PRODUCTION OF ACCELERATING EQUIPMENT FOR NUCLEAR MEDICINE IN NIIEFA. POTENTIALITIES AND PROSPECTS

M.F. Vorogushin#, Yu. N. Gavrish, A. P. Strokach
JSC "D.V. Efremov Institute of Electrophysical Apparatus", St. Petersburg, Russia

Abstract

The D.V. Efremov Institute (NIIEFA) is the leader in Russia in designing and manufacturing of the accelerating equipment for medicine. About one hundred of linear accelerators for the beam therapy and more than forty cyclotrons for production of radiopharmaceuticals have been designed, manufactured and delivered to clinics of Russia and some foreign countries.

The equipment designed and manufactured in NIIEFA in its technical characteristics is on a par with foreign analogs and sufficiently cheaper in expenditures for personnel training, hardware and software compatibility, warranty and post-warranty service, delivery of spare parts and updating.

In accordance with Federal Targeted Programs on the development of medical and pharmaceutical industries up to 2020, the production facilities, material and technical resources have been prepared for the organization of serial production of cyclotrons and gamma tomographs.

A leap forward in the nuclear medicine, understood as the introduction of nuclear–physical technologies into medicine, is directly connected with a broad application of charged particle accelerators. This is most distinctly manifested in diagnostics and treatment of the most dangerous and widely spread oncologic and cardiovascular diseases, which rate of mortality mainly defines an average age of human life in Russia.

A single-photon emission computer tomograph «EFATOM» [1] has been designed in NIIEFA for radionuclide diagnostics. It is used to visualize images obtained by using special radiopharmaceuticals. This method allows the anatomy and functioning of various organs to be studied as well as, osteal pathologies to be diagnosed. A wide range of available radiopharmaceuticals and methods makes possible diagnostics practically of any organ. The information obtained is used in oncology, cardiology, nephrology, neurology, endocrinology, traumotology, hematology, gastroenterology, in cases of cerebrum brain diseases, etc. A package of clinical programs was developed in cooperation with the staff of the State St. Petersburg University for diagnostics of the aforementioned scope of diseases. It was tested in leading clinics of Russia and was awarded the top assessment. Radionuclide examinations with emission tomographs are one of the main diagnostic methods all over the world. In developed countries, tens of millions radionuclide examinations are carried out annually, and this number increases by 10-12% each year.

#vorogushin@luts.niiefa.spb.su

Upon completing clinical tests, the «EFATOM» (see Fig.1) was included on the State Register of RF Medical Products, and in 2011 it was included on the List of products intended for serieal production. More than 15 thousand examinations have been performed with the «EFATOM» in clinical hospital № 83, Moscow.

The main features of the «EFATOM» are as follows. Analog signals are transformed in the digital detection block at the output of each photomultiplier with a subsequent processing by a ditgital processor. This allows the maximum resolution to be realized. The gantry provides fixing of two detection units and their travel along radial, axial and angular coordinates. Detectors' positioning is computer-controlled. Patient's support system provides patient's fixation in the lying position and its travel in vertical and horizontal planes. Both manual and computer control is possible.

Further progress of this diagnostic method can be facilitated by application of the gamma-tomograph together with a computer tomograph, which realizes a technology combining the functional sensitivity of the single emission tomography with a high anatomic resolution of CT. Designing and construction of such a combined apparatus is a near-future aim of NIIEFA in the field of diagnostics.

Figure 1: The «EFATOM» gamma-tomograph.

The accumulated clinical experience shows that nearly in 20% of cases more exact diagnostics with the positron-emission tomography (PET) using ultra-short-lived isotopes is required after the gamma-tomograph examination. PET allows the visualization of biological processes behavior in organs and tissues of a human-being on the molecular level, and both quantitative and qualitative assessments of the information obtained. For example, the accuracy of a malignant tumour detection,

ISBN 978-3-95450-170-0

including metastases of any localization, is up to 95-97%. In cardiology, PET allows the detection of the myocardium viability with a high accuracy. Early treatment along with a possibility to choose proper methods for treatment and to observe the dynamics of the process will significantly increase chances for recovery.

To produce medical isotopes directly in clinics, a series of compact cyclotrons [2] has been designed and manufactured in NIIEFA. The main technical characteristics of these machines are given in Table 1.

Table 1: Main Characteristics of Compact Cyclotrons.

Technical Characteristics	Cyclotron Model		
	CC-12	CC-18/9 M	MCC-30/15
Accelerated ions	H^-	H^-/D^-	H^-/D^-
Beam energy, MeV	12	12…18/ 6…9	18…30/ 9…15
Beam current, µA	50	150/70	200/100
Power consumption, kW	30	70	100
Shielding magnet weight, t	10	34	41
RF generator power, kW	15	20	25

Distinctive features of compact cyclotrons of the new generation are**:** shielding type magnet with the vertical median plane; vacuum chamber of the cyclotron made as a part of the magnet; resonance system completely located inside the vacuum chamber; possibility to move apart the movable part of the magnet to a distance of up to 800 mm to give an easy access to the in-chamber devices; system for external injection of hydrogen and deuterium negative ions; acceleration of negative ions of hydrogen and deuterium at one frequency of the RF field (the 2nd and 4th harmonics, respectively); extraction of beams of accelerated protons and deuterons by stripping negative ions on carbon foils practically with no loss of intensity; completely automated control of all cyclotron systems from a computerized operator workstation.

Figure 2 shows the CC-12 cyclotron at a test-facility in NIIEFA. Two CC 18/9 cyclotrons are operated in Russia; CC-18/9 and MCC-30/15 machines are in service in PET centers in Finland.

Over the last two years, the CC-18/9 machine was updated to vary the final energy of protons and deuterons and to increase the output beam current up to 150 and 70 µA respectively. In addition, target devices for production of F-18 (see Fig.3) and C-11 (see Fig.4) radionuclides have been designed for cyclotrons of the CC series. An automated system for remote replacement of targets allows one from five available targets to be placed under the beam at the operator option. The equipment of the CC—18/9 M cyclotron together with the target system has been manufactured and delivered to the JSC «NIITFA», Moscow and now it is under final acceptance tests [3].

Figure 2: The CC-12 cyclotron.

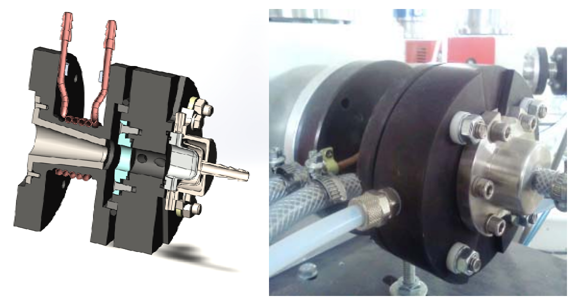

Figure 3: Target device for production of F-18.

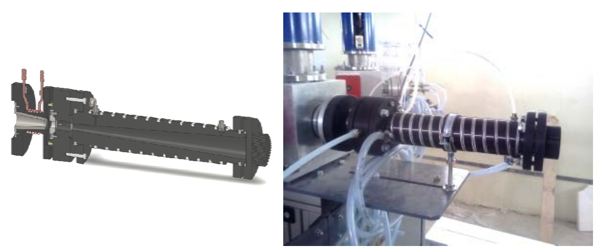

Figure 4: Target device for production of C-11.

In future, it seems reasonable to update the CC-12 cyclotron to equip it with an internal ion source instead of the external injection system and a local radiation shielding. Highly promising may be designing and manufacturing of a 70 MeV proton cyclotron with a beam current of about 200 µA intended for production of a more comprehensive set of radionuclides and for neutron and proton therapy of superficial tumors. NIIEFA is ready to take part in designing and manufacturing of a number of units of a medical cyclotron intended for proton, neutron and hadron therapy.

However, to the present day the radiotherapy with electron beams and X-rays still takes the main part among radiation methods in the vast majority of clinics all over the world. In the late 1990s, within the frames of cooperation with the «PHILIPS MEDICAL SYSTEMS. RADIOTHERAPY» firm (Great Britain), NIIEFA

ISBN 978-3-95450-170-0

pioneered in Russia in the small-scale production of 6 MeV medical accelerators for radiotherapy (SL-75-5M). Sixty similar machines were delivered to clinics of Russia; part of these accelerators have been operated till now.

Recently, an accelerator of new generation «ELLUS - 6M» with a set of additional medical equipment has been designed and manufactured in NIIEFA. This accelerator is an isocentric radiation facility intended for 3-D beam therapy with 6MeV X-rays in multi-static and arc modes. It is equipped with a multi-leaf collimator, portal vision system and patient-support system [4].

In 2012 in the N.I. Petrov Scientific Research Institute of Oncology of the RF Ministry of Health (St. Petersburg), clinical tests of «ELLUS-6M» were successfully completed. The accelerator was integrated into a radiotherapeutical system with a standard set of technological processes [5]:

- analysis of obtained diagnostic results on a tumor, in particular, its biological type, stage of a disease and choice of radiotherapy method to be applied;
- topometric preparation including the choice of a patient's treatment position and immobilization means on the therapeutic coach; reconstruction of 3-D volumes of anatomical structures and a tumor on the basis of the X-ray tomograph data;
- treatment planning including preparation of treatment prescriptions, calculation of dose field distributions for a chosen configuration, and a set of control programs for the accelerator;
- treatment simulation and verification. The accelerator control program is simulated on the simulator, which X-ray verification system compares projection images of a patient in the treatment position with projection images calculated by the planning system;
- treatment. The treatment basic method is built upon formation of a dose field with a multi-leaf collimator. The position of the collimator leaves for a particular field is preset from a file of data of the accelerator control computer. The portal vision system fixes parameters of a dose field in the process of treatment. Data for a passed treatment session are transferred through a local network to the information system of the radiotherapeutical system.

The results of performed medical tests have shown that the «ELLUS-6M» accelerator designed and manufactured in NIIEFA completely meets the requirements for modern therapeutic facilities with an X-ray energy of 6 MeV.

Progress in the field of radiotherapy is associated with a need for creation of domestically produced 3-D tomograph-simulators and treatment planning systems, high-energy (up to 25 MeV) radiation sources and mobile radiation sources for operational theatres. To solve these problems within reasonable periods of time and with lower costs, organization of joint manufacturing with the participation of foreign firms seems reasonable. The experience gained in NIIEFA proves that this measure will allow the compatibility of both hardware and software with the equipment available in clinics to be ensured and the matters of delivery of unique technologies and completing parts as well as servicing of the equipment to be solved.

In conclusion I wish to draw your attention that in accordance with the Federal targeted program «Development of Pharmaceutical and Medical Industry up to 2020 and Further», NIIEFA has performed works on the reconstruction and technical re-equipment of production rooms with a total area of about 3500 m^2 to organize serial production of medical cyclotrons and gamma-tomographs. Design documentation was worked out, production areas with engineering support for installation works and tests of equipment were prepared, and commissioning works of new machine tools and processing equipment, totally 60 in amount, were carried out. As a result, production facilities and processing equipment necessary for a planned annual production output of 10 CC cyclotrons with target devices and 20 «EFATOM» gamma-tomographs are provided.

However, until now the questions of procurement and introduction of domestic equipment for nuclear medicine, training of attending personnel, designing and construction of specialized areas to house radiation-dangerous equipment, its maintenance/repair and updating are still open. These problems can be solved by working out an inter-ministerial Program of Nuclear Medicine Development, including all the stages of creation, introduction and operation of equipment.

REFERENCES

[1] M.A. Arlychev et al., "EFATOM two-detector one-proton emission gamma tomograph". Technical Physics 54, pp. 1539-1537 (2009).
[2] O.G. Filatov, A.P. Strokach, M.F. Vorogushin, "Status and Progress of the Accelerating Equipment in NIIEFA», VANT, series: Electrophysical Apparatus, №.5 (31), pp.3-11 (2010).
[3] A.P. Strokach et al., "The CC-18/9M Cyclotron System", these proceedings, RuPAC'2014, October 6-10, Obninsk, Russia (2014).
[4] M.F. Vorogushin "NIIEFA Accelerators for Industry and Medicine" XXII Russian Rarticle Accel. St. Petersburg, Proceedings of RuPAC-2012, pp.167-172 (2012).
[5] S.V. Kanaev et al. "Problems of Transition to Modern Radiation Technologies in Russian Clinics", Medical Physics, №. 4 (48), pp. 17-27 (2010).

ISBN 978-3-95450-170-0