VACUUM-INSULATION TANDEM ACCELERATOR FOR BORON NEUTRON CAPTURE THERAPY *

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Abstract

Novel powerful electrostatic vacuum-insulation tandem accelerator had been proposed [1] and created at BINP. A 2 MeV 3 mA dc proton beam is obtained. Neutrons are generated by ^{7}Li(p,n)^{7}Be reaction in the near threshold mode [2]. Epithermal neutron flux is formed for the development of Boron Neutron Capture Therapy (BNCT) of malignant tumors. In this report results on proton beam obtaining, neutron flux generation and in vitro investigation are presented and discussed. This accelerator based neutron source looks like a prototype of compact inexpensive epithermal neutron source for the spread of BNCT. Plans on BNCT realization are declared.

In addition the facility is used for the development of nuclear resonance absorption technique for nitrogen detection, and for the investigation of neutronless fusion. First, 9.17-MeV gamma rays are generated by ^{13}C(p,γ)^{14}N reaction at 1.76 MeV protons [3]. Second, it is possible to measure α-particles energy spectrum of p+^{11}B reaction.

INTRODUCTION

Presently, Boron Neutron Capture Therapy (BNCT) [4] is considered to be a promising method for the selective treatment of malignant tumors. The results of clinical tests, which were carried out using nuclear reactors as neutron sources, showed the possibility of treating brain glioblastoma and metastasizing melanoma not subject to treatment by other methods [5, 6]. The broad implementation of the BNCT in clinics requires compact inexpensive sources of epithermal neutrons. In 1998 the source of epithermal neutrons based on an electrostatic tandem accelerator with vacuum insulation was proposed [1]. In this source, a 10-mA beam of 1.915 MeV protons bombarding a lithium target produces neutrons via ^{7}Li(p,n)^{7}Be reaction (with a threshold at 1.882 MeV). The resulting flux of neutrons with an average energy of 40 keV can be used for BNCT purposes after slight moderation.

Recently, a pilot variant of the accelerator-based neutron source for BNCT has started operation at the BINP [2], which produces a stationary beam of protons with an energy of 2 MeV and a current of up to 3 mA. This article describes Vacuum Insulation Tandem Accelerator (VITA) and presents results on proton beam obtaining, neutron flux generation and in vitro investigation.

VACUUM INSULATION TANDEM ACCELERATOR

In the conventional scheme of the tandem, two accelerating columns based on ceramic tubes are connected by the high voltage parts with the charge-exchange target in between. The prospect of high current (a few tens milliamperes) accelerator design according to this scheme is limited by its two basic disadvantages — the necessity of pumping the gas of charge-exchange target through accelerating columns and an inevitable current emission of secondary electrons and ions from the high current beam passage region to the inner surface of ceramic insulators.

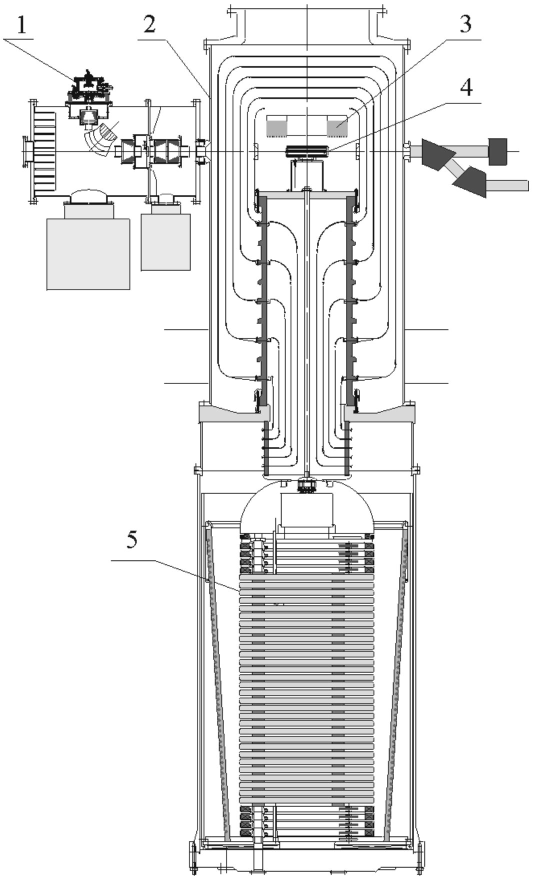

Figure 1: High-current electrostatic accelerator-tandem. 1 – H^{-} ion source, 2 – tandem-accelerator, 3 – pump, 4 – charge-exchange target, 5 – high-voltage source.

In the VITA proposed there are no ceramic accelerating columns (Fig. 1). In this scheme, to the cylindrical potential electrode 600 mm in diameter with charge-exchange target, placed into vacuum tank 1400 mm in

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diameter, high voltage is applied through ceramic feedthrough insulator which can be arbitrarily remote from the accelerated beam passage region. Potential is feed to the high-voltage electrode through insulator from 40 kW 1.25 MV sectioned rectifier of ELV-type industrial electron accelerator. The high voltage electrode is surrounded by five intermediate electrodes providing the homogeneous distribution of the potential and preventing the full voltage effects. Coaxial round holes for the beam passage are in the walls of vacuum tank and electrodes. The specific feature of the VITA is a high rate of acceleration – 33 kV cm^{-1}.

The charge-exchange target is a pipe with an inner hole of 10 mm diameter and 400 mm length.

Vacuum insulation tandem accelerator instead of the conventional scheme of tandems with ceramic columns allows hopping for the obtaining of high currents. However, the working capacity of VITA was not clear because of the great energy content between electrodes (up to 30 J). It is known [7], that breakdown of millimeter vacuum gaps with 10 J energy released results in drop of voltage durability of vacuum gap. A set of experiments on study of high voltage durability of 45 mm vacuum gap with large square electrodes was carried out on the 0.6 MeV tandem-accelerator. The results of these experiments showed that 50 J stored energy released in breakdown did not result in detraining of 45 mm vacuum gap [8].

The construction of the proposed accelerator started in 2003 at BINP, and finished in 2007 (see Fig. 2). In 2008 a stable proton beam with the required energy of 2 MeV and a current of 3 mA was obtained. The high monochromaticity and the stability of proton beam energy were achieved in the accelerator.

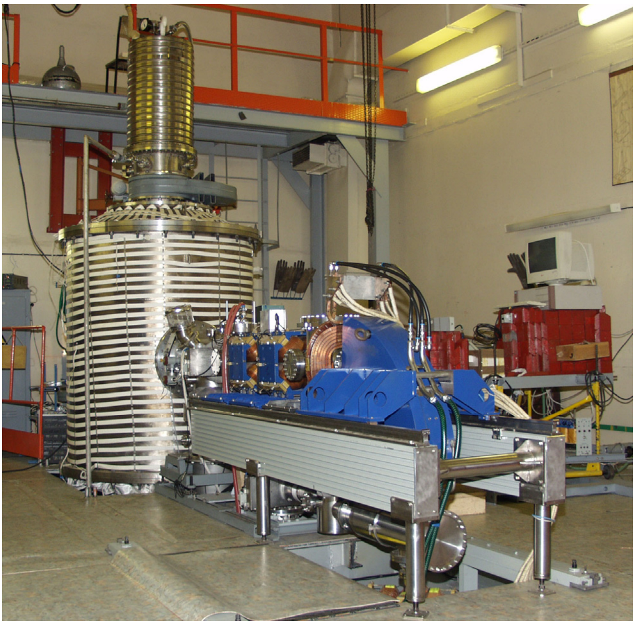

Figure 2. Photography of the VITA.

EPITHERMAL NEUTRON SOURCE FOR BNCT

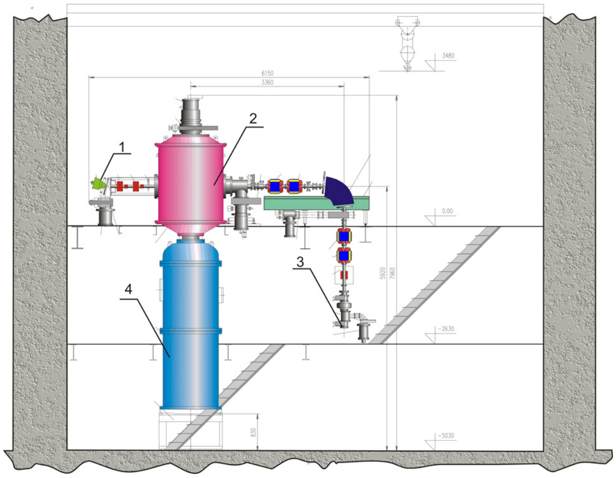

Figure 3. Pilot variant of facility for BNCT: 1 – negative hydrogen ions source, 2 – VITA, 3 –neutron producing target, 4 – high voltage power supply.

The scheme of accelerator based epithermal neutron source is presented in Fig. 3. It is intended to generate neutrons with the threshold $^7Li(p,n)^7Be$ reaction by bombarding a lithium target with a 2 – 2.5 MeV, 10 mA proton beam. It is world-recognized [9] that the best reaction to form the epithermal neutron beam is the $^7Li(p,n)^7Be$ 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.

All problems of a lithium target have been solved, namely i) the effective cooling was implemented [11] to keep the lithium layer solid in order to prevent the propagation of ^7Be radioactive isotope, ii) the controlled evaporation of a thin lithium layer was used [12] to reduce accompanying gamma radiation, iii) substrate materials as resistant to blistering as possible were found, iv) a protective subsurface container for holding and temporary storage of activated targets was constructed [12]. The target was assembled and neutron generation was performed [2].

The facility is equipped with the beam transport diagnostics, neutron and gamma dosimeter DKS-96, gamma-detector LB6500-3H 10 (Berthold Tech., Germany), NaI and BGO gamma spectrometers [13]. To study the dose fields, a plexiglas phantom is manufactured. The activation foils could be placed over the whole body of the phantom. New technical solution is realized for using the time-of-flight technique to measure neutron spectra [14].

For the near-threshold neutron generation mode, attractive due to low activation of the facility and the target, a solution was found providing 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 [15]. Kerma rate in a modified Snyder head phantom was calculated for the target with several variants of the moderator.

As a result the stable neutron generation was performed and first *in vitro* investigations were conducted.

PERSPECTIVES

At the present time the new charge-exchange target with an inner hole of 16 mm diameter is installed on the facility. The insulator that allows feeding the first electrode from the independent power supply was mounted. These two improvements would allow increasing the current of a proton beam up to 5 mA. The next goal is to increase the current of a beam to 10 mA that requires setting a new low energy beam transport and a new negative hydrogen ions source. These devices are already manufactured and tested.

Measuring the neutron spectrum and conducting the *in vitro* investigations with usage of boron carrier are planned for the nearest future.

Also the facility is planned to be used for the development of nuclear resonance absorption technique for nitrogen detection, and for the investigation of neutronless fusion.

CONCLUSION

At BINP, a pilot epithermal neutron source has been built and started up. It is based on a compact vacuum insulation tandem accelerator and uses neutron generation from the reaction $^{7}\text{Li}(p,n)^{7}\text{Be}$.

The stable neutron generation is performed and *in vitro* investigations are conducted for the BNCT development. The facility could be a solution for a problem of lack of compact sources of epithermal neutrons for a mass adoption of the BNCT.

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