THE CC-18⁄9M CYCLOTRON SYSTEM FOR PRODUCTION OF ISOTOPES FOR PET

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Abstract

The CC-18/9M cyclotron system has been designed, manufactured and delivered to JSC "NIITFA", Moscow to be operated in a pilot PET center. Acceptance tests have been conducted. Design parameters of the updated cyclotron have been obtained: energy of accelerated proton and deuteron beams was varied within the ranges of 12-18 and 6-9 MeV with currents of 150 and 50µA, respectively. For the first time in NIIEFA practice the cyclotron is equipped with a target system intended for production of F-18 and C-11 radionuclides for PET. At present, the cyclotron system is put into commercial operation in the PETcenter.

INTRODUCTION

Successful treatment of a series of diseases in cardiology, oncology and neurology to a great extent depends on their early diagnostics, which provides a significantly higher efficiency and less time needed for treatment. Nuclear medicine is an undisputable leader in early detection of diseases, and wide application of nuclear medicine methods is proved by the fact that more than a half of radioactive isotopes produced in the world are intended for medicine. Absolute leaders in introduction of nuclear medicine into practice are the USA, Japan and some European countries. In particular, in the USA the nuclear medicine methods were used in 46% of the total diagnostic studies performed in cardiology, 34% in oncology and 10% in neurology.

Establishing of centers rendering high-tech medical assistance based on modern methods of nuclear medicine allowing us to make an early diagnosis of the most important socially significant diseases is highly urgent in the Russian Federation is highly urgent in the Russian Federation.

A pilot PET-center primarily intended for further development and optimization of the home-made equipment with the future aim of its serial production has been created in the JSC"NIITFA", Moscow. A CC-18⁄9M cyclotron system was designed and manufactured in JSC "The D.V. Efremov Scientific Research Institute of Electrophysical Apparatus" (NIIEFA) to be used in this PET-center. The machine was put into operation in 2014.

NEW ENGINEERING SOLUTIONS. COMPARATIVE CHARACTERISTICS

The cyclotron system is based on an updated CC-18⁄9M machine, which prototype is the CC-18/9 cyclotron [1, 2]. Three CC-18/9 cyclotrons have been previously manufactured and delivered to PET-centers of the Turky University, Finland (2005), the Russian research Center for Radiology and Surgical Technologies, Pesochny, St. Petersburg, Russia (2006) and Snezhinsk town, Chelyabinsk region, Russia (2010). In the updated cyclotron, the energy of accelerated proton and deuteron beams is varied in the ranges 12-18 and 6-9 MeV respectively, which widens fields of its application and raises its competitiveness. Simultaneously the design current of protons increased half as much compared to that of the basic model

It was for the first time in the NIIEFA practice that the cyclotron was delivered together with the target system providing the production of isotopes necessary for PET-diagnostics. The general view of the cyclotron [3] is shown in Fig. 1.

Figure 1: The CC-18⁄9M cyclotron system.

When designing the updated machine, the major engineering solutions proved by practice when operating CC-18⁄9 cyclotrons were kept unchanged:

- Shielding-type electromagnet with vertically located median plane to give an easy access to in-chamber devices by moving apart the movable part of the magnet along the guides (see Fig. 2). In addition, the radiation exposure of the operating personnel in the process of scheduled maintenance and repair works is significantly reduced.

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- Choice of negative hydrogen and deuterium ions as particles to be accelerated and extraction of proton and deuteron beams practically without loss of the beam intensity by stripping negative ions on thin carbon foils.
- Use of the external injection system [4], which appreciably reduces the inflow of the working gas from the source to the vacuum chamber, makes easier the high vacuum production and consequently reduces ion losses in the process of acceleration by charge exchange on the residual gas molecules.
- Acceleration of hydrogen and deuterium ions at a fixed frequency (the 2-nd and 4–th harmonics, respectively).

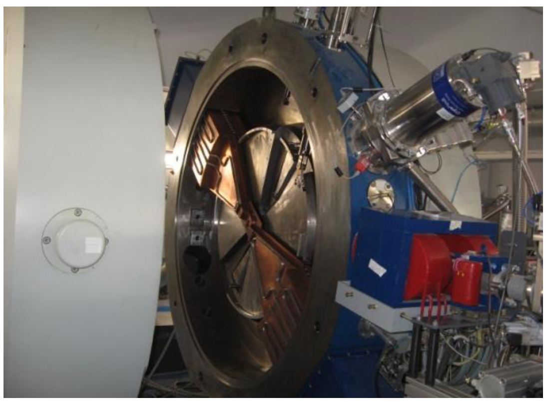

Figure 2: The CC18/9M cyclotron with an open vacuum chamber.

When designing the CC-18/9M cyclotron, special attention was paid to upgrading of output parameters as well as making easier its maintenance/repair.

- A new resonance accelerating system allowing the power losses to be reduced from 18 to 13 kW has been designed. The operating frequency of the RF power supply system is 40.68 MHz.
- A new manufacturing technology of the main magnet yoke was developed, which made easier the process of the electromagnet assembly and obtaining a necessary topology of the magnetic field.
- A new system was designed for on-line correction of the magnetic field topology when changing the type of particles to be accelerated.
- A new construction of hookup elements was designed providing a reduction in their cost, lower labor expenditures and less working hours needed for their manufacturing.

The main characteristics of the cyclotron system are given in Table 1.

TARGET SYSTEM

The target system designed and manufactured in the Efremov Institute is adapted to parameters of the CC-18/9M cyclotron beam. The system comprises water and gaseous target devices (see Fig.3 and Fig.4) [5] providing production of radioisotopes for PET-diagnostics.

Target devices can be mounted both directly on the output flanges of cyclotrons and on the end flanges of beamlines. Each target device comprises a unit providing targets' loading with a target material, system to deliver the activity to shielded boxes and system for monitoring the target status under irradiation.

Control of the target system is completely automated and is performed from the operator workstation [6]. Screens of the user interface are shown in Fig. 5.

The target system is designed by the modular principle. This allows a larger number of targets to be used and a wider assortment of radioisotopes to be produced. The target system is a completely self-contained system and can be adapted to any cyclotron used for commercial production.

Table 1: Main Characteristics of the CC-18/9M Cyclotron System Compared with Available Analogues

Main parameters	**CC-18/9 JSC "NIIEFA", Russia**	**CC-18/9M JSC "NIIEFA", Russia**	**Cyclone 18/9 IBA, Belgium**	**PET trace GE, Great Britain**	**TR-19/9ACS, Canada**
Type of accelerated particles	H^-/D^-	H^-/D^-	H^-/D^-	H^-/D^-	H^-/D^-
Type of extracted particles	H^+/D^+	H^+/D^+	H^+/D^+	H^+/D^+	H^+/D^+
Beam energy, MeV	18/9	12-18/6-9	18/9	16.5/8.4	19/9
Max beam current, µA, not less than	100/50	150/50	150/50	150/60	300
Energy variation	-	+	-	-	+
Number of simultaneously irradiated targets	2	2	2	2	2
Total power consumption, kW, no more than	60	60	55	70	65

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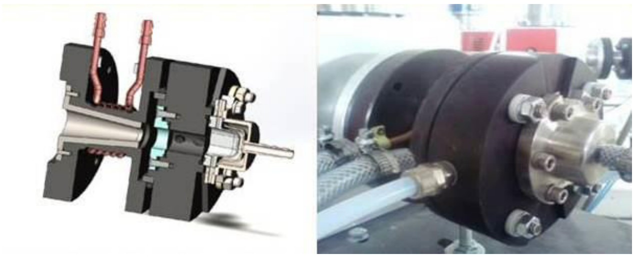

Figure 3: Target device for production of fluorine-18 (^{18}F) radionuclide.

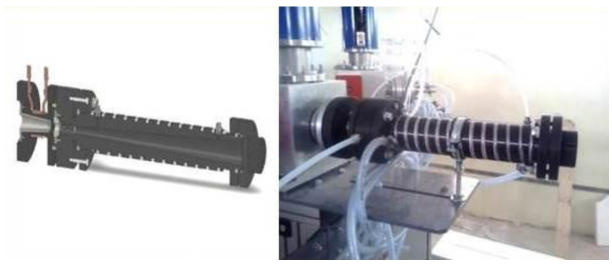

Figure 4: Target device for production of carbon-11 (^{11}C) radionuclide.

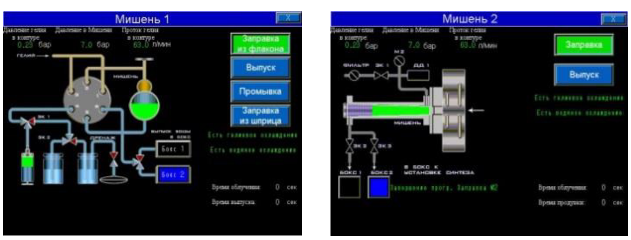

Figure 5: Status of water and gaseous targets on the monitor of the target system operator.

CURRENT STATUS AND PROSPECTS

In the tests of the target system with a proton beam current of 50 µA, the 5 Ci activity yield was attained with a 3 ml water target device for 2 hours of irradiation (production of ^{18}F). In this case, pressure in the working cavity of the target was 8 bars, which allows us to expect a higher yield after testing at a higher current of the beam of protons.

During 2016, the cyclotron system was operated in the mode of routine production of ^{18}F. More than 100 irradiation sessions were performed, and 7500 µAh of the beam time was used. The average proton beam current was 40 µA, average activity after 2-hour irradiation was 4.5 Ci and average yield of FDG was 70%.

As this cyclotron system is a pilot project, works to upgrade the performances of the external injection system, RF power supply system and automated control system were performed in parallel with its commercial operation. The near-future task to be solved is reduction of the beam intensity loss in the process of acceleration and beam transport through the beam line. Solution of this problem will allow us to increase the extracted proton beam current and to define the maximum and recommended yields of water targets.

The system comprising the cyclotron and target devices successfully demonstrated its service capability and proved an opportunity for commercial production of the radionuclides used in PET diagnostics.

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