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SMALL CYCLOTRON FOR MEDICAL USE : CYPRIS 325

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1. Introduction

The conceptual design of the CYPRIS unit was performed in cooperation between CGR MeV and SHI, based on the experiences of each company in the field of cyclotron. The first CYPRIS unit was manufactured by SHI at SHI EHIME factory in JAPAN and the beam was obtained on the target in January 1981. The second machine is under construction for Fisiologia Clinic, PISA in ITALY, by CGR MeV. The characteristics of CYPRIS are presented in this paper.

2. Aims

The importance of short-lived positron emitting radioisotopes like ^{11}C, ^{13}N, ^{15}O and ^{18}F have been increased in emission computerized tomography, as positron camerae have been developed. CYPRIS is designed for the production of these radioisotopes. The design is based on the following criteria :

- reliability and simplicity of operation,
- economical operation,
- compactness,
- high yield target under routine use,
- possibility of radiation shielding in housing of existing buildings.

Especially a lot of efforts are made to realize the first item because we think that it is the most important item for chemical and medical people. The kinds of precursors available by CYPRIS are shown by table 1.

Table 1

List of precursors available in CYPRIS

Nuclide	Precursors	Reaction
^{11}C	$^{11}CO, ^{11}CO_2, H^{11}CN$	$^{14}N(p,\alpha)^{11}C$
^{13}N	$^{13}N_2, ^{13}NH_3$	$^{12}C(d,n)^{13}N$ $^{16}O(p,\alpha)^{13}N$
^{15}O	$C^{15}O, C^{15}O_2, ^{15}O_2, H_2{}^{15}O$	$^{14}N(d,n)^{15}O$
^{18}F	$^{18}F_2, H^{18}F$	$^{20}Ne(d,\alpha)^{18}F$

3. Characteristics

Accelerated particles and their energies are the startpoint specifications in designing the cyclotron, and should be decided not only from a viewpoint of the radioisotope production, but also with a consideration of the design criteria of the cyclotron. We have taken proton and deuteron as the accelerated particles because these two particles are just enough for the production of ^{11}C, ^{13}N, ^{15}O and ^{18}F. The energy of deuteron is fixed at 8 MeV to insure the yield of ^{18}F. The energy of proton was determined at 16 MeV. This proton energy is a bit higher for the radioisotope production because 16 MeV proton can generate the contamination of ^{13}N in the production of ^{11}C with the nuclear reaction of $^{14}N(p,\alpha)^{11}C$. The Q value of the nuclear reaction $^{14}N(p,pn)^{13}N$ is 11.3 MeV. But the proton energy can be reduced by using a thick target foil (Ti 400 µm). The specifications and the layout of CYPRIS are shown in table 2 and figure 1 respectively.

Table 2

Specifications of CYPRIS

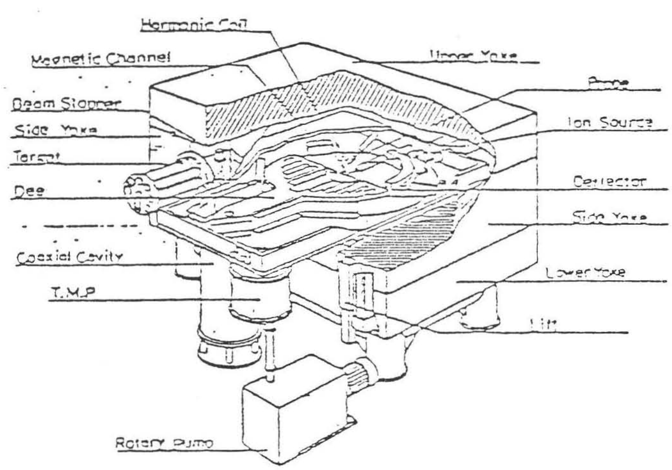
	Energy	Beam current
proton deuteron	16 MeV 8 MeV	50 µA 50 µA

Magnet	
pole diameter extraction radius	810 mm 325 mm
maximum magnetic field	17.5 kG
weight of magnet	14 tons
number of harmonic coils	4 pairs
main coil current	1 000 A

	Proton	Deuteron
RF		
harmonic mode	1	3
frequency	26 MHz	40 MHz
dee voltage	40 kV	25 kV
RF power	25 kW	
dee angle	180 °	
Injection and extraction		
puller	fixed position	
ion source	id	
deflector	id	
magnetic channels	passive	
Ion source		
type	hot cathode	
insertion	radial	
power	500 W	

Figure 1

Layout of CYPRIS



Some characteristics of CYPRIS in conformity with the design criteria 1-5 are summarized as follows :

1) Harmonic modes of acceleration are taken as 1 for proton and 3 for deuteron to make the RF system compact.

2) The number of mechanical components is made as small as possible to realize an easy operation and to increase the reliability. For instance, a single 180° dee is adopted to simplify the RF system, and the frequency drift of the RF cavity is compensated electrically by the frequency change of the master oscillator instead of the mechanical compensator

3) A rotating target system is adopted so that a specific target can be selected remotely to avoid the contamination in the radioisotope production, and the target is located at the outside of the cyclotron for easy maintenance.

4) Radiation shielding blocks can be piled up around the cyclotron if necessary. That is why no equipment is located on the two sides of the magnet yoke.

Control and operation

Some special considerations are incorporated in the control of the cyclotron to ensure easy operation. All the power supplies can be turned on in an automated sequence by pushing one button. In the RF system, the frequency of the master oscillator is sweeped automatically to establish the dee voltage. After that, the frequency is automatically tuned by making a feed-back loop to the master oscillator. The operation of the ion source is also automated. A pair of auxiliary coils is assembled on the magnet pole besides the main coil. The current of the auxiliary coil is automatically sweeped to search the beam and after the beam is found on the beam shutter, it can be always held at the peak value by changing the current of the auxiliary coil a little bit.

These conditions make it possible to facilitate the cyclotron operation by pushing only five buttons :

- cyclotron on
- select particle (proton or deuteron)
- select the target (8 targets)
- source on
- irradiation on

and setting one potentiometer that seselects the value of the beam current.

The operation status of all the devices are displayed on a CRT equipped with a micro-processor. When there are some faults on the cyclotron, they are indicated on the CRT and the instruction message is available on the CRT. About thirty minutes are required at most to get a sufficient vacuum for beam acceleration, and additional ten minutes are enough to get the beam on the target.

5) Results of beam test. We succeeded in getting the beam on the target this January 1981.

Full beam	50 μA	
at	8 MeV	deuteron
and	16 MeV	proton

The beam spot on the target is

vertically	20 mm
horizontally	30 mm

In the enclosure is described the range of AVF cyclotrons sold by CGR MeV and SHI.

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AVF CYCLOTRONS OF SHI AND CGR MEV

Model	Particle	Energy (MeV)	External current (μA)
520	p^- d^- ^3He α	3-24 3-15 7-31 10-30	100 100 50 50
560	p d ^3He α	5-40 10-20 15-52 20-40	100 100 50 50
560p	p	42	50
680	p d ^3He α	6-45 12-30 12-70 12-60	100 100 50 50
680p	p	50	50
930	p d ^3He α	10-80 10-50 20-130 20-100	40 40 30 30