THE PORTABLE NEUTRON GENERATOR DESIGNED FOR TREATMENT OF CANCER

A.N. Dovbnya, V.A. Tsymbal, A.F. Stoyanov, D.Y. Shahov, I.N. Zaytsev
National Science Center “Kharkov Institute of Physics and Technology”, Kharkov, Ukraine
E-mail: wind@kipt.kharkov.ua

We propose the construction of portable neutron generator designed for some oncological decease (particularly – uterus cancer, rectum cancer) by influence of neutrons. We propose to use reaction of deuteron interaction with lithium or beryllium nuclei for production of neutrons. The compact deuteron accelerator design is developed, we estimated neutron output for possible targets, the design of stand for testing and adjustment of installation is proposed.

PACS: 29.25.Dz

Cancer is probably the most dangerous to human life and health, and the development of methods for their treatment is one of the most actual challenges facing society.

Traditional treatments were (and still is) a surgical intervention, to which were added chemotherapy and treatment with ionizing radiation (neutron, proton therapy, gamma therapy, radiation with α-particles, β-particles, electrons).

All exposure to ionizing radiation on the tumor can be divided into two types:

- effect on all tissues (including health), but organized in such a way as to minimize the effects on healthy tissue.

The first type is, in particular, gamma-therapy, gamma rays pass through the collimator system "ray" and effect on the tumor, located within the human body, passing through the healthy tissue and destroying it, but due to the successive changes in the orientation of the accelerator the impact of the body healthy tissues is reduced.

The same is true for the proton therapy-protons pass through healthy tissue with low energy losses, the major energy losses occur in the tumor;

- brachytherapy, when ionization source is located in such a way, that it can directly impact to the tumor.

In brachytherapy, the sources of ionizing radiation are located near the tumor.

For some types of cancer deceases (in part cancer for men and cervical cancer for women), it is possible to provide direct contact between the radiation source and the affected tissue without surgeon interference, although the tumor is not located on the surface, the use of an external source of gamma radiation or an external neutron source collimation is impossible in this case.

Currently, the NSC KIPT "Accelerator" of Ukraine (project STCU R497) developed portable neutron generator for the treatment of cancer diseases mentioned above.

The proposed concept of a portable neutron generator is based on the idea to organize contact between the target and the accelerated charged particles in the vicinity of the tumor, resulting in a nuclear reaction produces neutrons, which act on the tumor.

Obviously, this requires passing a beam of charged particles through a long narrow tube – ion “needle”, which is situated at the end of the target.

This approach allows us to combine the advantages of brachytherapy (minimal effect on healthy tissue) with the advantages of an external radiation source (no need to introduce sources of radiation to the tumor).

In addition, the use of isotopes (e.g. – an isotope of californium ^{252}Cf) is much more expensive than the work of the PNG.

General requirements for the design of a portable neutron generator (PNG), are as follows.

The acceleration of charged particles is carried by electrostatic accelerator.

The accelerator must:

- not be heavy, cumbersome (requiring compactness);
- not be energy-intensive (requiring efficiency);
- it must be reliable in operation (reliability requirement).

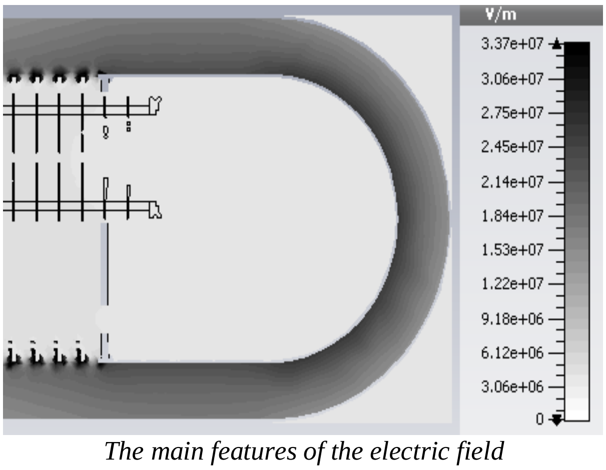
These requirements lead to limitation on the voltage and the size of the accelerator.

The distribution of the electric field in the area of the greatest values of the field in the proposed construction of the accelerator, conductor, part of the accelerating column and the outer casing are shown in Figure.

Note that the size reduction of the accelerator leads to the breakdown capability, and the size increase- to loss compactness and reliability of PNG operation.

The highest field value will be on the surface of the accelerator conductor, furthermore concentration field in the vicinity of the gradient rings is possible.

When designing units of PNG accelerator one of the most important tasks was to ensure that no field concentrations due to the presence of sharp edges in the high voltage part.



The main features of the electric field in high-voltage part of PNG accelerator (V/m)

The following reactions leading to the emergence of neutrons (obviously, we will not consider the formation of neutrons in fissile medium) [1 - 3].

PHOTONEUTRON NUCLEAR REACTIONS

Nuclear interaction with radiation, reaction (γ, n). The reaction can be implemented on the basis of electron-bremsstrahlung electrons, accelerated in the accelerator.

The implementation of the reaction requires energy γ-quanta exceeding at least 1.66 MeV (for beryllium), the reaction threshold is much higher for all remaining cases.

One of the main requirements to PNG is compactness requirements and cost efficiency. To implement the reaction (γ, n), the accelerator voltage is required, at least not less than 1.66 MV, i.e. the installation will be quite bulky and energy intensive. Furthermore, when energy rays $\gamma \leq 2$ MeV neutrons produced have sufficiently low energy that can significantly reduce the dose absorbed in the vicinity of the source and reduce the effectiveness of the treatment and decrease the effectiveness of treatment

REACTIONS (p, n)

The main reactions, resulting in the formation neutrons as a result of interaction with a nucleus of protons are the following:

$$^{3}H+p \rightarrow {}^{3}H+n-0.764 \text{ MeV}, \quad (1)$$

$$^{7}Li+p \rightarrow {}^{7}Be+n-1.646 \text{ MeV},$$

$$^{7}Li+p \rightarrow {}^{7*}Be+n-2.076 \text{ MeV}; \ {}^{7*}Be \rightarrow {}^{7}Be+\gamma+430 \text{ keV}.$$

The third of the following reactions is at proton energies exceeding 2.378 MeV, this energy can not be realized under the given possibilities of the accelerator. Reaction with tritium nuclei can practically be used for the production of neutrons, but in case of contact with the body (which is possible when abnormality) it is dangerous for the personnel and the patient, so it’s use is undesirable. Thus, one can use only the reaction of lithium ^{7}Li nuclei with protons. The reaction of the interaction of the protons with lithium nuclei has a threshold, the threshold is 1.8 MeV, which significantly exceeds the accelerator PNG opportunities.

Based on the above it can be concluded that the use of photonuclear reactions and (p, n) in PNG is irrational.

REACTIONS (d, n)

The main reactions leading to the emergence of neutrons resulting from the interaction of the target nuclei with deuterons, are the following:

$$^{2}H+{}^{2}H \rightarrow {}^{3}He+n+2.265 \text{ MeV}, \quad (2)$$

$$^{2}H+{}^{3}H \rightarrow {}^{4}He+n+17.588 \text{ MeV},$$

$$^{2}H+{}^{9}Be \rightarrow {}^{10}B+n+4.362 \text{ MeV},$$

$$^{2}H+{}^{7}Li \rightarrow {}^{8}Be+n+15.028 \text{ MeV},$$

$$^{2}H+{}^{7}Li \rightarrow 2{}^{4}He+n+15.122 \text{ MeV},$$

$$^{2}H+{}^{7}Li \rightarrow {}^{4}He+{}^{5}He+14.165 \text{ MeV},$$

$$^{5}He \rightarrow {}^{4}He+n+0.958 \text{ MeV}.$$

The most effective, in terms of the neutron yield and the possibility of practical implementation, is the reaction of deuterons with nuclei of lithium:

$$^{2}H+{}^{7}Li \rightarrow {}^{8}Be+n+15.028 \text{ MeV}, \quad (3)$$

$$^{2}H+{}^{7}Li \rightarrow 2{}^{4}He+n+15.122 \text{ MeV},$$

$$^{2}H+{}^{7}Li \rightarrow {}^{4}He+{}^{5}He+14.165 \text{ MeV},$$

$$^{5}He \rightarrow {}^{4}He+n+0.958 \text{ MeV}. \quad (4)$$

It is important to note that the implementation of this reaction the neutron output time increases with the increase concentration of deuterium nuclei in a thin layer of lithium target, and therefore, it is possible a kind of "bonus" – the formation of additional neutrons by the scheme:

$$^{2}H+{}^{2}H \rightarrow {}^{3}He+n+2.265 \text{ MeV}. \quad (5)$$

Evaluation of the neutron yield changes over time and their energy characteristics – one of the tasks that need to be decided when developing PNG design. Moreover, the reaction (5) gives neutron output in the absence of the target, that is taken into account in the formulation of security requirements during the testing and adjustment of the PNG.

It is also possible the use of beryllium target (reaction $^{2}H + {}^{9}Be \rightarrow {}^{10}B + n + 4{,}362$ MeV), or Be-Li alloy, but the neutron yield in this case is lower.

Assessment of potential output Q neutrons at deuteron current expected for lithium (and beryllium) target yields $Q \sim 10^{9}$ neutrons/s, which corresponds to the requirements of the PNG performance, so the reaction of deuterons with lithium (or lithium – beryllium) target is effective.

We fulfill adjustment and testing of the PNG at the stand. The main elements of the stand are:

- the actual neutron generator;
- the phantom (in the simplest case consists of water) that simulates the body tissue;
- external protection.

An external protection is necessary due to the fact that in the process of adjustment and testing is expected to operate the PNG for a sufficiently long time, and the staff will be located in the immediate vicinity of the stand.

REFERENCES

1. L. Kertis. *Introduction into nuclear physics*. M.: «Atomizdat», 1965.
2. K. Berkutz, K. Virtz. *Neutron physics*. M.: «Atomizdat», 1968.
3. E. Segre et al. *Experimental nuclear physics*. M.: «Foreign literature Publishing», 1955.

Article received 25.02.2016

ПОРТАТИВНЫЙ НЕЙТРОННЫЙ ГЕНЕРАТОР, ПРЕДНАЗНАЧЕННЫЙ ДЛЯ ЛЕЧЕНИЯ ОНКОЛОГИЧЕСКИХ ЗАБОЛЕВАНИЙ

А.Н. Довбня, В.А. Цымбал, А.Ф. Стоянов, Д.Ю. Шахов, И.Н. Зайцев

Предложена конструкция портативного нейтронного генератора, позволяющего лечить ряд онкологических заболеваний (в частности – рак прямой кишки и рак матки) воздействием нейтронов. Для образования нейтронов предлагается использовать реакцию взаимодействия дейтронов с ядрами лития или бериллия. Разработана конструкция компактного ускорителя дейтронов, выполнены оценки выхода нейтронов для возможных мишеней, предложена конструкция стенда для тестирования и наладки установки.

ПОРТАТИВНИЙ НЕЙТРОННИЙ ГЕНЕРАТОР, ПРИЗНАЧЕНИЙ ДЛЯ ЛІКУВАННЯ ОНКОЛОГІЧНИХ ЗАХВОРЮВАНЬ

А.М. Довбня, В.О. Цимбал, О.Ф. Стоянов, Д.Ю. Шахов, І.М. Зайцев

Запропоновано конструкцію портативного нейтронного генератора, що дає можливість лікувати деякі онкологічні захворювання (зокрема – рак матки та прямої кишки) впливом нейтронів. Для створення нейтронів планується використовувати реакцію взаємодії дейтронів з ядрами літію або берилію. Розроблено конструкцію компактного прискорювача дейтронів, виконані оцінки виходу нейтронів для можливих мішеней, запропонована конструкція стенда для тестування та налагодження установки.