COMPACT TANDEM ACCELERATOR BASED NEUTRON SOURCE FOR THE MEDICINE.

V. Shirokov, A. Babkin, P. Bykov, G. Krainov, G. Silvestrov, Y. Tokarev (BINP, Novosibirsk, shirokov@inp.nsk.su), M. Bokhovko, V. Kononov, O. Kononov (IPPE, Obninsk).

Abstract

Status of original heavy hydrogen ion accelerator-tandem is described. Potential electrodes with vacuum insulation organize tract for accelerating ion beam before and after gas stripper, located inside the high voltage electrode. There are no accelerating tubes in the tandem proposed. 20 kHz, 10 kW, 500 kV compact sectioned rectifier is a high voltage source. Both the geometry of neutron source and results of the rectifier testing are presented. Measured and calculated neutron yield and spatial-energy distribution, as a result of nuclear reactions produced by heavy hydrogen ion in lithium, beryllium and carbon thick targets are given. The possibility of use of this neutron source for the neutron or neutron capture therapy is discussed.

INTRODUCTION

In different radiation therapy methods neutron therapy takes special place. It has wide range of abilities and efficiency, especially in case of radioresistance tumors.

Depending on tumor type and treatment method neutrons beam with energy 0.1-20 MeV, neutron flux density 10^7 - 10^8 cm^{-2} c^{-1} and crossection ~10 cm are required [1].

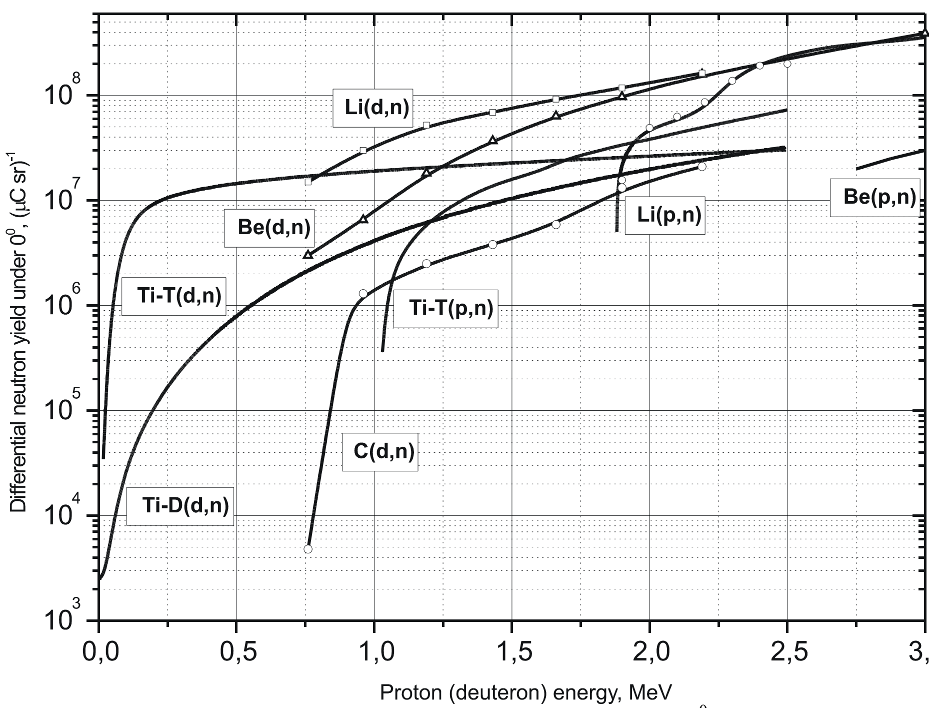

Figure 1: Differential neutron yield under 0^0.

Nowadays in clinical practice basically used nuclear reactors or powerful cyclotrons. Placing such facility in common oncology hospital looks impossible. Neutron generators based on $T(d,n)^4He$ are used in some clinics (Hamburg, Munster – Germany, Snezhinsk – Russia). But wide range such facility using are limited by problems with high radioactivity tritium targets operation. So very promising looks approach to create neutron source based on low cost, compact accelerator, which mountains not cause nuclear safety problems.

More appropriate accelerator type for this purpose is high voltage accelerator which could produce protons and deuterons beams with current 1-10 mA. Neutron beams with flux densities 10^7 - 10^8 cm^{-2} c^{-1} with neutron energies up to 20 MeV could be obtained on such facilities from next nuclear reactions: $T(p,n)^3He$, $^7Li(p,n)^7Be$, $D(d,n)^3He$, $T(d,n)^4He$, $^7Li(d,n)^8Be$, $^9Be(d,n)^{10}B$ ets.

One of this paper tasks is to specify neutrons yield from more promising for medical purposes nuclear reactions. For task realization was performed differential neutrons yield measurement under 0^0 in an accelerator particles energy range 0.75-2.5 MeV for nuclear reactions $^{6,7}Li(d,n)$, $^9Be(d,n)$, $^{12,13}C(d,n)$, $^7Li(p,n)$, using thick targets. Measurements were done on Van de Graaf accelerator EG-2.5 operated in IPPE, Obninsk. As neutrons detectors were used previously calibrated small-size pulse ionization fission chambers with ^{235}U and ^{238}U layers inside.

Results of differential neutron yield comparison under 0^0 for different reaction presented on fig.1. With experimentally measured data for reactions $^7Li(p,n)^7Be$,

^{7}Li(d,n)^{8}Be, ^{9}Be(d,n)^{10}B и ^{12}C(d,n)^{13}N also presented calculated neutron yield for some others reaction obtained by techniques described in [2].

Findings show the possibility to produce neutron flux density more 10^7 cm^{-2} c^{-1} , by using ~1 MeV ion beam in ^{7}Li(d,n)^{8}Be и ^{9}Be(d,n)^{10}B reactions. For therapeutic beam forming collimators and shielding with length at least one meter are required. In case of beam current 10 mA in reaction Li(d,n) neutron flux density $3 \cdot 10^7$ cm^{-2} c^{-1} could be reached, and for Be(d,n) reaction - $0{,}8 \cdot 10^7$ cm^{-2} c^{-1}.

10 mA, 1 MeV deuteron beam can be obtained with high-voltage tandem accelerator. The same type of vacuum-insulation accelerator for the purpose of boron neutron capture therapy is now under construction in BINP [3]. It is very useful, when ion source is being under `ground` potential and high-voltage source potential corresponds to only one half of ion full energy.

RESULTS AND DISCUSSION

Figure 2 shows the construction of vacuum insulation tandem accelerator. In the proposed tandem accelerating columns are absent. The high-voltage spherical electrode 1, concentrically surrounded by system of different potential thin-wall shields 2 and gas stripper 3 are placed inside vacuum tank 4.

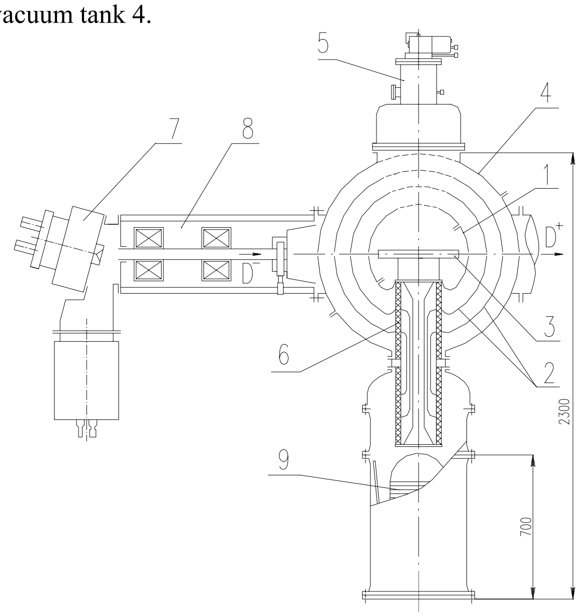

Figure 2: Layout of tandem-accelerator

It is proposed to use a surface-plasma source with a cesiated emitter of H^- ions developed in BINP [4], as the ion source 7 for the tandem. 10 mA negative heavy hydrogen ion beam is injected into tandem accelerator gaps after passing low energy tract 8.

The gaps between vacuum tank (diameter is determined to be 1000 mm), shields and high-voltage electrode (diameter 600 mm) are the accelerating gaps. Coaxial round holes for the beam passage are in the all electrodes.

Accelerated up to 500 KeV, negative heavy ion beam passes over stripper gas and a positive heavy ion beam, as a result charge-exchange process, is accelerated up to 1 MeV and formed at the outlet of the tandem. The neutron generating lithium or beryllium target is the endpoint for the 10 kW heavy ion beam.

Computer simulation of 10 mA beam transportation from the ion source up to the stripper tube in electric and magnetic fields taking account of space charge and emittance of the beam is carried out [5]. It was determined that transporting of 10 mA beam may be provided by electric fields approximately 33 kV/cm with length and diameter of stripper tube equal to 400 mm and 10 mm accordingly.

High-voltage electrode and shields provide the homogeneous distribution of the potential inside the accelerating gaps. The separate accelerating gap storage energy and level of vacuum gaps overvoltages after full or any separate vacuum gap breakdown determine number of shields in the vacuum insulation tandem. All vacuum high voltage gaps sequential breakdowns are not permitted due to any vacuum gap overvoltage with dissipation of full energy, stored up in tandem accelerator. For the proposed tandem the number of accelerating gaps is determined to be 3 and maximum storage energy for the separate gap is not more, than 10 J and full system storage energy is equal to 50 J. The compensating capacitive divider mounted in parallel to sections of gas part of feedthrough insulator 6 for decreasing level of overvoltages.

It isn`t allowed to redistribute the separate shields potential due to field emission from the electrodes of high-voltage vacuum gaps.

A set of experiments on study of high voltage strength of vacuum gap with large square electrodes is carried out at prototype tandem-accelerator with electrodes square $\approx$ 0.7 m^2 and 45 mm high voltage vacuum gap [6].

Fig.3 shows the breakdown electrostatic field intensity E opposite number of regular breakdown N in high voltage experiment. First breakdowns of vacuum gap took place at intensity of higher, than vacuum gaps accelerator tandem one: $\approx$ 33 kV/cm and storage energy up to 30 J released at breakdowns did not result in detraining of vacuum gap. We did not record high voltage vacuum gap breakdowns under 68 kV/cm intensity during several hours at the end of the experiments cycle.

Full electrons emission current from high voltage electrode surface under 33 kV/cm electrostatic field intensity was determined practically to be equal to zero.

High voltage potential of power source 9 is applied to the high-voltage electrode using tightening pipe passing along feedthrough insulator axis. This pipe tightens two (vacuum and gas) sectioned parts of insulator. Power source and inner part of insulator placed in SF_6 under pressure $2 \cdot 10^5$ Pa. Upper, external surface of insulator, placed in vacuum. The intensity of electrostatic field along sections of insulator is not more, than 16 kV/cm. Stripper gas supply tube and oil-tubes for cooling the stripper tube placed inside the tightening pipe. In the high-voltage source area the stripper gas tube and oil tubes are dielectric ones and located along the source axis.

The feedthrough insulator can be arbitrarily remote from the accelerated beam passage region. .

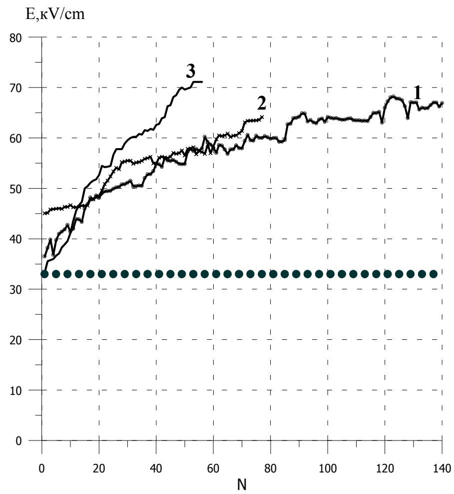

Figure 3: Training curves. 1,2 – 9J; 3 – 31J.

Inside the insulator (around the tightening pipe) thin-wall pipes of various lengths are concentrically located to connect the respective rings of different potential on the upper sectioned vacuum part of the insulator and its lower sectioned gas part. The voltage is applied to these rings from the 2 resistive dividers, mounted along the 2 parts of insulator. Thin-wall pipes provide the homogeneous distribution of the potential throw high voltage radial gas gap inside the feedthrough insulator.

Figure 4: High frequency rectifier.

The stripper is a tube with an inner hole of 10 mm diameter and 400 mm length. In the center of the tube gas leaks at a rate providing the efficient density of the stripper target 3×10^{16} mol·cm^{-2} required for the 99 % ion charge-exchange. The gas flow from stripper to vacuum is equal to 55 l·mtorr/sec. The outward vacuum pump 5 evacuates stripper`s gas through special form holes in high voltage electrode and shields head. In the geometry under consideration at a given rate of gas leak, the pressure distribution in the whole volume, required for the gaps high voltage strength, is provided at a pumping rate of ~3000 l/s. The vacuum pump can be placed not only on the top, but on the side of tandem.

20 kHz, 10 kW, 500 kV compact sectioned rectifier (fig. 4) with magnetic coupling and parallel power supply for cascades is a high voltage source [7]. Accelerating voltage pulsation under working load is not more 0.1%. Small size of the power source (specific power may be increased up to 80 kW/m^3) is provided due to higher frequency of power supply.

The water load and inverting amplifier prototype have been made for the testing, as separate rectifier sections, and rectifier, as a whole.

The electric intensity along the rectifier column is equal to 9 kV/cm. Up to this time the main rectifier parameters are: 20 kHz, 450 kV and 7 kW.

CONCLUSION

Compact tandem accelerator based neutron source project for the fast neutron therapy for cancer is proposed. Main parameters are: heavy hydrogen ion 10 mA beam energy – 1 MeV, fast neutron flux density - (0.8-3)· 10^7 n/cm^2 ·c.

The tandem accelerator with vacuum insulation has no accelerating tubes, so the necessity of pumping the gas of stripper target through accelerating columns, as the inevitable current emission of secondary electrons and ions from the high current beam passage region to the inner surfaces of ceramic insulators are absent.

Ion source is being under `ground` potential. Accelerating voltage is stabilized with accuracy of 0.1 %. High frequency 10 KW, 0.5 MV sectioned rectifier is a very compact source for 1.0 MeV tandem accelerator. The same type of stable-voltage rectifier can be used in the boron neutron capture therapy complex, which needs so stabilized accelerating voltage [3].

REFERENCES

[1] B.Zyrianov *et al.* Remote neutron therapy. Tomsk University, 1991.

[2] O.Kononov, V.Kononov, M.Bokhovko. Accelerator based neutron sources for the neutron and neutron capture therapy. Preprint IPPE-2985. Obninsk, IPPE, 2003.

[3] Yu. Belchenko *et al*. Status of high-current electrostatic accelerator-tandem for the neutron therapy facility. APAC'01, 2001, Beijing, China.

[4] Y. Belchenko and E. Grigoryev. Surface-plasma negative ion source for the medicine accelerator. Rev. Sci. Instr. **73** (2002) 939.

[5] G. Derevyankin *et al.* The ion-optical channel of 2.5 MeV 10 mA tandem accelerator, Preprint BINP 2002-24, Novosibirsk, BINP, 2002.

[6] Sorokin, V. Shirokov. High-voltage gaps in a tandem electrostatic accelerator with vacuum insulation. //Instruments and Experimental Techniques, v 46, N1, 2003, p.1.

[7] A. Babkin, et al. High-frequency 500 KV compact rectifier. //Nuclear Energy, v. 93, N6, 2002, p.471.