TARGET SYSTEM FOR THE CC-SERIES CYCLOTRONS DESIGNED AND MANUFACTURED IN NIIEFA

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A prototype of the target system for the CC-series cyclotrons for production of PET radionuclides C-11 and F-18 has been designed, manufactured and tested in the Efremov Institute. The target system will produce radionuclides sufficient to ensure the needs of a standard PET-center.

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INTRODUCTION

The use of new advanced methods for diagnostics in nuclear medicine is one of the most important tasks, which will allow better results of treatment of a broad range of the most complex and frequently occurring diseases to be obtained. Large-scale introduction of the PET method into clinical practice in oncology, cardiology and neurology is nowadays an urgent problem, which should be settled by creating a network of PET-centers on the territory of the Russian Federation. One of components of such a PET-center is a cyclotron with a target system providing production of ultra-short-lived radionuclides of a necessary assortment in necessary amounts.

Technical characteristics of the CC-18/9 and CC-12 cyclotrons designed and manufactured in NIIEFA completely meet the requirements imposed today on cyclotrons intended for PET. However, until now, the aforementioned machines have not been equipped with target systems adapted to their particular design.

Each target device and systems ensuring its proper operation should comply with parameters of a particular cyclotron, such as charged particles energy, beam current and beam energy profile. The degree of accuracy of target device parameters' calculation determines if radionuclides' production is possible, the efficiency of their production and a highly important factor – safety of the personnel.

At present, specialists of the Efremov Institute have designed and manufactured a target system for the CC-series cyclotrons for production of the major radionuclides for PET diagnostics, such as F-18, C-11, N-13 and O-15.

TARGET SYSTEM DESCRIPTION

The target system for the CC-series cyclotrons comprises the following:

- target devices for production of F-18, C-11, N-13 and O-15 radionuclides;
- cabinet of the target control system;
- system for targets' loading with target materials;
- gas-supply system;
- controller unit of the target system automatic control system;
- operator workstation.

Computer model of the target system is shown in Fig. 1.

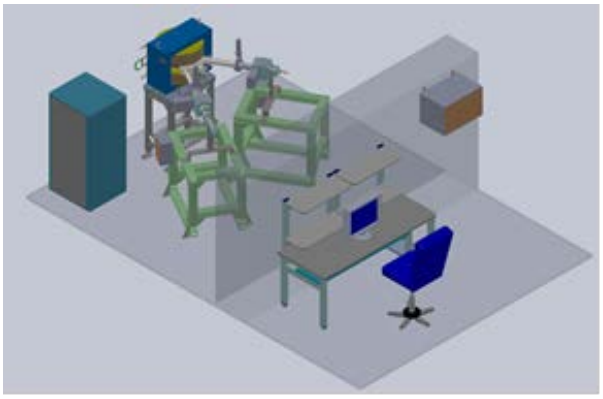

Fig. 1. Computer model of the target system for CC-12 and CC-18/9cyclotrons

Target systems of the CC-series cyclotrons can be equipped with target devices from two up to eight in number depending on the needs of a particular PET-center.

The cyclotrons make possible simultaneous irradiation of two targets with currents in any proportion of the maximum beam current (I_{max}=150 μA).

Depending on requirements of a particular consumer, cyclotrons are equipped with a beamline to transport the beam to a required distance, and a possibility to install up to 6 target systems is provided.

To decrease the size of the cyclotron hall, a manipulator for automatic remote replacement of targets can be used instead of the switching magnet.

The CC-18/9M cyclotron in addition to gaseous and water targets for production of ultra-short-lived radionuclides F-18, C-11, N-13 and O-15 can be equipped with target devices with solid targets for production of a wide assortment of short-lived radionuclides (now under designing).

TARGET DEVICES FOR PRODUCTION OF F-18 RADIONUCLIDE

The F-18 radionuclide is produced by nuclear reaction $^{18}O(p, n)^{18}F$ under irradiation of $H_2{}^{18}O$ (95 % enriched with ^{18}O) with protons.

Proton energy is 12 MeV (the CC-12) and 18 MeV (the CC-18/9M).

The targets are designed for a maximum beam current of 80 μA.

Target devices of two sizes, 2 and 3 ml in volume, have been designed in NIIEFA. For two hours of irradiation, the 2 ml target device gives the activity yield up to 3 Cu on the CC-12 cyclotron and up to 5 Cu on the CC-18/9M cyclotron. The 3 ml target device ensures the activity yield up to 5 Cu on the CC-12 cyclotron and up to 7 Cu on the CC-18/9M cyclotron for the same time interval.

Bodies of targets and collimators are cooled with water; foils of the intput window and targets are cooled with helium.

Target devices (Fig. 2) ensure a necessary size of the irradiation field; target cooling, beam current measurement, water supply and discharge from target volume.

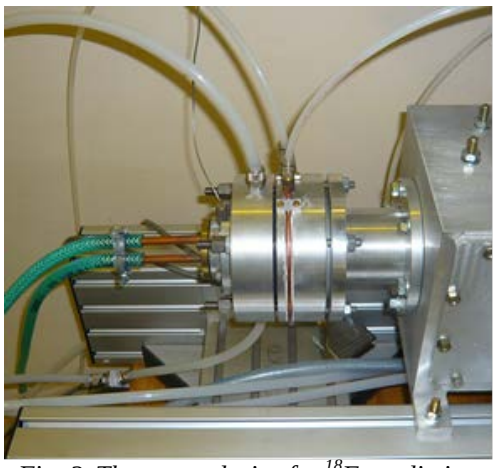

Fig. 2. The target device for ^{18}F prodiction

The collimator unit shown in Fig. 3 ensures a necessary size of the target irradiation field.

A unit for helium cooling of target is connected to the collimator unit. The helium cooling unit and the target are insulated from the ground, and this allows the beam current on target to be measured.

The vacuum volume of the cyclotron ion guide is separated from the target device helium cooling unit with a stainless steel foil. The helium cooling unit is also separated with stainless steel foil from the target side.

Fig. 3. Water-cooled collimator unit

From the target control system helium is supplied to the helium cooling unit through a pipeline and by blowing out between the output window foil and the target foil provides their cooling.

The design of the collimator unit and helium cooling unit is unified for target devices for production of F-18, C-11, N-13 and O-15.

The target body made of Nb or Ta of maximum purity is attached to the helium cooling unit. On the backside, the target body is cooled with water. The water-cooling unit is shown in Fig. 4.

Fig. 4. Water-cooling unit of target body

Overall dimensions of the target device are: diameter-130 mm and length-210 mm. When designing these target devices, drawbacks of targets given in papers [1-5] were taken into account.

TARGET DEVICE FOR C-11 RADIONUCLIDE PRODUCTION

The ^{11}C radionuclide is produced by the nuclear reaction $^{14}N(p,\alpha)^{11}C$ under irradiation of gaseous nitrogen with protons. The formed ^{11}C radionuclide is stabilized as $^{11}CO_2$ dioxide.

Energy of protons is 12 MeV the (CC-12) or 18 Mev (the CC-18/9M).

The beam current is up to 80 μA.

The target body is made of aluminum.

The target volume is 100 cm^3.

The initial nitrogen pressure in the target is 8…10 bar.

The output window foil and the target foil are made of stainless steel of 20 μm thickness.

The target device (Fig. 5) ensures the activity yield up to 50 GBq for 30 minutes of irradiation.

Fig. 5. The target device for ^{11}C production

Combined cooling is used: the target body is cooled with water; foils of the output window and target are cooled with helium.

Overall dimensions of the collimator unit, helium cooling unit and water-cooled target body are: diameter-130 mm and length-350 mm.

A prototype of this target device is the one described in [1].

CABINET OF THE TARGET CONTROL SYSTEM

The target control system consists of the following:

- system for fore-pumping of air from the helium loop prior to filling with helium;
- system for helium cooling of target with a compressor to pump helium in the cooling loop;
- system for water cooling of target, collimator and helium loop;
- system to supply compressed air to pneumatic drives;
- local controls.

The target control system is remotely controlled from operator's workstation.

The cabinet of the target control system is located in the cyclotron hall (Figs. 6, 7).

Fig. 6. Cabinet of the target control system n in the target hall of the cyclotron

Fig. 7. Cabinet of the target control system

To cool targets, collimators and coolers of the target control system, distilled water of the cyclotron inner loop is used in the water cooling system.

SYSTEM FOR TARGETS LOADING WITH TARGET MATERIALS

Each target device is equipped with a separate loading unit with a target isotope.

Unit for filling the target with water is placed in a direct vicinity of the target device. The unit for target filling with water is shown in Fig. 8.

Before starting the work, the target is blown out with helium, and is filled with water enriched with ^{18}O isotope through a pneumatic drive by a syringe. On termination of the irradiation process, corresponding valves are remotely open, and the water displaced by helium from the target volume is transported to the hot cell of a synthesis module. A radiactivity sensor of the module records the obtained activity.

Fig. 8. The unit for the target filling with water

The unit for a gas target filling (Fig. 9) is also located in a direct vicinity of the target device.

Fig. 9. The unit for filling the target with nitrogen for ^{11}C production

The ^{11}C radionuclide, which is necessary for synthesis of radiopharmaceuticals, is produce under irradiation of natural gaseous nitrogen with protons. To do this, the target device is filled with nitrogen of high purity.

On termination of irradiation, the gas is vented through a corresponding electrically-operated valve via a capillary to the module of radiopharmaceutical synthesis.

The velocity of the gas venting from the target is regulated by a throttle valve in the gas filling system.

AUTOMATIC CONTROL SYSTEM OF THE TARGET SYSTEM

The automatic control system of the target system is built on the module principle. It consists of an operator workstation and block of controllers, located in the same place with the cyclotron operator workstation. The

controller block is the host device of the automatic control system. It serves for acquisition, processing and analysis of data on the status of the target system. The controller prevents emergency situations and disables incorrect operator's actions in accordance with an algorithm of the controller software.

Information on the status of the target system is transmitted to the operator's workstation, where it is displayed in a form suitable for user. The ACS of the target system ensures the control of operation of up to 8 water or gas targets in any combination. In addition, one solid target can be connected.

The Mitsubishi FX3UC controller was chosen as a controller of the ACS. High performance, simple maintenance and reliability of these controllers are the determining factor to choose them for the designed target system.

In addition to the aforementioned advantages, when choosing controller for the target system ACS, we have taken into account the fact that automatic control systems of the CC series cyclotrons are built on the basis of Mitsubishi FX controllers. These controllers allow the ACS of the target system to be integrated sufficiently simply into the ACS of the whole cyclotron system.

The Mitsubishi GT1275 panel was chosen for the control console of the operator workstation, which allowed a user-friendly operator interface to be designed (Fig. 10).

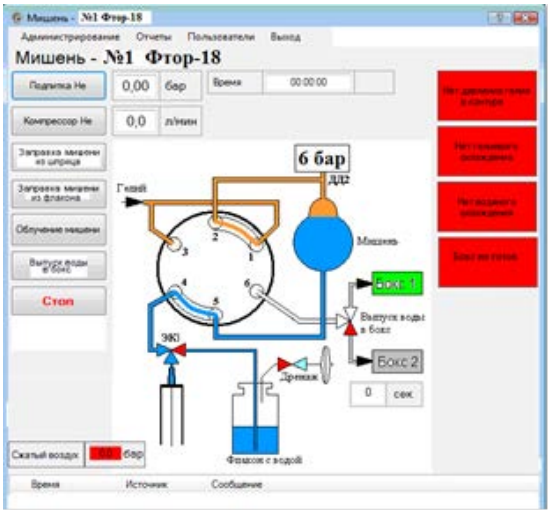

Fig. 10. The control program interface

To control the target system operation, such parameters as the beam current on target, pressure in the target, current time of irradiation, if there is helium cooling of the inter-foil space and water cooling of collimators and target bodies are displayed as well as information on each synthesis module if it is ready for loading a radionuclide produced.

The controller block cabinet is shown in Fig. 11.

Fig. 11. The cabinet of the controller block of the automatic control system

CONCLUSIONS

The target systems described in the paper will be an integral part of the cyclotron equipment, which NIIEFA plans to deliver for PET-centers in Russia, countries of the former Soviet Union and abroad. The designed target systems produce the whole assortment of ultra-short-lived radionuclides necessary for PET-diagnostics in amounts sufficient to ensure stable operation of a PET-center.

REFERENCES

1. B.V. Zabrodin, V.N. Lomasov, A.V. Motorny. *Radionuclide visualization methods: textbook.* St.-Petersburg State Polytechnical University, 2006, p.75.
2. Peter Wiberg. *Device for fitting of a target in isotope production.* US patent № 6433495 B1.
3. Charles W. Alvord, Andy Williamson. *Tantalum water target body for production of radioisotopes.* US patent № 7831009 B2.
4. Bruce W. Wieland. *Batch target and method for producing radionuclide.* WO 2003099374 A2 patent.
5. D.S. Sysoev, V.V. Zaitsev, M.I. Mostova, O.A. Shtukovsky. *Target device for a cyclotron with the 18 MeV proton energy for production of F-18 as-anion fluoride.* Utility Patent № 114260.

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МИШЕННЫЙ КОМПЛЕКС ДЛЯ ЦИКЛОТРОНОВ СЕРИИ СС ПРОИЗВОДСТВА НИИЭФА

Е.Н. Абрамов, Ю.Н. Гавриш, П.А. Гнутов, М.Л. Клопенков, Р.М. Клопенков, К.А. Кравчук, А.Н. Кужлев, А.А. Мельников, В.Г. Мудролюбов, Г.В. Муравьев, А.П. Строкач, Б.В. Забродин, А.В. Регель

В НИИЭФА им. Д.В. Ефремова разработан, изготовлен и испытан опытный образец мишенного комплекса циклотронов серии СС для производства ПЭТ-радионуклидов углерод-11 и фтор-18. По производительности наработки радионуклидов комплекс обеспечит потребности типового ПЭТ-центра.

МІШЕНЕВИЙ КОМПЛЕКС ДЛЯ ЦИКЛОТРОНІВ СЕРІЇ СС ВИРОБНИЦТВА НДІЕФА

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У НДІЕФА ім. Д.В. Єфремова розроблений, виготовлений і випробуваний дослідний зразок мішеневого комплексу циклотронів серії СС для виробництва ПЕТ-радіонуклідів вуглець-11 і фтор-18. За продуктивностю напрацювання радіонуклідів комплекс забезпечить потреби типового ПЕТ-центру.