ACCELERATOR BASED NEUTRON SOURCE FOR THE NEUTRON-CAPTURE AND FAST NEUTRON THERAPY AT HOSPITAL

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Abstract

Discussed is the proton accelerator complex for neutron production in lithium target, which can operate in two modes. The first provides a neutron beam kinematically collimated with good forward direction in 25° and average energy of 30 keV, directly applicable for neutron-capture therapy with high efficiency of proton beam use. The proton energy in this mode is $1.883 \div 1.890$ MeV that is near the threshold of ^{7}Li(p,n)^{7}Be reaction. In the second mode, at proton energy of 2.5 MeV, the complex produced neutron beam with maximum energy board of 790 keV which can be used directly for fast neutron therapy and for neutron-capture therapy after moderation.

The project of such neutron source is based on the 2.5 MeV original electrostatic accelerator tandem with vacuum insulation which is supplied with high voltage rectifier. Design features of tandem determining its high reliability in operation with high current (up to 40 mA) H^- ion beam are discussed. They are: the absence of ceramic accelerator columns around the beam passage region, good conditions for pumping out of charge-exchange gaseous target region, strong focusing optics and high acceleration rate minimizing the space charge effects. The possibility of stabilization of protons energy with accuracy level of 0.1 % necessary for operation in the near threshold region is considered. The design description of H^- continuous ion source is also performed.

For operation with 100 kW proton beam it is proposed to use liquid lithium targets. A thin lithium layer on the surface of tungsten disk cooled intensively by liquid metal heat carrier is proposed for use in case of vertical beam, and a flat liquid lithium jet flowing through the narrow nozzle — for horizontal beam.

1 INTRODUCTION

At present, the beam therapy is one the basic method for curing malignant tumors. Recently, the ever increasing attention in therapy was drawn to the use of neutron beams. The neutron therapy, i.e. the irradiation of malignant tumor by the neutron flux is presently realized in two versions: a neutron-capture therapy (NCT) and fast neutron therapy (FNT). At present, the mostly studied and used in clinic practice is the version of the boron neutron capture therapy (BNCT) [2,3]. The boron containing compounds enriched in the isotope ^{10}B are synthesized. This compound introduced into the patient blood produce in the tumor cell the ^{10}B isotope concentration 30 μg/g while in surrounding normal tissue cell to be ~ 10 μg/g. In neutron reaction ^{10}B(n,α) ^{7}Li the charged particles are produced with the total kinetic energy ~ 2.4 MeV and with a range in a tissue ~ 10 μm i.e. of the order of the size of a man's tumor cell. Because of higher concentration of ^{10}B-isotope in the tumor cells mainly the cancer cell are destroyed.

The nuclear reactor is the most powerful stationary source of neutrons. At present, in the world there are a few active operating therapeutical beams on the nuclear reactors of various kinds and powers [1]. The following factors can be considered as the serious disadvantages of reactor therapeutical facilities: 1) A powerful reactor is very complex and expensive facility whose maintenance put quit strong requirements to nuclear safety. 2) With quite a rare exception, the cancer therapy centers and clinics are usually remote from the physics centers having nuclear reactors.

These circumstances led to that in recent years, the problems of the development of a neutron source for NCT based on the compact and inexpensive accelerator which can used for every cancer clinic are the subject of intense discussions. At present, various versions of neutron sources for NCT using the cheap accelerators of direct action are conceptually developed [2-4].

For obtaining neutrons the nuclear reactions on light nuclei are supposed to use. For obtaining neutrons in these reactions is need to have the protons up to $2 \div 2.5$ MeV. The reaction ^{7}Li(p,n)^{7}Be is widely used for obtaining monoenergetic neutrons in the nuclear physics experiments and it is quite well studied [5]. This reaction is the threshold reaction. There is a broad resonance near the threshold. Because of this resonance, the reaction cross-section increases sharply over the threshold value and it has foot-step form. Fig.1 shows the doubly differentiated yield of neutrons from a thick metal lithium target for various laboratory escape angle (step is

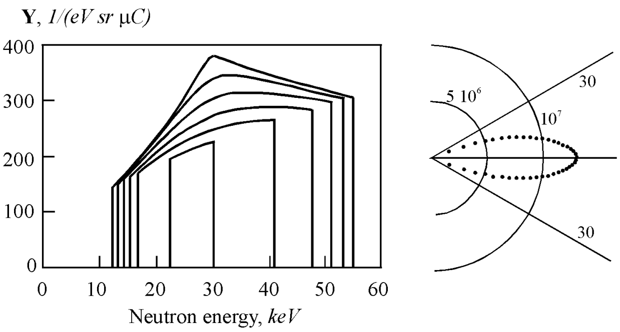

Fig. 1.

5°) and an angular distribution of escaping neutrons in polar coordinates at an initial proton energy of 1886 keV. With an increase in proton energy the neutron escape angle is turned by 4 π *rad* at $E_p \approx 1920$ keV and the total neutron yield increases up to $1 \times 10^{13}\,s^{-1}$ at an energy of protons 2.5 MeV and a beam current of 10 mA. At such intensity it turns to be possible to produce the source of appropriate to NCT epithermal neutrons by the formation of the required spatial-energy distribution of neutrons with the help of the compact moderator-collimator unit.

2 MAIN ELEMENTS AND ARRANGEMENT OF ACCELERATOR COMPLEX

Selecting the variant of accelerator for neutron source, it's desirably to provide the possibility of operation in two regimes, considered before, both in the near threshold region allowing to use the source for irradiating in open geometry without external collimator and for production of epithermal and fast neutrons at protons energy 2.5 MeV with moderators. But in spite of attractiveness and elegance of operation in the near threshold region such method of neutron-production demands a high monochromaticity and stability of energy of proton beam (0.1 %). This demand makes impossible the use of widely discussed variant of high frequency accelerator of RFQ type and may be satisfied only for electrostatic one.

In this project we offer to create the neutron source based on the construction of vacuum insulation tandem accelerator developed at BINP using the sectionalized rectifier from electron accelerator of ELV type as a powerful source of high voltage. Advantages of tandem in comparison with accelerator on full energy from the point of providing maximum reliability in works with high current continuous beam are obvious: the ion source is placed under ground potential and the operating voltage is only the half of full proton energy of 1.25 MeV. The design of vacuum insulation tandem provides the reliability significantly exceeding the reliability of tandem based on accelerating columns with ceramic insulators, also. The reliability of high voltage ELV rectifier was confirmed by many years of operation of such accelerators in industry. The use of such rectifier as a high voltage source for tandem supplying is attractive also by its high efficiency (more than 90 %) and for power of proton beam exceeding 20 kW it is enough important factor for work in hospital.

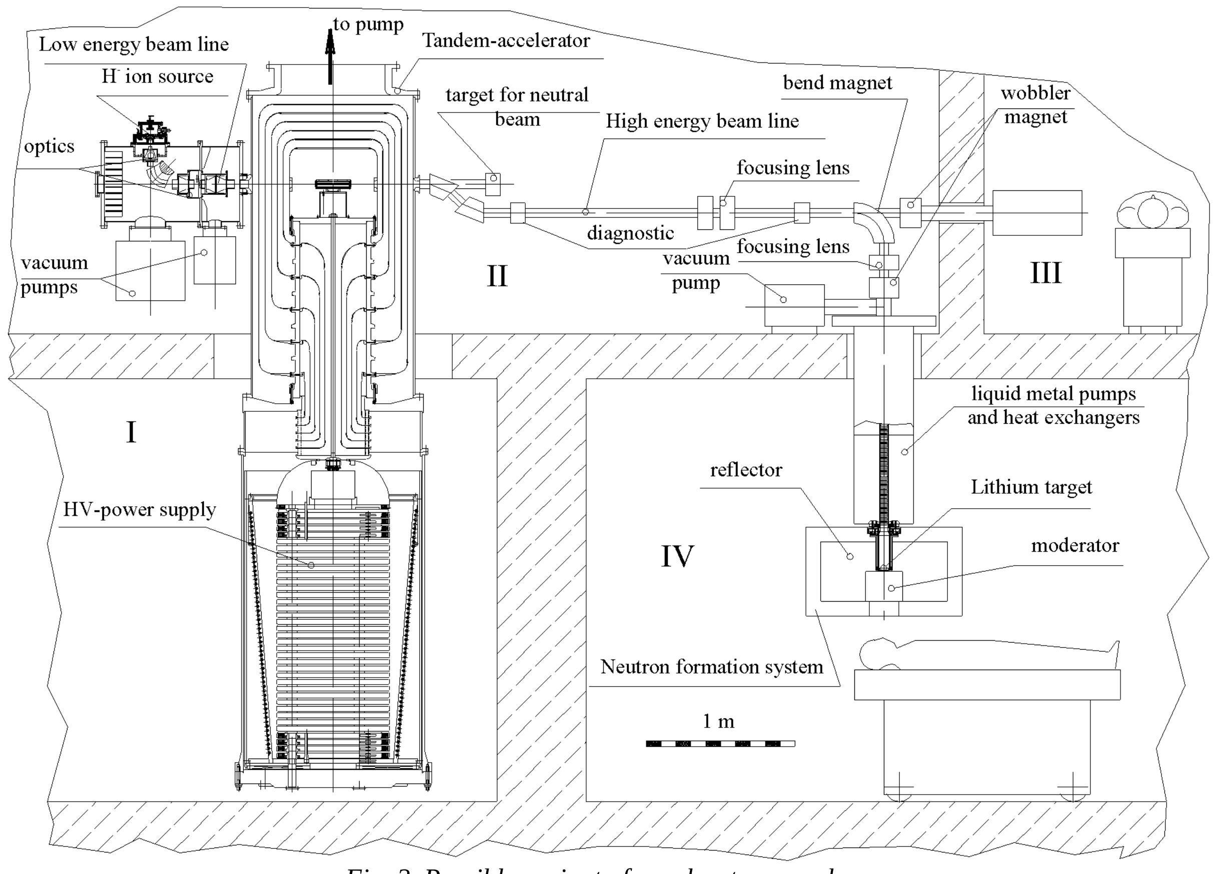

Fig. 2. Possible variant of accelerator complex.

Possible variant of accelerator complex arrangement is performed at Fig.2. The whole installation is placed in two-floor building in four separate rooms. The high voltage source (HVS) and main powerful power supply sources are mounted in one of the rooms (I) of the first floor. The accelerator-tandem is mounted through the hole in ceiling above the HVS. From the one side of accelerator the source of H^- with differential vacuum pumping system and the optical system of beam transport for injection in accelerator are placed. The beam after charge-exchange process accelerated up to 2.5 MeV (doubled energy) comes from the other side of tandem and then the parallel shift system displaces the beam to the transport channel. This system separates the high intensity proton beam and low current beam of neutrals which can be used both to control the efficiency of charge-exchange process and for precise measurements (after additional stripping) of beam energy by means of special bending magnets.

Proton beam is directed by transport channel in two medical rooms. The horizontal beam enters the medical room III for works with vertical jet liquid lithium neutron producing target. The heat removal of power released by proton beam is realized by pumping of liquid lithium through the heat exchanger. The transport channel has 90° bending magnet which directs the beam to another neutron-producing target situated in the irradiation room IV. This target is a tungsten disk cooling intensively by water or liquid metal coolant and covered by thin layer of lithium on which proton beam is thrown. Such target can operate both with solid and liquid lithium, therefore it can be used only with vertically directed proton beam.

Lithium neutron-producing targets are the most responsible and stressed elements of the whole complex, because all the power of proton beam (more than 20 kW) is dissipated in the thin lithium target. To obtain an uniform distribution of beam on the surface approximately 5 cm in diameter a method of recirculating scanning by means of wobbler magnet is used. This magnet is a rotating dipole of cobalt-samarium magnets. Possibility of applying of two variants of target is foreseen — the open target to work in the region near threshold and the target with moderator and reflector.

3 CONCLUSION

A project of proton accelerator complex for fast neutron therapy and for neutron-capture therapy is proposed and discussed in details. This project is based on the experience accumulated in following directions.

1. The experimental and theoretical investigations of the spatial-energy distribution of neutrons produced in $^7Li(p,n)^7Be$ reaction.

2. Great experience accumulated in neutronic calculations of the absorbed doze distributions at FNT and also the promising results of collaboration with Medical Radiological Research Center (Obninsk) in using of neutron beams in curing of the malignant tumors.

3. The project of electrostatic accelerator tandem without accelerator columns — integral part of generally accepted accelerator scheme, is developed. Specifics of geometry of accelerating electrodes and tandem optics allows to reach maximum reliability in conditions of acceleration of high current proton beams in continuous mode and allows to ensure optimum conditions of pumping out the charge-exchange target region and to use the reliable gaseous target of continuous operation. Main constructive and technical decisions of tandem construction were tested on 1 MeV prototype which operates now in pulsed mode of H^- ion source and is used as an injector in a synchrotron.

4. It is proposed to use the sectional rectifier (a part of the industrial ELV-type accelerator developed at BINP and widely used for technological aims in Russia and abroad) as a powerful high voltage source. There is experience of rectifier voltage stabilization with accuracy of 0.1%.

5. Wide experience has been accumulated at BINP in design of negative ion sources of different types and a well-known school of specialists in this field has been formed. It allows to create H^- continuous ion source with current 40 mA in short time.

6. Creation of lithium neutron-producing targets with high (up to several kW/cm^2) power density is based on wide experience of BINP in producing cylindrical lenses with solid or liquid lithium and liquid metal targets applied in high energy physics for secondary particles beam generation.

There is a pool of experience in IPPE in dealing with proton beams of considered range of parameters, and there is a 2 MeV electrostatic accelerator with 2 mA current in Obninsk. Experimental works on optimization of lithium targets parameters and neutron beam forming both in "open" geometry and using moderators and reflectors can be carried out with this accelerator.

All aforesaid assures that the proposed accelerator complex can be created and transferred for exploitation in clinic during $1.5 \div 2$ years.

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