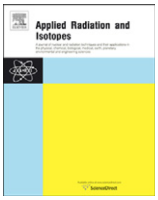
Applied Radiation and Isotopes 69 (2011) 1635–1638

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



BINP accelerator based epithermal neutron source

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ARTICLE INFO

Available online 16 March 2011

Keywords:
Boron neutron capture therapy
Epithermal neutron source
Accelerator

ABSTRACT

Innovative facility for neutron capture therapy has been built at BINP. This facility is based on compact vacuum insulation tandem accelerator designed to produce proton current up to 10 mA. Epithermal neutrons are proposed to be generated by 1.915–2.5 MeV protons bombarding a lithium target using ^{7}Li(p,n)^{7}Be threshold reaction. In the article, diagnostic techniques for proton beam and neutrons developed are described, results of experiments on proton beam transport and neutron generation are shown, discussed, and plans are presented.

1. Introduction

In 1998, an original source of epithermal neutrons was conceived (Fig. 1; Bayanov, et al., 1998) based on a tandem accelerator with vacuum insulation, suitable for a widespread use of BNCT in clinical practice. It is intended to generate neutrons with the threshold ^{7}Li(p,n)^{7}Be reaction by bombarding a lithium target with a 2–2.5 MeV, 10 mA proton beam. It is world-recognized (Blue and Yanch, 2003) that the best reaction to form the epithermal neutron beam is the ^{7}Li(p,n)^{7}Be reaction: neutron production is high, and the neutron spectrum is relatively soft. However, the mechanical, chemical, and thermal properties of lithium metal prevented it from being a candidate for a target.

The construction of the proposed source started in 2003 at Budker Institute of Nuclear Physics (BINP), and in 2007, the stable proton beam with the required energy and a current of 2.7 mA was obtained. High monochromaticity and the stability of the proton beam energy were achieved in the accelerator. This allowed us to obtain near-threshold neutron generation, which is attractive due to a directed neutron flow and low background radiation. All problems of a lithium target have been solved, namely (i) the effective cooling was implemented (Bayanov, et al., 2004) to keep the lithium layer solid in order to prevent the propagation of ^{7}Be radioactive isotope, (ii) the controlled evaporation of a thin lithium layer was used (Bayanov, et al., 2008) to reduce the accompanying gamma radiation, (iii) substrate materials as resistant to blistering as possible were found. In 2008, the target was assembled and neutron generation was performed (Kuznetsov, et al., 2009).

2. Current results

Now, the facility is being upgraded to increase the proton beam current up to 5 mA, to provide sustained stable neutron generation, to form epithermal neutron flux for *in vitro* investigations.

In the course of the experiments, it was found out that the potential of the first electrode of the accelerator, which is supplied with high voltage through the divider decreases a lot while the beam is transported, and varies depending on the gas conditions and the beam parameters. At once, the potential of this electrode sets the entrance lens power, which is the most powerful and determines the further beam transport. To exclude the effect of non-controllability of the entrance lens power, a high-voltage entrance (200 kV) was designed and manufactured to correct the first electrode voltage.

The facility was equipped with the beam position diagnostics (Fig. 2) and the movable beam profile meter (Fig. 3), which allowed us to study and optimize the proton beam transport. To determine the total beam current in different parts of the facility, a target like a copper cone with water cooling is used (Fig. 4). To limit the secondary electron penetration into the region of the accelerator channel, the negative potential electrodes are provided in the target unit that allows the exact measurement of current.

The beam transport in the bending magnet was studied, and the dependence of the needed current in the magnet coils on the proton beam energy was determined.

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doi:10.1016/j.apradiso.2011.03.010

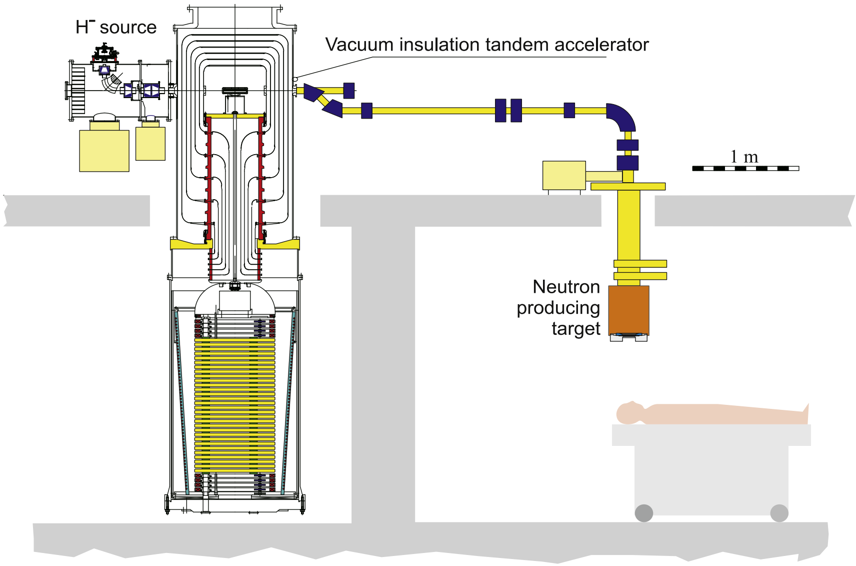

Fig. 1. Accelerator based neutron source for NCT.

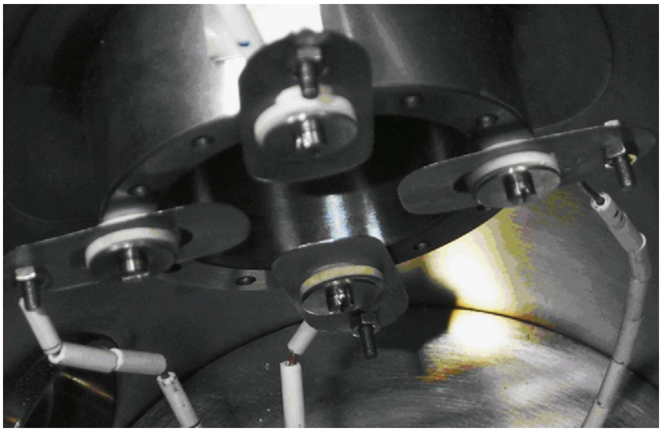

Fig. 2. Pick-up electrodes for control of proton beam intensity on high-energy tract periphery.

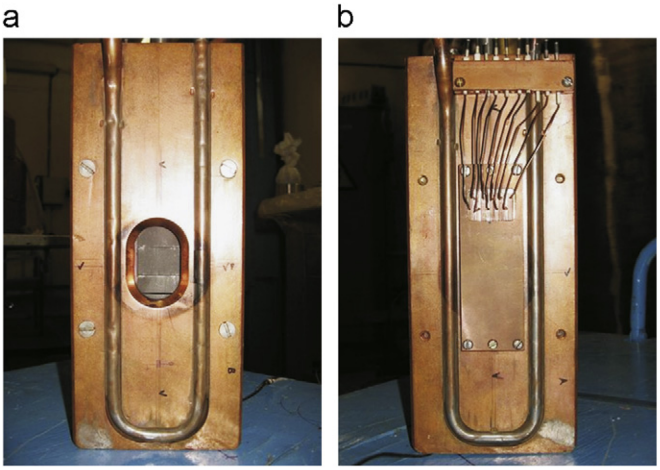

Fig. 3. Movable beam profile meter.

A thin tantalum foil was placed instead of the neutron producing target for investigation of the proton beam sweeping. The beam dimensions and position were controlled by the foil glow (Fig. 5). The tantalum foil was isolated from the facility that allowed to study the current dependency on the sweep amplitude and to determine the optimal parameters of the sweep system.

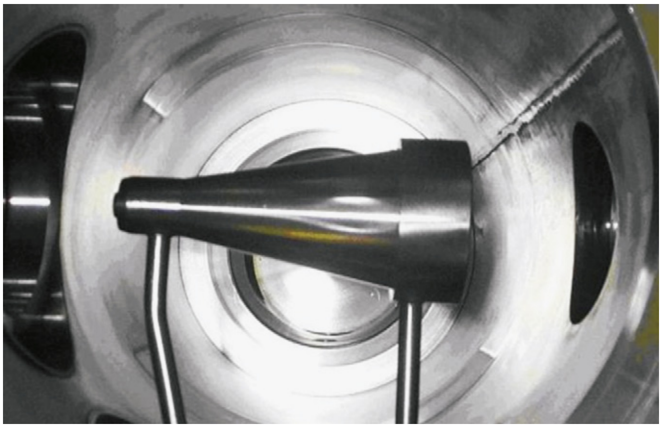

Fig. 4. Cone target for current measurement.

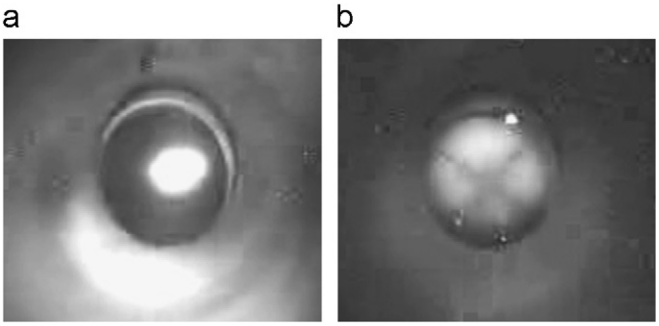

Fig. 5. Luminescence of the target without (left) and with (right) sweep of the beam.

To solve the problem of the target activation by Be-7 isotope, a protective subsurface container for holding and temporary storage of the activated targets was proposed, designed, constructed, and put into operation (Bayanov et al., 2010a). The container allows implementing sustained neutron generation.

An original solution for implementing the time-of-flight technique with a continuous proton beam is proposed (Aleynik, et al., this issue). For a short interval of time the energy of proton increases from 1.865 (lower than the threshold of the ^{7}Li(p,n)^{7}Be reaction that is 1.882 MeV) up to 1.915 MeV. The energy increase is performed by supplying the square pulse of 50 kV for 200 ns on neutron-generating target that is insulated from the facility body (Fig. 6). During these 200 ns the generation of neutrons is performed. The registration of neutrons is made with neutron detector Saint-Gobain, consisting of cerium activated lithium silicate glass scintillator GS20. The assembled time-of-flight diagnostic system is calibrated and tested.

The facility was equipped with neutron and gamma dosimeter DKS-96 (Russia), gamma-detector LB6500-3 H 10 (Berthold Tech., Germany), NaI and BGO gamma spectrometers (Bayanov et al., 2010b).

To study the dose fields, a plexiglas phantom was designed and manufactured (Fig. 7). The activation foils could be placed over the whole body of the phantom. To register the epithermal neutrons, use of the In, Au, W, I, Mn, and Al foils were proposed. The phantom was irradiated with a plutonium–beryllium neutron source with an activity of $4.34 \cdot 10^6$ Bq to work out the technique.

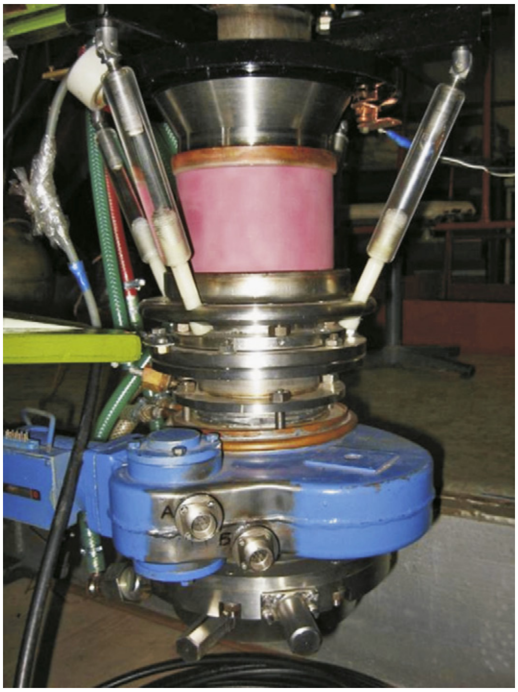

Fig. 6. Photo of the neutron producing target suspended on the ceramic insulator.

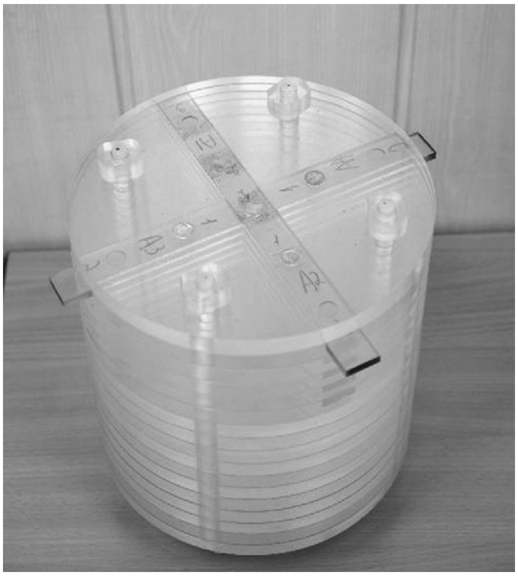

Fig. 7. Plexiglas phantom.

For the near-threshold neutron generation mode, attractive due to low activation of the facility and the target, a solution was found providing a density of epithermal neutrons of 3×10^8 cm^{-2} s^{-1} at an acceptably small flux of fast and thermal neutrons at the proton beam energies of 1.915–1.95 MeV and a current of 10 mA (Taskaev, et al., this issue). Kerma rate in a modified Snyder head phantom was calculated for the new target with several variants of the moderator. Changes in the proton beam energy and the moderator make it possible to form the neutron flux with different features including higher density, and to select the optimal one for BNCT.

3. Perspectives

The manufacture of a new low-energy beam transport line and a new stripping target are now close to be finished. The low-energy tract provides the hydrogen negative ion beam acceleration till 200 keV. This essentially facilitates their input into the accelerator. Besides, the bending magnet may be placed directly inside the vacuum chamber, which allows hastening the gas pumping out and lowering the charge-exchange losses. The main change in the stripping target is the tube diameter increase from 10 to 16 mm. This also provides the beam loss minimization. The possible reduction of the accelerator electric strength due to the increased gas flows can be compensated by more efficient cryogen pumps instead of the turbo-molecular ones. All these arrangements will enhance the beam transport and increase the stability of the accelerator operation.

To increase the proton beam up to 10 mA, a new 15 mA hydrogen negative ion source is proposed to be manufactured and installed that will be similar to the one manufactured for IBA company (Belgium) and already started up.

In the nearest future, the *in vitro* investigations are planned to be started. We invite all interested participants to contact the authors for evaluating the possibilities of active involvement in this project (Sauerwein, et al., 2010).

4. Conclusions

The pilot innovative facility for neutron capture therapy has been built at Budker Institute of Nuclear Physics, Novosibirsk. This facility is based on a compact vacuum insulation tandem accelerator and near-threshold neutron generation from the reaction ^{7}Li(p,n)^{7}Be. A 2.7 mA proton beam was obtained, and neutron generation was implemented at the facility.

Now, the facility is being upgraded to increase the proton beam and to provide a stable operation. The work on sustained stable neutron generation for *in vitro* investigations and neutron spectra measurements has been fulfilled at the facility.

Achievement of the stable neutron generation will allow the organization of the Shared Center to develop the BNCT technique.

Acknowledgments

The authors would like to thank the financial support from International Science and Technology Center (project # 3605) and Ministry of Education and Science of Russian Federation (grants # P 704 and # 02.518.11.7146).

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