DEVELOPMENTS AT THE DEBRECEN MGC-20E TYPE LOW ENERGY MULTIPARTICLE CYCLOTRON FOR MEDICAL RADIOISOTOPE PRODUCTION

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This paper reports on the developments done during the twelve years of operation of the MGC-20E low energy multiparticle (p, d, $^3He^{2+}$, $^4He^{2+}$) cyclotron at ATOMKI (Debrecen, Hungary) in the field of radioisotope production for medical and biological applications. Two horizontal and one vertical beam lines are available for radioisotope production. Single photon emitters (^{67}Ga, ^{111}In, ^{123}I,) and PET isotopes (^{11}C, ^{13}N, ^{15}O, ^{18}F) have been produced using highly enriched targets and computer controlled target stations $^{22,24}Na$, ^{43}K and $^{81,82m,83,84}Rb$ have been produced and used for tracing biological processes in different plants. ^7Be, ^{48}Ti and ^{56}Co have also been produced for industrial applications.

1. Introduction

The MGC-20E (NIIEFA, Leningrad, USSR) variable energy compact cyclotron (K = 20) of the Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI, Debrecen, Hungary) was installed in 1985 [1]. Protons, deuterons, $^3He^{2+}$- and α-particles can be accelerated with currents up to 300 μA for internal beams and up to 50 μA for external beams. The elaboration of the cyclotron laboratory was partly supported by the International Atomic Energy Agency (Vienna, Austria).

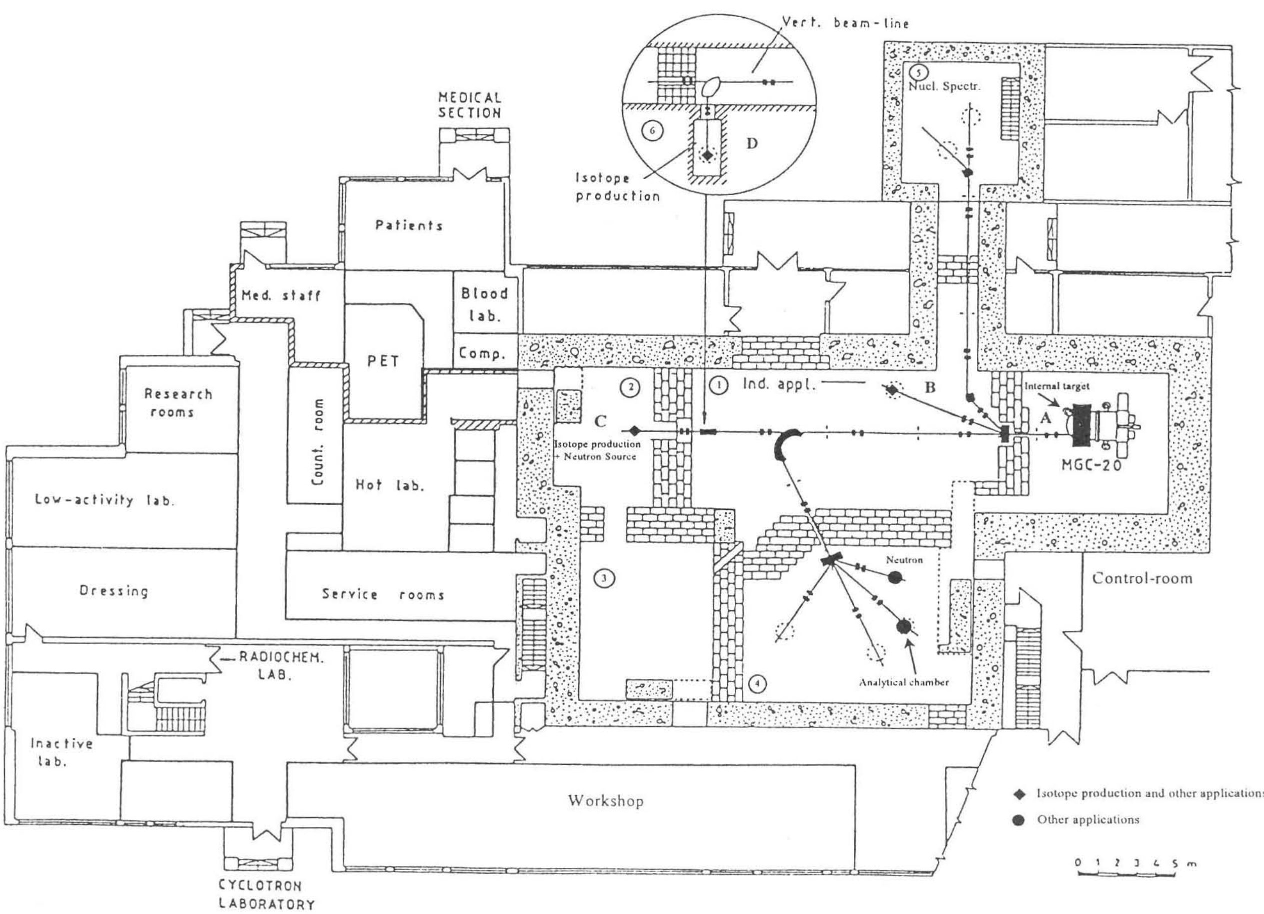

Figure 1 Layout of the cyclotron laboratory

The planned main fields of applications of the cyclotron were: basic nuclear research, development of activation techniques for analytical purposes and for wear studies, agro-biological and bio-medical applications of intense fast neutron sources and radioisotope production for applied research and medical diagnostics [2]. Numerous projects have been completed in these fields and several ones are in progress. Recently, radiation damage induced by fast neutrons in silicon- and SiO_2-based devices have emerged as a new topic of study.

The layout of the cyclotron laboratory is shown in Fig. 1. The main functional units are: the cyclotron vault, six target rooms, the radiochemistry laboratory, the medical area and rooms for service. The radiochemistry laboratory serves for processing the irradiated targets and separation of both single photon (^{67}Ga, ^{111}In, ^{123}I) and positron emitting isotopes (^{11}C, ^{13}N, ^{15}O, ^{18}F). In 1992 the gamma-camera of the medical unit was changed to a GE 4096 PLUS type eight ring Positron Emission Tomograph. Since then the dominant application of the cyclotron is the production of ^{11}C, ^{13}N, ^{15}O and ^{18}F radioisotopes.

2. Status of the cyclotron and the transport system

The parameters of the MGC-20E cyclotron are far from those of modern compact cyclotrons used for large-scale isotope production. Possibilities of extending the maximum particle energies and currents up to higher values are limited. The above mentioned radioisotopes, which are the most commonly used ones in routine medical diagnostic and therapy practice, can be produced only by using highly enriched and very expensive targets. Therefore, the loss of target materials must be kept as low as possible. The transported beam must be free from "hot spots" and its maximum diameter must be 10 mm on target.

During the 12 years of operation continuous efforts and developments were done to improve the performance of the cyclotron and the beam transport system. The old ion getter pumps were changed to diffusion pumps and new pneumatic gate valves have been installed. The vacuum system have been remote controlled by programmable logic controllers (PLCs). New beam scanners have been developed and installed to assure continuos control at high beam intensities. Beam steering magnets have been developed and installed at all beam lines used for radioisotope production. These magnets consist of stators of three phase electromotors without modification of the winding. A special power supply has been built for them. The amplitudes of the currents are regulated continuously. A frequency of 1 kHz is used to assure uniform steering of the beam macropulsed with 100Hz. Stainless steel vacuum tubes are used to minimise the field losses. Special beam current measuring units have been built which are capable of simultaneous, independent control of the beam current at four different places.

These improvements resulted in easier operation and beam transport and better quality beams on targets. The maintenance of the system became simpler. The rate of activation of the components of the cyclotron, the beam transport system and the irradiation facilities decreased, too.

3. Status of the radioisotope production facilities

Developments of the irradiation facilities, target systems and irradiation techniques were also necessary to improve the reliability and efficiency of the isotope production. Three facilities are used for isotope production with external beams (Stations B, C and D in Fig.1). A water cooled internal target (Station A in Fig. 1) supplied by the cyclotron manufacturer is also available. However, it has not been used for isotope production because it makes the beam handling difficult and its activation would be disadvantageous from the point of view of the maintenance schedule of the multipurpose operation mode of the cyclotron. An overview of the isotope production beam lines and stations are collected in Table 1.

To avoid cross contamination and to assure independent work, all isotope production facilities have independent and duplicated water and He-cooling systems with hermetic pumps and membrane compressors for cooling the bombarded surface and/or the back side of the target. The necessary parts are electrically insulated from the ground

Table 1. Characteristics of the available isotope production facilities.

Station	Location	Layout	Beam	Collimator	Beam diagnostics	Cooling	No. of targets	Control	Target transfer
A	cyclotron room	internal	sweeped	fix	slits	H_2O, He	1	manual	in container
B	target room No. 1	horizontal	steered	fix	slits, quartz, Faraday-cup	H_2O, He	1	manual	in container
C	target room No. 2	horizontal	steered	variable, 4 diff. diams	slits, profile monitor, Faraday-cup	H_2O, He	8	PLC	in container, via tube
D	target room No. 6	vertical	steered	variable, 3 diff. diams	slits, profile monitor, Faraday-cup	H_2O, He	4	PLC	container, via tube

rendering possible the beam current measurement.

The experimental beam line (Station B in Fig.1) is a simple modular system which have been developed at the 22.5° direction to the right after the switching magnet. It is used for irradiation of solid, liquid and gas targets for experimental purposes. A target holder frame is pressed pneumatically to the quick connection port at the end of the beam line. The frame serves for containing the modules available: a holder for the vacuum separating foil, collimator, electron-suppresser, a sectored collimator unit with a quartz screen for beam diagnostic and different target modules. The vacuum is provided by the diffusion pumps of the cyclotron. The beam can be steered. The whole system is controlled manually. The advantage of it is its versatility, the simple and quick preparation and handling. The main drawback of it is that the irradiated target can be changed manually or using long tong manipulators.

The vertical beam line for routine production (Station D in Fig. 1) [3] was established in the basement of the cyclotron for the routine production of the most important gamma emitters (SPECT isotopes). The beam line (Fig. 2) and the target changing system were installed in a special large volume hot cell which is built from concrete and steel. The cell is equipped with manipulators and has a large lead glass window and a passable shielded door.

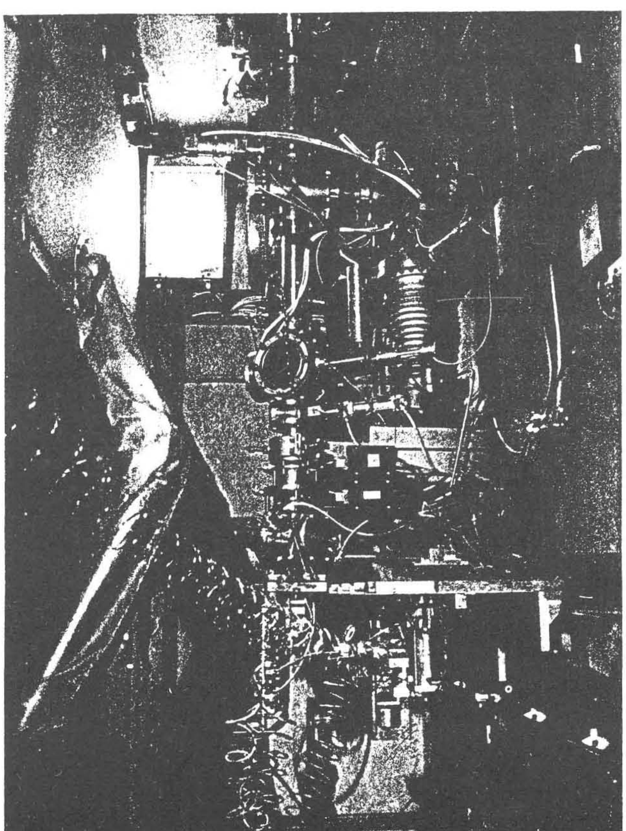

Figure 2 Layout of the vertical beam

The beam line is equipped with a quadruple magnet, a beam steerer magnet, a variable collimator, a beam profile monitor and a separate vacuum system. Target units are available for routine high current irradiation of solid, liquid and gas targets for producing not only single gamma photon emitting SPECT isotopes (^{67}Ga, ^{111}In, ^{123}I) but PET isotopes (^{11}C, ^{13}N, ^{15}O, ^{18}F), too. An automatic target exchanger has been built. Four different target units can be mounted simultaneously onto the movable support carriage, which is moved horizontally by a linear motion system connected to the wall. The linear motion system consists of a roller bearings, a hardened high-alloy guide rail and an actuator with ball screw. Pneumatic cylinders are used to move the selected target unit from the carriage to the beam line. Then a special pneumatic system lifts the target unit to the irradiation position and holds it there during the course of bombardment. This unit is equipped with a special multifunction connection unit. It automatically connects the target unit to the necessary vacuum, compressed air, He-cooling, water-cooling and to the beam current measurement circuits. The target units have two window foils with a He-gas flow in between them. Thus, the exchange of the damaged target unit with the spare unit can be performed easily and quickly in case of a foil eruption. This reduces the disruption of patient schedules, the unnecessary radiation exposure of the personal and the unscheduled maintenance. After irradiation the gas and liquid targets are pumped via tubes directly to the separation systems in the radiochemistry laboratory. The solid targets are dropped into a special automated container by a remote controlled system then the container is pulled to the radiochemistry laboratory. The whole system is controlled by a commercially available PLC + PC control system.

The horizontal beam line for routine production (Station C in Fig. 1), as a new isotope production facility, was installed in the target room next to the radiochemical laboratory to fulfil the raising demand for PET investigations. It has an independent vacuum system and equipped with a beam profile monitor, a multihole collimator system and a remote handling foil exchanger. The beam profile monitor is capable of working at low as well as at high beam intensities. The diagnostic units and collimators are installed close to the target face. The beam line is closed with a separating metal foil. The electro-pneumatically operated vertical ladder exchange system with its eight target unit holder greatly extends the target handling capacity for the radionuclide production. A robot arm provides the ability to transfer the active vacuum separating foil or the irradiated solid targets to a remote

Table 2. Summary of the isotopes produced for medical applications.

Radionuclide produced	Nuclear reaction	Target material	Energy range (MeV)	Activity/ batch(GBq)	Frequency/ week
^{11}C(20.38 min)	$^{14}N(p,\alpha)^{11}C$	$^{14}N_2$ +0.5 % O_2	14.5 - 5	12	4
^{15}O(2.03 min)	$^{14}N(d,n)^{15}O$	$^{14}N_2$+0.5 % O_2	10 - 2	10	20
^{18}F(109.7 min)	$^{18}O(p,n)^{18}F$	H_2O(^{18}O-97 %)	14.5 - 3	25	4
^{67}Ga(78.3 h)	$^{67}Zn(p,n)^{67}Ga$	Zn(^{67}Zn-99 %)	14.5 - 8	10	1
^{111}In(2.81d)	$^{111}Cd(p,n)^{111}In$	Cd(^{111}Cd-99 %)	14.5 - 8	20	1
^{123}I(13.2 h)	$^{123}Te(p,n)^{123}I$	TeO_2(^{123}Te-95 %)	14.5 - 8	6	1

Table 3. Summary of the isotopes produced for applications other than medical ones.

Radionuclide produced	Nuclear reaction	Target material	Energy range (MeV)	Applications
^{24}Na	$^{27}Al(n,\alpha)^{24}Na$	Al-powder Al_2O_3 powder	d(10 MeV)+Be → n	water transport in trees
^{43}K	$^{40}Ar(\alpha,p)^{43}K$	Ar-gas, circulated	20 - 10	water transport in trees
^{83}Rb	$^{83}Kr(p,n)^{83}Rb$	Kr-gas, circulated	14.5 - 8	water transport in plants liquid leakage test
^{48}Ti	$^{48}Ti(p,n)^{48}V$	Ti-foil	14.5 - 5	liquid leakage test underground tube positioning
^{56}Co	$^{56}Fe(p,n)^{56}Co$	Fe-foil	14.5 - 5	liquid leakage test
^{7}Be	$^{7}Li(p,n)^{7}Be$	Li-foil	14.5 - 5	Source for radioactive beam
^{209}At	$^{209}Bi(^{3}He,3n)^{209}At$	Bi, vacuum evaporated	26 - 20	study of At chemistry

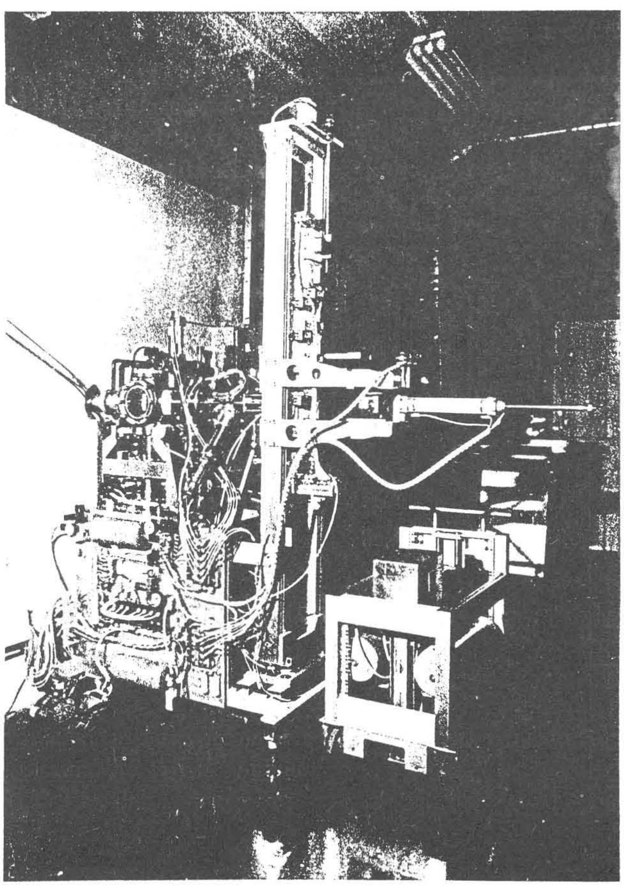

Figure 3. The horizontal beam line with the target station.

controlled lead container used for transport to the hot cells. Additionally, it reduces the radiation dose to the staff. The control system of the beam line and of the target station is based on PLCs and it is monitored by a PC from the isotope production control room. The beam diagnostic parameters are duplicated in the cyclotron control room.

4. The isotopes produced

During the twelve years of operations a broad range of radioisotopes have been produced. An overview of the isotopes routinely used for clinical diagnostic investigations is presented in Table 2. The isotopes produced for industrial and research purposes are listed in Table 3. We have developed the necessary target units, the irradiation and separation techniques. Detailed investigations are in progress to study the physical processes in gas and liquid targets. Numerous excitation functions of the relevant nuclear reactions and new evaluations have been studied and published by us. Some non-medical applications carried out in collaborations are also listed in Table 3.

References

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