

# BINP pilot accelerator-based neutron source for neutron capture therapy

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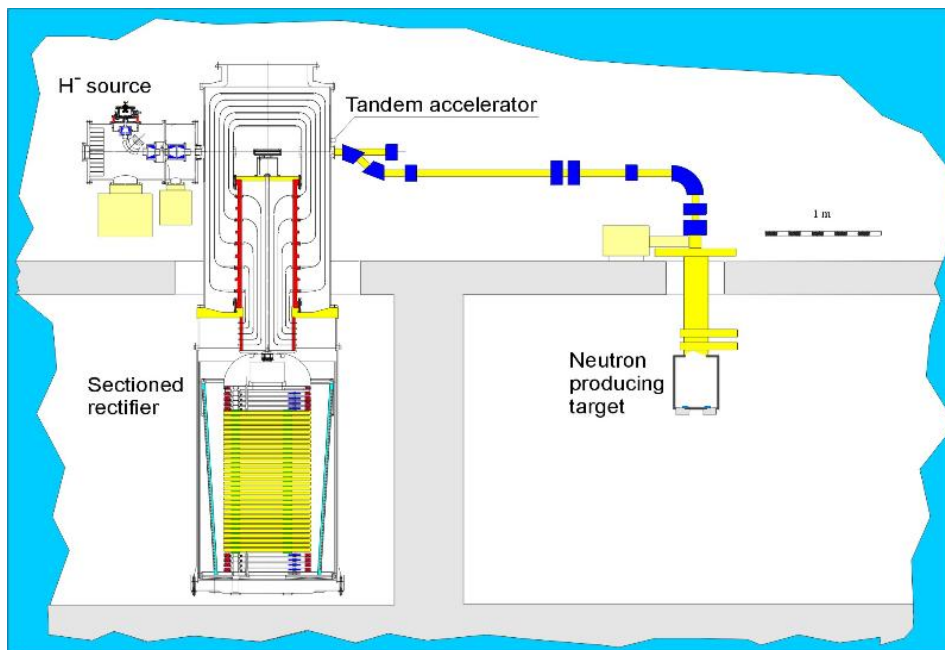
Neutron source based on accelerator has been proposed for neutron capture therapy at hospital. Innovative approach is based upon tandem accelerator with vacuum insulation and near threshold  ${}^7\text{Li}(p,n){}^7\text{Be}$  neutron generation. Pilot innovative accelerator based neutron source is under going to start operating now at BINP, Novosibirsk. Negative ion source with Penning geometry of electrodes has been manufactured and dc  $\text{H}^-$  ion beam has been obtained. Study of beam transport was carried out using prototype of tandem accelerator. Tandem accelerator and ion optical channels have been manufactured and assembled. Neutron producing target has been manufactured, thermal regimes of target were studied, and lithium evaporation on target substrate was realized. In the report, the pilot facility design is given and design features of facility components are discussed. Current status of project realization, results of experiments and simulations are presented.

*Keywords: BNCT, Accelerator*

## 1. Introduction

Accelerator-based neutron source has been proposed for neutron capture therapy at hospital [1]. Pilot variant of facility for neutron therapy is shown in Fig. 1. Negative hydrogen ion beam is injected into electrostatic vacuum insulation tandem accelerator. After charge-exchange of negative

hydrogen ion into proton inside the charge-exchange tube in the center of high-voltage electrode, a proton beam is formed at the outlet of the tandem. It is accelerated up to double voltage of high-voltage electrode. Neutron generation is proposed to be carried out by protons bombarding a lithium target using  ${}^7\text{Li}(p,n){}^7\text{Be}$  threshold reaction.



*Fig. 1. Pilot variant of accelerated based neutron source for NCT.*

In ordinary mode, at proton energy of 2.5 MeV, the neutron source produces neutron beam with maximum energy of 790 keV appropriate for neutron capture therapy after moderation. The most efficient innovative operating mode of the facility is at proton energy of 1.915 MeV that is 33 keV higher than the threshold of the  ${}^7\text{Li}(p,n){}^7\text{Be}$  reaction. In this case, kinematically collimated forward beam of neutrons with the mean energy of 40 keV may be used for BNCT after a slight moderation. Creation of accelerator with proton beam intensity of 10 mA will decrease exposure time for necessary therapeutic dose to tens of minutes. Pilot innovative neutron source based on accelerator for neutron capture therapy of cancer is now on the threshold of its operation at the BINP.

In this paper, the pilot facility design is presented and discussed. Design features of facility components are discussed. Current status of project realization and results of experiments are presented.

## 2. Negative ion source

Surface-plasma negative ion source with Penning geometry of electrodes [2] is to be used for obtaining a beam of hydrogen negative ions. The dc  $\text{H}^-$  ion beam of 15 mA was obtained and investigated on the prototype of negative ion source. The value measured for the normalized emittance of  $0.3 \pi \text{ mm mrad}$  met the requirements. Then negative ion source and power supply were fabricated and installed on accelerator (Fig. 2). Now 5 mA 25 keV beam was obtained on the facility.

## 3. Low energy beam transporting

Beam transporting to the accelerator is fulfilled with two magnetic lenses movable lengthwise (Fig. 3). Coordinated input of the beam into the accelerator will be realized in one of the two

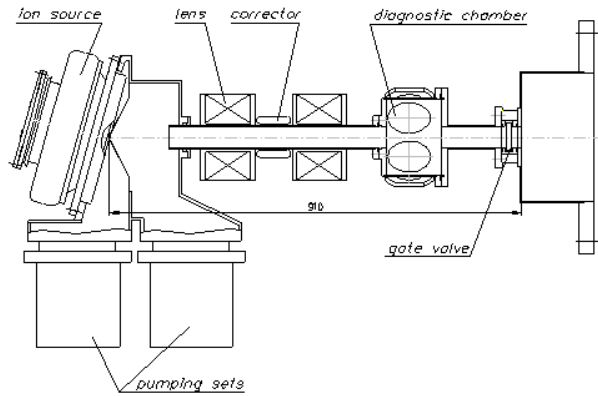


Fig. 3. Low energy beam channel.

following ways [3]: "strong" scheme with the use of strong magnetic lens and beam over focusing at the entrance to the accelerator, and "weak" introduction without beam over focusing with increased first gap and more smooth increase of electric field intensity in the accelerator. Since both of the schemes have advantages and disadvantages and both of them have only slight difference in the ion-optical path design, the recommended solution is to provide the possibility to check both "weak" and "strong" beam focusing experimentally. Magnetic lens with outer water cooling was designed and manufactured. Ion optical channel was manufactured and assembled. In Fig. 4, ion source with low energy ion optical channel is shown.

Study of the coordinated input of 10 mA beam into the 160 kV prototype of the tandem accelerator (electric field  $36 \text{ kV cm}^{-1}$ ) was carried out. It was cleared out that beam was accelerated without breakdown, and 80 % of beam passed in aperture of stripping target (10 mm).



Fig. 2. Negative ion beam source.

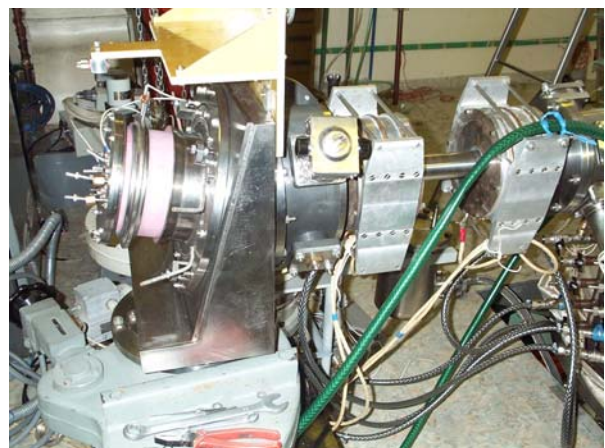


Fig. 4. Ion source with beam transporting unit.

#### 4. Accelerator

In the accelerator (Fig. 5), the beam is accelerated in the electric field of  $33 \text{ kV cm}^{-1}$ . Five intermediate and one high-voltage electrode 600 mm in diameter are placed inside a vacuum tank 1400 mm in diameter. Inside the high-voltage electrode, stripping gas target is placed, made as a tube 400 mm length 10 mm in diameter. To decrease gas flow in accelerating channel, gas recirculation with turbo-molecular pump inside the high-voltage electrode is provided. Vacuum volume is to be pumped out through the profiled covers of

intermediate electrodes with cryogenic pump placed on top. 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 sectioned rectifier is mounted and tested at 1.4 MV voltage for continuous steaming operation. The feedthrough insulator was manufactured. Then, whole accelerator was fabricated, assembled (Fig. 6, 7), and necessary high voltage was reached during May, 2006.

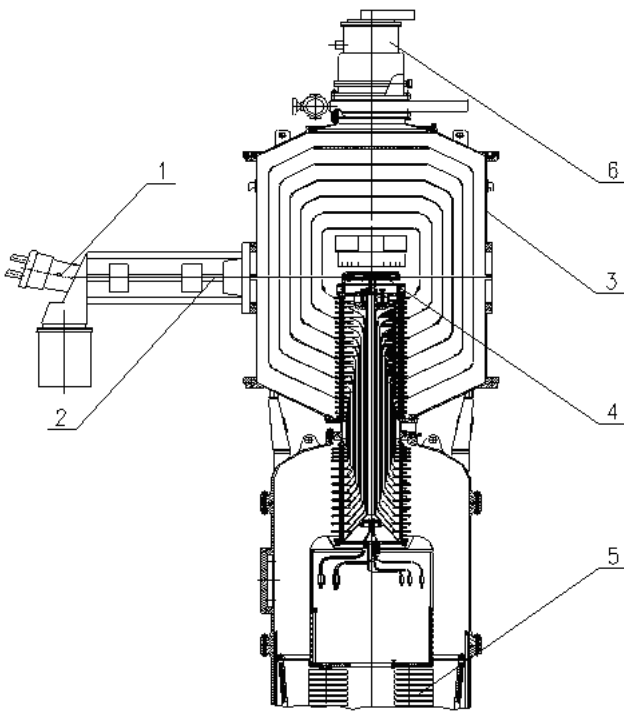


Fig. 5. Accelerator design: 1– negative ion source; 2– low energy beam path; 3– vacuum chamber; 4 – insulator; 5 – high voltage source; 6 – pump.



Fig. 6. Assembled accelerator.



Fig. 7. The process of accelerator assembling.



## 5. High energy beam transporting

Manufacture of system for transportation of proton beam from accelerator to neutron generating target (Fig. 8) is under finishing now. The beam at transporting is focused by quadrupole lens doublet, then it is deviated 90° in vertical plane with use of bend magnet (Fig. 9), focused again by quadrupole lens doublet, passed through magnetic sweep system, and finally falls onto the neutron producing target. Minimal size of the proton beam on the target is 2.5 cm, according to the simulations. High stable power supply for bend magnet and quadrupole lens is under developed now.

## 6. Neutron producing target

Neutron producing target (Fig. 10) is described in detail in the article presented on this Congress [5].

## 7. Conclusions

Pilot innovative accelerator based neutron source is under going to start operating now at BINP, Novosibirsk. If our proof-of-principle experiments planed on summer–autumn of 2006 will be successful, the accelerator based neutron source will provide a compact and low cost solution for BNCT.

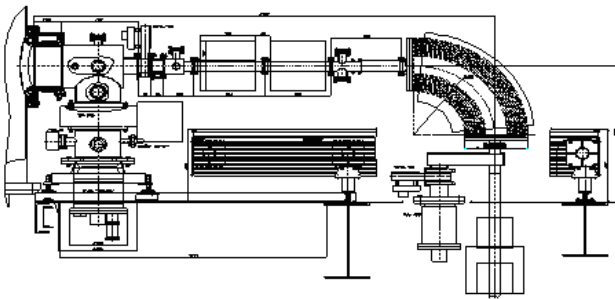


Fig. 8. High energy beam channel.

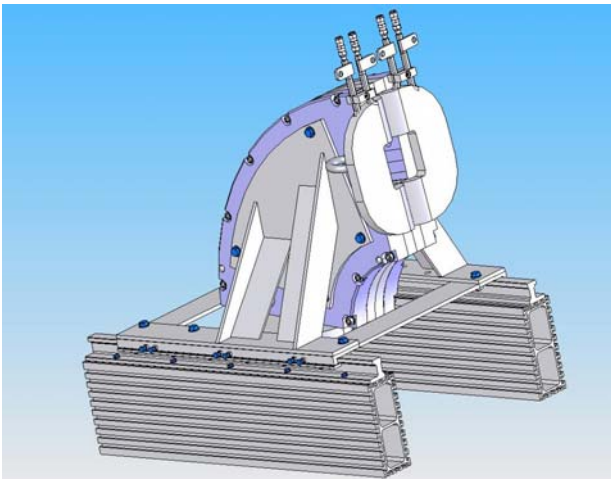


Fig. 9. Bend magnet.

## References

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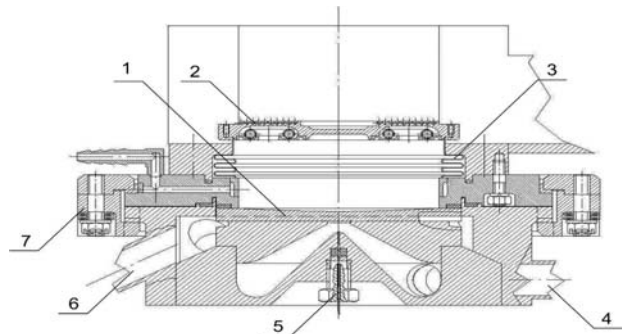


Fig. 10. Neutron producing target:  
1 – backing with lithium layer, 2 – counter-plate with heater and container of lithium evaporation unit,  
3 – silphon, 4 – water input, 5 – thermocouple,  
6 – water output, 7 – bayonet.