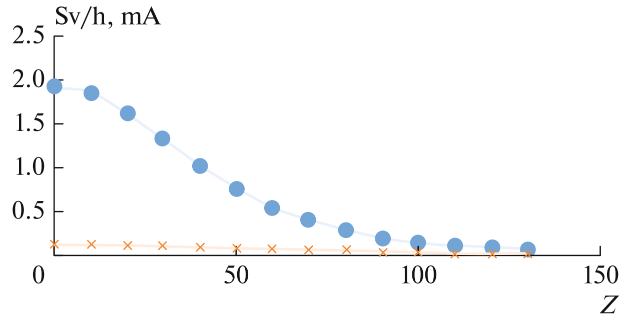

Fig. 7. Graph of the dependence of the neutron dose (●) and gamma (×) on the distance from the target.

allows one to directly and remotely control the carriage and perform the automatic scanning of the volume.

The distribution of the neutron dose and gamma over the depth of the phantom for the 2.07-MeV beam is obtained.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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