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The accelerator neutron source for boron neutron capture therapy

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Abstract. The accelerator based epithermal neutron source for Boron Neutron Capture Therapy (BNCT) is proposed, created and used in the Budker Institute of Nuclear Physics. In 2014, with the support of the Russian Science Foundation created the BNCT laboratory for the purpose to the end of 2016 get the neutron flux, suitable for BNCT. For getting 3 mA 2.3 MeV proton beam, was created a new type accelerator - tandem accelerator with vacuum isolation. On this moment, we have a stationary proton beam with 2.3 MeV and current 1.75 mA. Generation of neutrons is carried out by dropping proton beam on to lithium target as a result of threshold reaction $^7Li(p,n)^7Be$. Established facility is a unique scientific installation. It provides a generating of neutron flux, including a monochromatic energy neutrons, gamma radiation, alpha-particles and positrons, and may be used by other research groups for carrying out scientific researches. The article describes an accelerator neutron source, presents and discusses the result of experiments and declares future plans.

1. Introduction

Currently, Boron Neutron Capture Therapy (BNCT) is considered as a promising technique for treatment of malignant tumors [1]. It provides selective destruction of tumor cells by prior accumulation inside them a stable boron-10 isotope and subsequent irradiation with epithermal neutrons (Figure. 1). Because of the absorption of a neutron by boron, a nuclear reaction takes place with a large release of energy in the cell, leading to its death. Clinical trials on nuclear reactors showed that BNCT could treat glioblastoma, brain metastases of melanoma and several other tumors. For the widespread introduction of this technique in practice, compact sources of epithermal neutrons based on charged particle accelerators are required.

Currently in the Budker Institute of Nuclear Physics (BINP), at the accelerator obtained a stationary proton beam with energy 2.3 MeV and a current of 1.75 mA with high monochromatic energy 0.1% and stability of current efficiency of 0.5%, carried out neutron generation [2] and research of radiation influence on cells structure [3]. For therapy should increase the proton beam current of at least to 3 mA. 16-20 November 2015 we conducted a series of experiments of irradiation of cells at our facility together with the staff and PhD students from the Hospital of Tsukuba University (Japan).

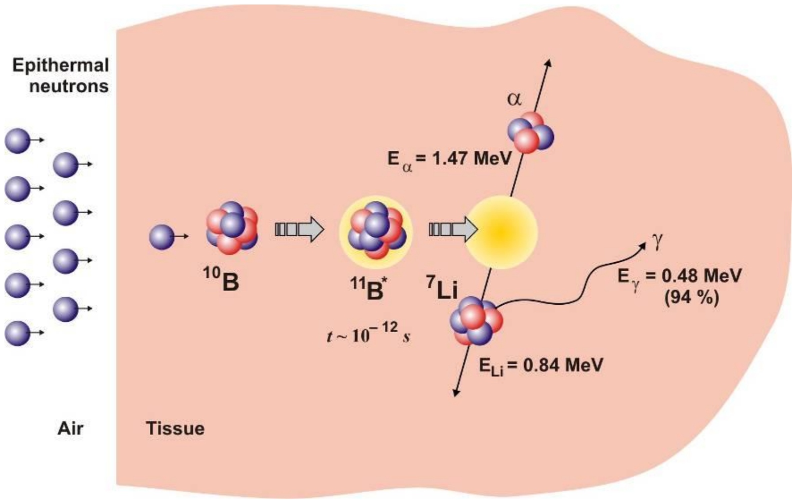


Figure. 1. Scheme of $^{10}B(n,\alpha)^{7}Li$ reaction

2. Accelerator based on epithermal neutron source

It is world-recognized [1] that the best reaction to form the epithermal neutron beam for BNCT is the $^{7}Li(p,n)^{7}Be$ reaction: neutron production is high, and the neutron spectrum is relatively soft. The source of epithermal neutrons based on the original tandem accelerator with vacuum insulation and the lithium neutron producing target was proposed in BINP [3]. The scheme of the proposed neutron source is shown at Figure 2. The facility consists of a source of negative hydrogen ions, a tandem accelerator generating a proton beam and a neutron producing target. Because of the complexity of creating such an accelerator neutron source for producing the proton beam it a new type of accelerator has been proposed, the tandem accelerator with vacuum insulation. It was also proposed to implement $^{7}Li(p,n)^{7}Be$ reaction, despite of the complexity of manufacturing the target: low melting temperature, low thermal conductivity and high chemical activity of lithium.

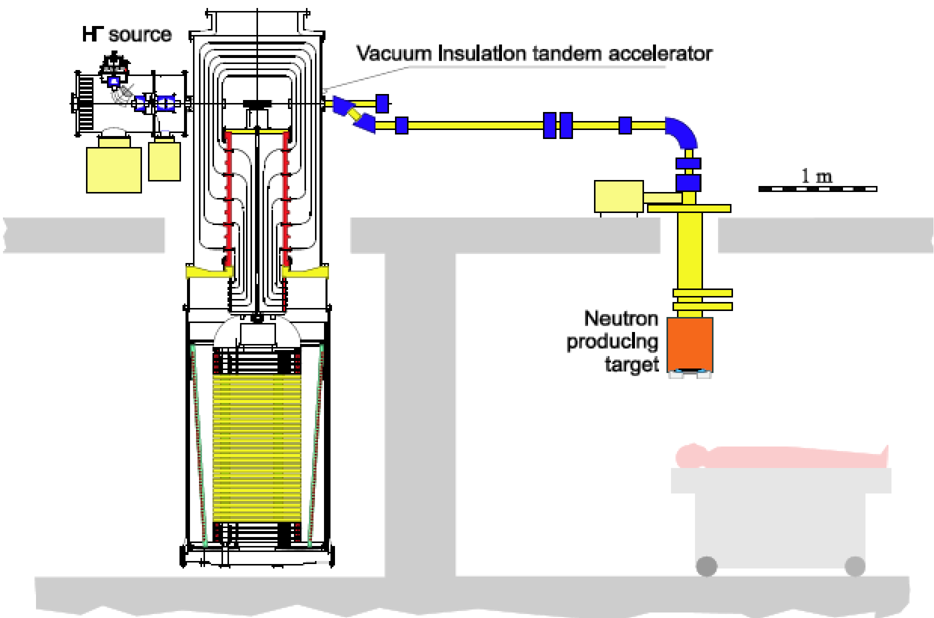


Figure. 2 Accelerator based on neutron source for BNCT

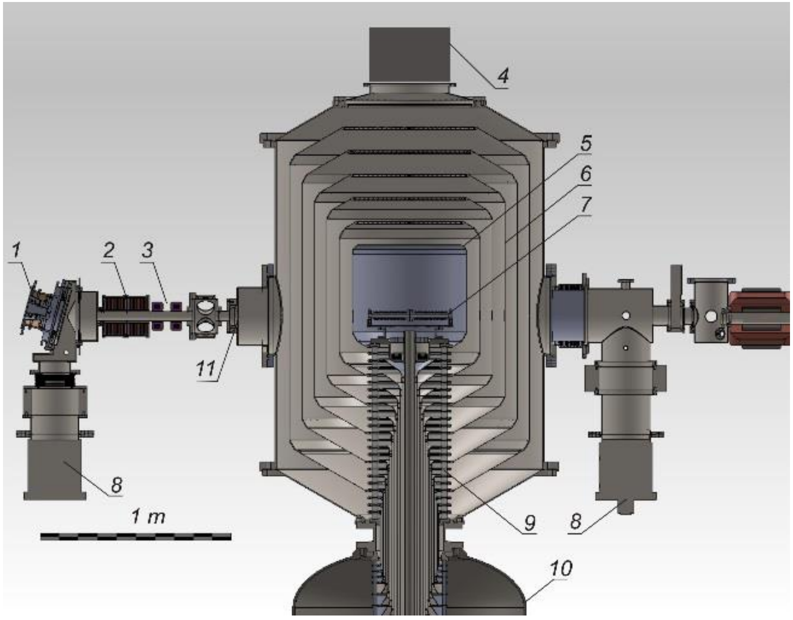


Figure.3 Tandem accelerator with vacuum insulation: 1 – source of negative hydrogen ions, 2 – magnetic lenses, 3 – correctors, 4 – cryogenic pump, 5 – high voltage electrode, 6 – intermediate electrodes, 7 – gas stripping cell, 8 – turbomolecular pump, 9 – insulator, 10 – high-voltage power supply, 11 – inlet diaphragm.

Figure. 3 shows the accelerator. Coming from the source (1) negative hydrogen ion beam with 23 keV energy is rotated in a magnetic field at an angle of 15 degrees, focused by a pair of magnetic lenses (2), injected into the accelerator and accelerated up to 1 MeV. In the gas (argon) stripping cell (7), which is installed inside the high-voltage electrode (5), negative hydrogen ions are converted into protons. Then protons by the same 1 MV potential are accelerated to 2 MeV energy. The potential for the high-voltage (5) and five intermediate electrodes (6) of the accelerator is supplied by a high-voltage source 10 (most of the source is not shown) through the insulator (9), wherein the resistive divider is set. Evacuation of gas is performed by turbomolecular pumps (8) mounted at the ion source and at the exit of the accelerator, and a cryogenic pump (4) via jalousies in the electrodes.

3. Additional flux of charge particle in accelerating channel

The main problem of achieving the objective of the Laboratory is double increase of the proton beam current. To clarify the reasons of breakdowns preventing an increase in current the process of acceleration of the ion beam in the accelerator has been studied. It was found that the acceleration of the ion beam is accompanied by additional flux of charged particles in the accelerating channel. It was found [4] that the appearance of charged particles is due to ionization of stripping gas and residual gas by the injected beam and due to penetration of positive argon ions of the stripping cell into the accelerating channel. The electrons caused by ionization of the gas are accelerated mainly to 1-MeV and absorbed by the elements of high-voltage electrode or stripping cell leading to a significant bremsstrahlung. Penetration of positive argon ions from the stripping cell into the accelerating channel is accompanied by their further acceleration to 1 MeV, which can lead to a significant secondary emission of electrons due to absorption of accelerated argon ions in the wall of the vacuum chamber.

4. Experiment for suppressing accompanying flux of charged particles

To suppress the flux of accompanying particles it was proposed and made two modernizations. Firstly, we improved vacuum conditions particularly in the beginning of the acceleration of the ion beam. For this purpose we have made a new input node, wherein a vacuum resistance formed as a cooled diaphragm was set and a cryopump On-Board 10 (CTI-Cryogenics, USA) with a pumping speed 2500 l/s for argon and 5000 l/s for hydrogen was mounted. At Figure.4 is shown a cryopump on input node, that place is pointed 11 at Figure.3

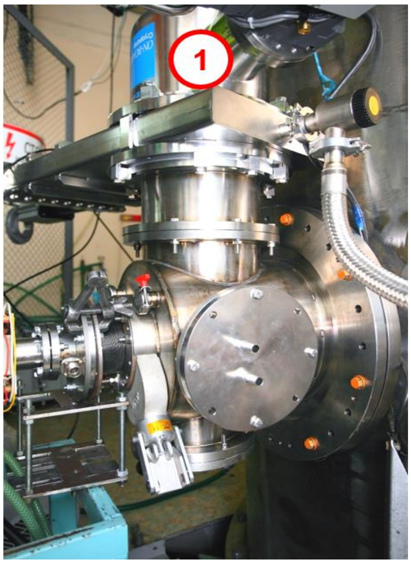
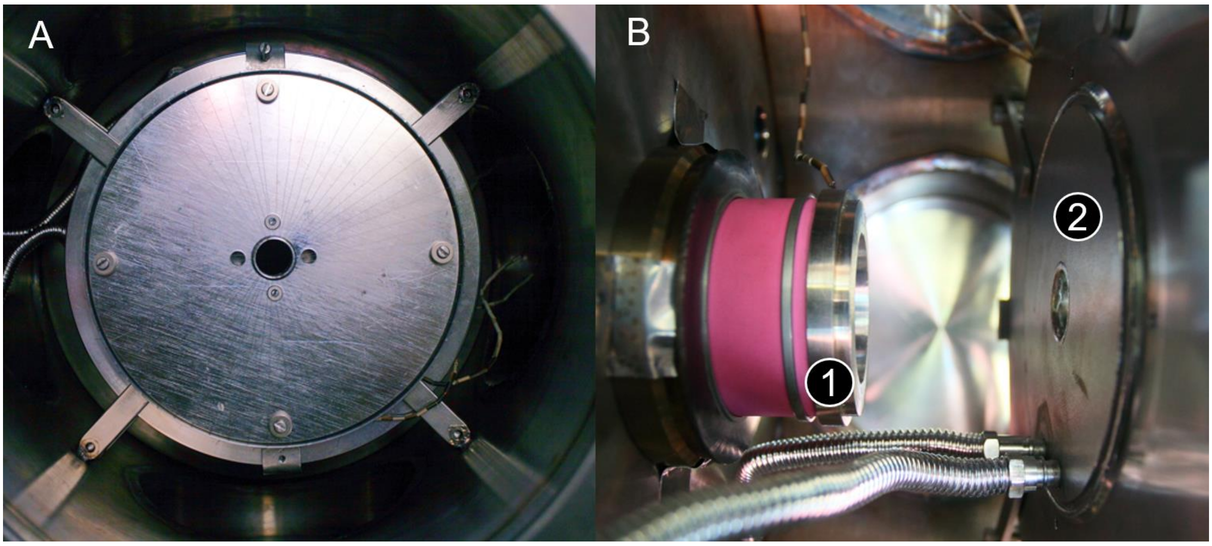


Figure.4 Input node. 1– Cryopump

Figure.5 Water cooled diaphragm

Secondly, the wall of the vacuum chamber bombarded by positive argon ions and ultraviolet radiation from the stripping tube. We set an argon detector with grid at the inlet of accelerator on the water-cooled diaphragm. 300 Volt was applied on the grid to block a secondary electron emission. Also, metal circle was set under same voltage behind the water-cooled diaphragm to block electrons which may permeate with H^- beam. A photograph of modification describe above is shown in Figure. 6a, 6b.



(a) (b)

Figure.6. (a) Argon detector with grid under voltage. (b) 1 – Metal circle under voltage, 2 – Water-cooled diaphragm.

5. The results

During the experiment, the voltage have being changing at the grid and ring. The obtained dependences are presented in Figure.7, 8.

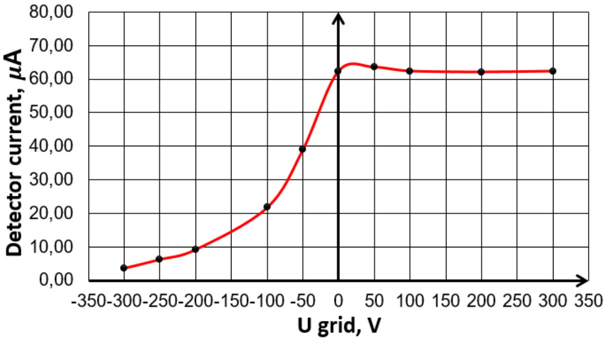


Figure.7 Counter-current of argon at detector

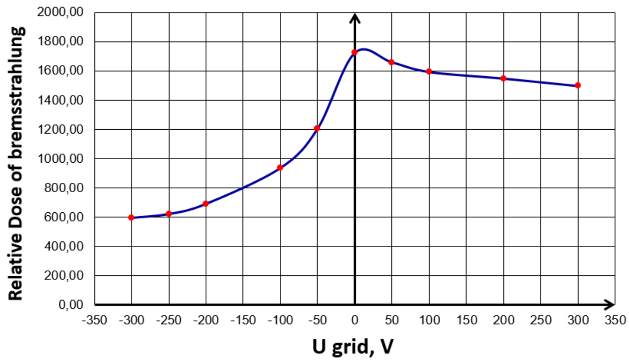


Figure.8 Relative dose of bremsstrahlung

The experiment produced the following results:

- Inclusion of additional cryopump on inlet of accelerator reduces bremsstrahlung dose 1.4 times.
- When voltage is applied on a grid on inlet of accelerator, dose bremsstrahlung is decreased in 2.5 times and the current at the detector in 10 times (Figure.7, Figure.8).

The main result is the additional flux of electrons accelerated up to 1 MeV was reduced in 3.2 times, up to 0,5% from injected beam, through inclusion additional cryopump and applied voltage on grid. The total flux of charged particles was reduced up to 5% from current of injected ion beam.

6. Future prospect

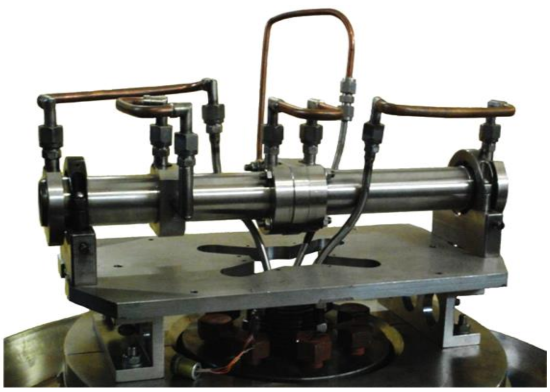


Figure.9 Stripping target

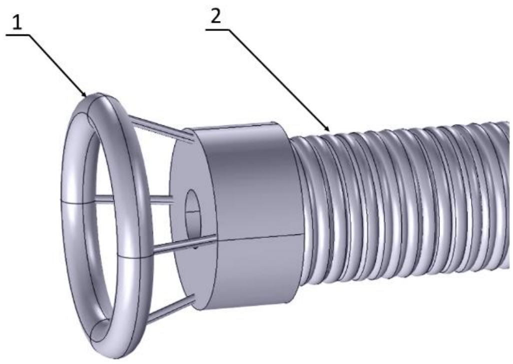


Figure.10 1– Electrostatic ring. 2–Stripping target

There are 2 modifications of stripping target (Figure.9) for suppression of the ion flux from it. It was proposed to use a stripping target with electrostatic rings. The design of modified stripping target is shown at Figure.10, idea of electrostatic ring is the following, voltage about 100V is supplied on the rings placed at the both end of tube, and subsequently argon ions are held in potential barrier inside tube. The design of target with magnetic suppressing is described in [5].

7. Conclusion

At Budker Institute of Nuclear Physics an accelerator based epithermal neutron source for BNCT is created and the Laboratory for preparation for the therapy is formed. It is necessary to increase the proton beam current from 1.75 to 3 mA. Additional flux of charged particles in accelerating channel doesn't allow to increase a beam current and produce a high dose of radiation. Experiments were conducted for improving the vacuum conditions which allowed to significantly reduce the accompanying currents in the accelerator and the dose of bremsstrahlung. The next step will be to conduct BNCT at the facility.

8. Acknowledgments

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