PROTON LINEAR ACCELERATOR FOR BORON-NEUTRON CAPTURE THERAPY

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At the present time radiotherapy, surgery and chemotherapy are the main methods of treatment of malignant tumors. They may be used individually or in combination with other methods. The main disadvantage of the traditional methods of radiotherapy is the fact that ionizing radiation damages not only malignant cells but also surrounding healthy tissues. There are also tumors resistive to most extensively used gamma-radiation and malignant new formations like multiform glioblastoma (badly localized form of the brain tumor with plenty of branches) and melanoma (aggressive form of the skin cancer) which are practically incurable and cause the death of about a million people a year. Currently methods of treatment of malignant tumors with ions accelerated to high energies, and neutron methods directed to decrease the harmful effect on healthy tissues, are developed in the world.

In theory the ideal method of radiotherapy may be the method in which only cancer cells are disintegrated, and healthy cells are not affected. The method of boron-neutron-capture therapy (BNCT), which is essentially a binary radiation method, satisfies this ideal best. In BNCT method the source of strong ionizing short-range radiation is in the cancer cells. This radiation is generated as a result of interaction between external thermal neutron field and atoms of ^{10}B (stable isotope), with which cancer cells are saturated previously. In the reaction ^{10}B(n,á)^{7}Li two short-range ions (helium and lithium) are generated which disintegrate the cancer cell (Fig.1).

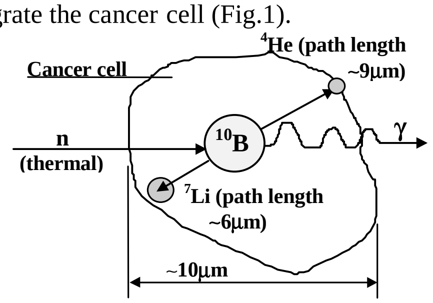

Fig.1.

In this reaction the lithium ion may occur both in the ground state, and in the excited state with emitting γ-quanta:

$^{10}B + n_{th} \longrightarrow {}^{7}Li^{*}$ (0.84 MeV) + ^{4}He (1.47 MeV) + γ (0.48 MeV) 93.7%

$^{10}B + n_{th} \longrightarrow {}^{7}Li$ (1.01 MэB) + ^{4}He (1.78 MэB) 6.3%

Path lengths of lithium and helium ions do not exceed the average size of a cell. Therefore, only cells containing boron atoms are affected. Boron atoms are injected to the tumor by pharmacological boron-containing preparations capable of accumulating only in cancer cells. The boron concentration in the tumor of about 30ìgm/gm and neutron flux of about 10^9 n/cm^2 is necessary for adequate therapy. The cross-section of the mentioned reaction on ^{10}B nucleus is thousands times higher than cross-sections of ^{14}N(n,p)^{14}C and ^{1}H(n,ã)^{2}H undesirable reactions on nitrogen and hydrogen that tissues contain.

Hence the BNCT method may be used for treatment of badly localized aggressive forms of tumors including above mentioned. Selective pharmacological preparations find cancer cells and deliver boron there. The neutrons interact with boron containing cells and destroy them.

The progress of the BNCT method is determined by the achievements in the field of creation of the boron containing preparations and in creation of the neutron sources with the required parameters. Investigations of the BNCT method have shown that the irradiation immediately by thermal neutrons is not efficient because of their small penetrability. The best procedure considers an irradiation by epithermal neutrons with energies of 0.5eV up to 10 KeV, which better penetrate through osseous and soft tissues and thermalize as they penetrate through these tissues before reaching the tumor.

At the present time most of neutron sources for medical investigations of the BNCT method are based on the nuclear reactors. Such investigations are being carried out at the Brookhaven Medical Research Reactor (BMRR), at the Gorgia reactor (GTRR), at the Massachusetts Institute of Technology Reactor (MITR), at the National engineer laboratory in Idaho (INEL), at the PBF reactor in Patten (Netherlands), and so on.

To obtain a beam with appropriate spectral neutron characteristics, with a minimal contamination by gamma-radiation, thermal and fast neutrons, the output devices of these sources are equipped with special moderators, reflectors and absorbers. It is complicated and frequently expensive devices.

The sources of fast neutrons based on proton accelerators are suggested, which also require complicated output devices and high beam powers (tens and even hundreds kilowatt) [1].

Recently a new version of the neutron source was suggested based on proton accelerator with energy of 2 MeV possessing a number of advantages in comparison with reactor–based sources [2-4]. It was suggested to use ^{7}Li(p,n)^{7}Be reaction near the threshold for neutron generation. The threshold proton energy in this reaction is 1.881 MeV. Despite the fact that cross sections of the reaction near the threshold are low, such approach possesses some positive properties, which compensate partly this disadvantage. Energies of the generated neutrons in the threshold region are close to epithermal that simplifies considerably the problem of moderating and allows us to do it without complicated output devices. The neutron flux from the lithium target is kinematically collimated and irradiated object may be located in several centimeters from the source that increases efficiency of use of a neutron beam. The neutron flux is directed to a forward hemisphere and radiation protection is considerably simplified in comparison with that of the reactor version. The proton accelerator for this purpose is compact, simple and inexpensive in operation and may be installed immediately in hospitals. This condition also is important because the number of nuclear reactors suitable for BNCT all over the world is limited and cannot satisfy with need all requiring in treatment by this method. Development and creation of such accelerators do not require further development of physics and technology of accelerators.

At the University in Idaho the investigations of neutron sources for BNCT are being carried out on a linear accelerator with RF quadruple focusing (RFQ) and on a proton electrostatic accelerator with energy of 2 MeV [5]. The investigations have shown that for BNCT based on these accelerators, the proton currents of 3 –5 mA are necessary. Under this condition the neutron fluence of $5x10^{12}$ n/cm^2 is achieved with total doze per hour of 2000cGy on a tumor containing 30 μgm/gm of ^{10}B, what is necessary for therapy and is tolerant for normal tissues. A special lithium target with the cooling system is necessary for removal of a heat power of 6-10kW. The experimental results and mathematical calculations have shown that this source can produce neutron beam for BNCT at proton energies of 1.91 MeV with the intensity and nominal overall effectiveness of those available at research reactors, and with lower thermal deposition than in conventional accelerator based designs.

We propose to create a proton linear accelerator for the BNCT method based on the existing at NSC KPTI linear accelerator of multicharge ions (MILAC) analogous to that in Idaho. It is supposed to create a new accelerating section for energy of 2 MeV with alternating phase focusing (APF) and moving bunch center that provides considerable capture both in radial, and in longitudinal motion. At the first stage it is assumed to create an accelerator with the proton current of 1-2 mA. Further it will be increased to 5 mA. For creation of such accelerator most of the existing equipment of MILAC accelerator could be used: RF equipment, vacuum system, the basic part of the injector, control system, working areas. The choice of such scheme of the accelerator is stipulated by large rate of acceleration, availability of the ready equipment, experience in development and creation of such systems, simplicity of manufacturing, greater compactness in a comparison with RFQ systems, and also existing industrial basis.

The common view of BNCT circuit is shown on Fig.2.

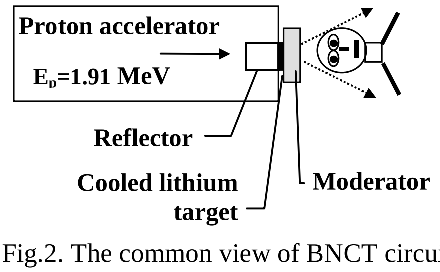

Fig.2. The common view of BNCT circuit.

At the present time in the Ukraine there are no neutron sources suitable for the BNCT method. The proposed neutron source could be constructed in the short time with the minimal financial contribution, and to supply beginning of investigations in this field. The evaluations show that it can be created during about two years, and financial contribution of $ 100,000 is necessary for this purpose. At the present time Ukrainian medical researchers are taking an active interest to the BNCT method which was accepted as the most promising in treatment of malignant diseases, especially above mentioned. There is a number of large medical institutions interested in development of this method, and are ready for cooperation in this area.

Creations of a neutron source will need some modernizing of existing systems, creation of new accelerating section, target device with a system of cooling and creation of radiation protection.

The parameters of a designed proton accelerator are shown in table.

Table

Main parameters of linear proton accelerator for BNCT

	The name of a parameter and unit		
1	Input energy of ions,	keV	150
2	Output energy of ions,	keV	1910
3	Mass-to-charge ratio, À/q		1
4	Operating frequency	ÌHz	150
5	Electric field in gaps, MV/m		8
6	Aperture of drift tubes, mm		16-26
7	Length of accelerating structure,	m	1.2
8	Number of drift tubes		12
9	Number of focusing regions		3
10	Number of bunching regions		4
11	Radial acceptance	π mm mrad	2
12	Longitudinal capture,	deg.	150
13	Energy spread (for $\Delta W_{in.}$=1%)	%	1.5
14	Longitudinal of output bunch	deg	30
15	Pulse RF power	kW	200
16	Duty factor	%	2.5
17	Average beam current	mA	1-2

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