INSTALLATION OF A COMPACT, VARIABLE-ENERGY CYCLOTRON IN A HOSPITAL AND PRELIMINARY RESULTS OBTAINED

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Abstract

The setting up of a compact, variable-energy cyclotron within a preexisting hospital structure and the way by which have been resolved the setted technical restraints are described. Some preliminary results obtained are also given.

1. Introduction

Justification for the installation of a cyclotron in a hospital has already been the subject of a number of general reviews (1,2,3) in the last years. The arguments generally used are as follows :

- Possibility of manufacturing radioelements with very short half-lives requiring the presence of a producing unit on the site of use ;
- Interest in developing analysis by "in vivo" neutron radioactivation which also assumes the presence of irradiation facilities in a hospital ;
- Development of charged particle activation analysis applied in a biological sample ;
- Possibility of practicing neutrontherapy using neutrons produced by secondary reactions of charged particles on light nuclei. The type of machine and, above all, its maximum energy needed to achieve the latter are still matters for controversy.

The first three of these arguments were taken into consideration in choosing the cyclotron and its installation at the Service Hospitalier Frédéric Joliot.

The technical imperatives guiding installation were :

- the need to install the cyclotron as close as possible to the diagnosis rooms and yet keep background noise as low as possible ;
- the need to dispose of a beam transport system and automatic target holders allowing the staff to change the product to be irradiated quickly and without having to enter the vault ;
- the need to cool samples subject to high temperatures during irradiation ;
- the need to outfit radiochemistry laboratories to handle high radioactivity (several Ci of γ emitter) under conditions of correct security for the manipulator but with the possibility of flexible use.

2. Characteristics of the cyclotron

The unit installed at the SHFJ is a compact, variable-energy (CGR-MeV) isochron cyclotron, accelerating protons from 3 to 21 MeV, deuterons from 3 to 13 MeV, helium-3 from 5 to 31 MeV and helium-4 from 6 to 26 MeV. The extracted beam can reach 70 µA on protons and deuterons and 50 µA on helium-3 and helium-4.

The poles of the magnet have a diameter of 1.20 meters (3.96 ft.) ; it weighs 28 tons ; the space between valleys is 0.14 meters and that between hills is 0.025 meters. The magnet consists of 4 pairs of spiral-shaped sectors ; between the main coils, the field gradient is adjusted by means of 7 pairs of circular coils ; extraction is controlled by 4 harmonic coils.

The ions are accelerated by means of 2 "dees" with an opening of 50°. The time value plotted on the control panel is obtained by 2 cylindrical piston tuning cavities. The frequency range extends from 20 to 40 MHz. The vacuum is created by a 30 m^3/hour primary pump and a 3000 l/second oil diffusion pump. The ion source, which is of the Livingston-Jones type, is controlled from the control desk.

Extraction is obtained from an electrostatic deflector as well as a passive corrector. Two quadrupoles determine the geometry of the beam desired. This beam can be directed in 3 different directions using a deflector magnet. The geometry of the beam is controlled at the end of the path by moveable quartz seen on a TV set in the control room.

3. Description of the installation

The cyclotron was installed in existing premises. The old walls were retained but lined with high-density concrete. The cyclotron and the ground-floor laboratories are separated by a corridor (fig.1). On one side of this corridor are an irradiation room (21 m^2) where neutrons used in "in vivo" analysis are found, the cyclotron room (33 m^2) and the high power supply room (18 m^2) communicating with the cyclotron room by a lock chamber. The irradiation and cyclotron rooms are surrounded by concrete walls the exterior side of which is (d = 2.3) 1.50 meters thick and the corridor side of which are 1.20 meters thick including 0.8 meters of high-density concrete (d = 3.5).

The roof of these two rooms, made of ordinary concrete 20 cm thick containing a 70 cm pool of water which makes the roof lighter in weight but provides sufficient protection.

On the other side of the corridor are located the high-activity and radiochemis-

Proc. 7th Int. Conf. on Cyclotrons and their Applications (Birkhäuser, Basel, 1975), p. 440-443

try laboratories equipped with impermeable hot-cells and fume chambers. The block just described constitues the "hot zone". Just after this zone is the "cold zone" consisting of the cyclotron control room (25 m^2), laboratories, counting and diagnosis rooms as well as an electronic laboratory. The diagnosis rooms are located on the same floor as the cyclotron and are 35 meters from it. Above the ground floor (i.e. above the cold zone) is an 18-bed hospitalization unit.

The basement houses a mechanical workshop, an area for animals and annex laboratories. The building covers a ground area of 880 m^2 and a total working area of 1,850 m^2 on three floors. Fig.1 represents the hot zone consisting of the cyclotron, its annex areas and the chemistry laboratory.

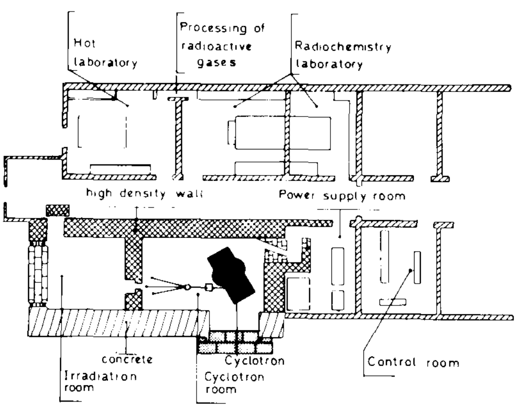

Fig.1 - Laboratories and cyclotron facilities.

4. Beam transport system and targets

No internal irradiation device was planned for the cyclotron. However, a transport system for extracted beams carries the particles off in 3 directions ; 2 at an angle of 15° in relation to the axis of the beam lead to 2 types of targets located in the chamber. The 3rd direction in the axis of the extracted beam is sent to the irradiation room where a thick Beryllium target 3 cm in diameter is installed.

The lenses of the beam transport system were designed to obtain, in place of irradiation, homogeneous spots varying from a few mm^2 to 25 cm^2. This was done so that the power of the dissipated beam would be as low as possible per unit of area. Moreover, since the targets used in producing radioelements are inside the cyclotron chamber, their installation presents special constraints imposed by the level of radiation at that point and the rapidity with which they must be recuperated. Irradiation is carried out at atmospheric pressure and transport tubes are closed by a 25 μ titanium foil annularly cooled by water. The target holder and this titanium foil surround a cavity in which arrives air under pressure flowing at 30 m^3/hour used to cool both the target and the titanium foil. This effective device has, however, the disadvantage of creating radioactivity from elements in the air difficult to eliminate as well as creating ozone which will slowly damage the plastic pipes constituting the circuit evacuating cooling gas. A helium cooling device has been studied and will replace the device just described. Its characteristics are as follows : outlet flow : 100 m^3/hour ; helium volume of the closed circuit : 20 liters ; gas-water exchanger. This type of device can evacuate approximately 1 kw of heat. Two of the three irradiation beams are planned for solid and liquid targets, on the one hand and for gas targets, on the other and will be equipped respectively with a pneumatic tube and an automatic device for the changing of targets. The pneumatic tube is a rectangular tube made of stainless steel connecting the end of one of the beams with a hot cell in the high activity laboratory. The rectangular tube allows easy positioning of targets in their irradiation position. The transported targets and targets holder weigh approximately 600 grams. The transit time is 7 seconds. Transport is carried out using compressed air. So that the target holder will not reach its irradiation position too abruptly, the direction of the compressed air is inverted just as the target reaches the desired position; this creates an air pocket. When the target has reached its irradiation position, a jack pushes it against the head of the beam channel. These handling operations are all controlled from the cyclotron control room. At the end of the other beam channel where the gas targets are irradiated is found a rig supporting 4 target holders which allow the successive production of 4 types of radioelements with no need for anyone to enter the chamber and manually change the target holders. Each target is fed with target gas from the chemistry laboratory by stainless steel pipes. A pipe extending from each target carries off the irradiated gas to the utilisation laboratory. These target holders can move on the rig and be placed in an irradiation position by means of a motor operated from the control room. Once the target has reached its irradiation position, the rig is pushed against the head of the beam channel.

5. Radioprotection

The installation of the cyclotron in the center of the hospital on the same floor as the laboratories and diagnosis rooms required the installation of a radioprotective device adapted to this situation. The cyclotron control room gives onto the corridor leading to the cyclotron itself and contains a radioprotection control panel showing the state of safety and the irradiation rate of some premises. Authorization to start up the cyclotron can only be given once all the zones into which the beam can penetrate are rendered inaccessible by closing corresponding doors. A door is considered closed once the corresponding key has been locked onto the radioprotective control panel. Because of its design, the door must be closed in order to remove the key. The accelerator can only start up if : 1) the cyclotron operator has completed the necessary rounds in the machine and experimental rooms ; 2) the corresponding button for each round has been pushed in ; 3) the door has been closed and its key removed ; 4) this key has been locked into place on the radioprotective control panel ; 5) the key of the radioprotective control panel has been placed in its lock and turned.

In addition, the door leading to the protection-pool above the cyclotron room must be bolted and the emergency stop-button turned off. It is consequently impossible to enter the cyclotron chamber or the irradiation room when the accelerator is operating. However, authorization to enter the cyclotron room while HF and magnetic field are operating can be obtained as long as certain safety features are observed : presence of the probe in the center of the cyclotron, ion source and deflector on stop, presence of a γ detector and waiver key locked on the radioprotective control panel. There are also waivers for access to the irradiation room while the accelerator is operating. In addition, ionization chambers in the cyclotron and irradiation rooms provide the γ irradiation rate at every moment either by a color, variable-impulse luminous signal or by a recording on paper expressed in Rad/hours. The irradiation dose has been measured in different places of the controlled zone under exceptional operating conditions for the cyclotron (deuterons of 13 MeV, internal beam 140 μA, extracted beam 70 μA). The results are shown in Table 1. Except for a limited zone in the corridor near the cyclotron, the neutron and γ doses are much less than the maximum dose allowed. Outside the controlled zone and especially the diagnosis room, the background noise is not increased by the operation of the cyclotron.

6. Preliminary results obtained with the SHFJ cyclotron

Among the three objectives of the service's research program, production of radioelements,"in vivo" neutron activation analysis and "in vitro" charged particle radioactivation analysis, only the first has been started. It has been agreed that a variable-energy cyclotron is indispensable mainly to attain the other two objectives.

Location of measurement	γ dose mR/h	Neutron dose mR/h
Supply room (*)		
- in front of chamber door	55	60
- elsewhere	2	2
Corridor-in front of :		
- supply room	1.6	1
- cyclotron	3	1
- chemistry lab.	0.5	0.8
Pool-cyclotron level (*)	45	0.2
Non-controlled corridor		
Zone	< 0.1	< 0.1
Outside of building	< 0.1	< 0.1

(* zone normally inaccessible)

Table 1 - Summary of irradiation dose in the controlled zone caused by the cyclotron in operation (13 MeV deuterons - internal current 140 μA - external current on a copper target 70 μA).

Indeed, in the field of "in vivo" radioactivation analysis (4) an accurate knowledge of the dose absorbed by the tissues assumes the analysis of neutron spectra which can only be correctly known if the energy definition of the particles producing the neutrons is also perfectly well defined. However, the neutron spectra desired must be different according to the type of tissue irradiation (deep, superficial, localized on "in toto"). This assumes a variable energy for the primary charged particles. There is no question here of using metallic absorbants which, in addition to energy degradation, causes an energy distribution of the residual beam which will be wider as the thickness of the screen increases. This remark also applies to "in vitro" activation analysis for which some of the interferences can only be effectively eliminated if the energy of the particles is also dispersed as little as possible.

In terms of preparing radioelements, Table 2 lists some of those routinely produced in our laboratory as well as their production yield.

Radio-nuclide	Half-life	Target	Nuclear Reaction	Yield
^{11}C	20 min	N_2	p,α	2000 μCi/μA/min
^{13}N	10 min	CO_2	d,n	230 "
^{18}F	110 min	Ne	d,α	200 "
^{197m}Hg	24 h	Au	p,n	230 μCi/μA/h
^{199}Tl	7,4 h	Hg	p,n	220 "

PROTONS ENERGY = 20 MeV, DEUTONS ENERGY = 10 MeV

Table 2 - Yield production of routinely produced radioisotopes with the SHFJ cyclotron.

Even though thallium (6,7) is used to explore the medullary zone of the kidney, the results using mercury 197m are compared with mercury 197, a nuclear reactor product, as an agent used to diagnose lung tumors.

Among short-lived isotopes, nitrogen 13 (8,9) is used in studying lung ventilation and perfusion ; carbon-11 is incorporated in the form of formaldehyde or methyl iodide in organic molecules with an affinity for brain tissue (10).

7. Conclusion

The energy and current characteristics of the variable-energy cyclotron installed at the SHFJ is well adapted to the service's medical research program. Due to high maximum energy of the 4 particles accelerated by small cyclotron, a large number of radioelements can be produced with good yield. Due to the wide range of variable energy, research on "in vivo" and "in vitro" radioactivation analysis can also be undertaken. In addition, the installation of the cyclotron in the center of a medical diagnosis service allows the rational and easy use of very short-lived radioelements, the importance of which has been shown for a long time.

REFERENCES

(1) Gallop J.W., Vonberg D.D., Post R.J., Powell W.G., Sharp J. and Waterton P.J. A cyclotron for medical research. Proc. Inst. Elect. Enginners. 104,452-466 (N°17 pt B) 1957.

(2) Ter-Pogossian M.M. and Wagner H.N.Jr. A new look at the cyclotron for making short-lived isotopes. Nucleonics. 24, 50-56,62, October 1966.

(3) Laughlin J.S., Mamacos J.P. and Tilbury R.S. Isochronous cyclotron installation for radionuclide production. Radiology. 93,331-337, 1969.

(4) In vivo neutron activation analysis. Proc. of a panel Vienna. 17-21 April 1972. IAEA. Vienna 1973.

(5) Maccabee H.D. Energy and L.E.T. spectra of cyclotron beams production and measurement. In "Use of cyclotrons in chemistry, metallurgy and biology" edited by C.B. Amplett. 1970. p 183. Butterworthes.

(6) Comar D. and Crouzel C. Preparation of carrier free radioactive thallium for medical use (in preparation)

(7) Raynaud C., Comar D., Buisson M. and Kellershohn C. Radioactive thallium. A new agent for scans of the renal medulla ? Radionuclides in nephrology. Proc. of an Inter. Symp. M.D. Blanfox and J.L. Funck Brentano editors. 1972 by Grune and Stratton Inc.

(8) Crouzel C. and Comar D. Production of N 13 solution for injection by means of a medical compact cyclotron. Radiochem. Radioanal. Letters 20,4-5, 278. 1975.

(9) Rivière R., Crouzel C., Crouzel M. and Comar D. Explorations dynamiques pulmonaires réalisées à l'aide d'azote 13. C.R. 17e Colloque de Médecine Nucléaire de langue française. Paris 1975 (Raynaud C. and Kellershohn C. Ed.) CEA Gif/Yvette.

(10) Mazière M., Marazano C. and Comar D. Marquage de médicaments au carbone-11. Intérêt en Médecine Nucléaire. C.R. 16e Colloque de Médecine Nucléaire de langue française. Tome 1 p. 58. (Meyniel G., Gaillard G., Isabelle D. Ed.) Bloc-Santé - Clermont Ferrand, 1975.