INITIAL OPERATION OF THE SHERBROOKE EBCO 19 MEV CYCLOTRON.

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Abstract

A variable energy TR19 cyclotron built by EBCO Technologies was installed and commissioned at the Centre Hospitalier Université de Sherbrooke at the end of 1997. This negative ion cyclotron is capable of accelerating a 150 μAmp of protons to over 19 MeV energy and two simultaneous beams of protons of energies between 13 and 19 MeV can be extracted on opposite sides of the magnet. A novel target changer permits the positioning of the variable energy beams, which leave the magnet at different angles, into long gaseous targets. Properties of the beams used for the production of both PET and SPECT isotopes, made possible by the variable energy feature, are discussed.

1 Introduction

The TR series of cyclotrons designed by the accelerator design group at TRIUMF and manufactured by EBCO Technologies are all four sector, strong focusing negative ion accelerators, capable of accelerating beams of protons and deuterons. All of the accelerators are cryogenically pumped with external multi-cusp ion sources. They are all equipped with radially movable extractor foils to extract the accelerated ions by stripping the electrons at various radii in the cyclotron. They are all capable of delivering beams of variable energy (any energy between the maximum permitted by the magnet down to 1/2 of the maximum value.) The general features of the design have been discussed in several papers [1,2,3].

The commercial versions of the cyclotrons manufactured by EBCO Technologies are based on two magnets. The largest magnet which weighs 40 tons is capable of accelerating protons to an energy of 32.2 MeV. The smaller magnet which weighs 22 tons is capable of accelerating protons to 19.2 MeV. Both magnets use poles with 45° hills and valleys, the maximum hill field being 2T and the valley field being 0.5T.

The magnets are shimmed to permit acceleration of negative hydrogen ions without the use of trim coils. To accelerate deuterons, coils are added to the hills and valleys to reduce the average magnetic field at the outer radii to maintain isochronism.

The cyclotron installed at the medical center at Sherbrooke accelerates only negative hydrogen ions and is capable of delivering two simultaneous external beams of protons between 13 and 19 MeV with beam currents to a maximum value of 150 μAmps.

2 The General Facility

A cyclotron located in a hospital being used for the production of isotopes for both research and clinical purposes must have the ability to irradiate various targets for the production of a large variety of different isotopes. It must also be well shielded to conform to the ever more stringent requirements for radiation safety. Finally it must be easy to operate and easy to tune at the various energies required to optimize its use.

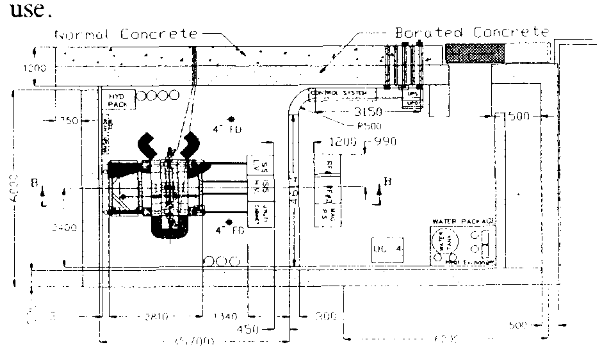

Fig.1 General Layout Plan View

The general installation is shown in Figures 1 and 2 which show the equipment installed in the vault. The concrete walls of the vault contain 15 mg/cm ^{3}of boron carbide to absorb the neutrons, and boron loaded epoxy paint was used on the floor.

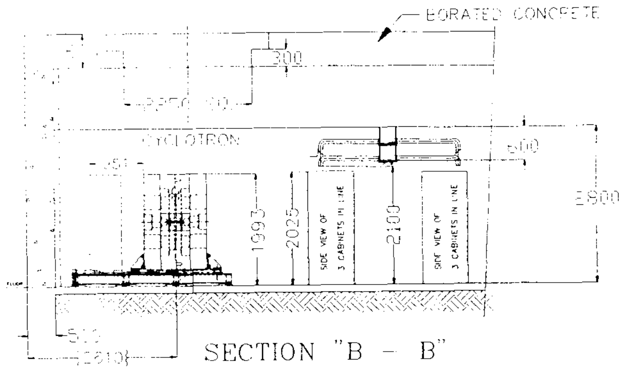

Fig.2 General Layout Sectional View

Local shielding is used around the targets as seen in Figure 1. The attenuation factor of 100 provided by this 30 cm thick shield, which weighs 4 tonnes per side, prevents the activation of the vault and the equipment installed near to the cyclotron. No measurable activity has been detected anywhere in the vault after the machine has been operated for 10 hours continuously with a beam of 100 μAmps on target. No radiation was measured in the hot chemistry lab which is on the outside of the 1.2m thick composite wall at the top of Figure 1.

3 Ion Source and Injection System (ISIS)

The general arrangement of the ISIS is shown in Figure 3. The multi-cusp source is operating at less than 10% of its capability in this configuration [4,5].

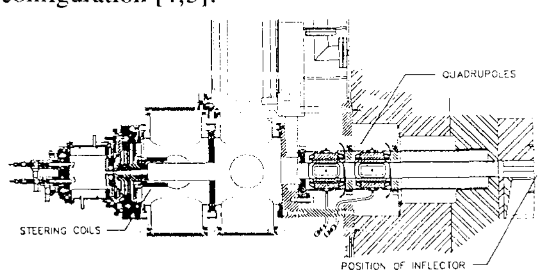

Fig.3 Ion Source and Injection System

A Faraday cup with a 10 mm diameter hole that can be pneumatically inserted and removed remotely by the control system is positioned just in front of the quadrupole magnets in the Figure. This cup is used to interrupt the beam coming from the source and to set the output characteristics of the source. In its normal automatic operating mode the computer turns on the cyclotron and sets up the ion source to deliver a current of 600 μAmps DC into this cup.

Before the beam is injected into the cyclotron the quadrupole magnets are detuned from their nominal values to limit the current that can be accelerated. The beam is defocused at the entrance collimator in front of the inflector and about 7% of the maximum possible beam is accelerated. The behaviour and operating characteristics of the inflector are described in other papers at this conference [6,7]. Approximately 10% of the beam delivered to the Faraday cup can be accelerated if the transmission through the quadrupoles is maximized. As an aid to the operator the control screen is a graphic representation of the system and access to any active element is obtained by the use of a mouse pointer. The control system permits one button tuning and detuning of the quadrupoles by accessing the corresponding elements on the panel.

4 Extraction System

The beams are extracted by the insertion of a thin graphite stripper foil (mass 200 micrograms/cm^2) to the radius appropriate for the energy desired. The energy is displayed on the console and changes as the probe is moved. A general diagram of the arrangement of the strippers and target bodies is shown in Figure 4.

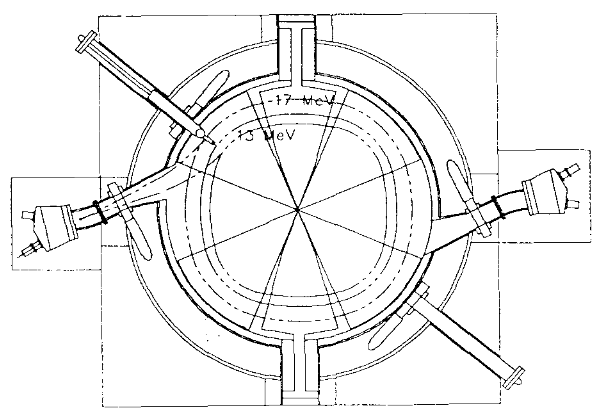

Fig.4 General Plan of Beam Extraction

As can be seen from the diagram the stripper moves along a hill of the magnet at an angle to a radial line. The angle is chosen to produce an intersection of the extracted beams of varying energy at a point outside of the yoke of the magnet. If the pivot point of the target changing mechanism is positioned at the cross over point, beams of various energies will pass into the selected targets along their axes.

The target changer is shown in Figure 5. It consists of a target mounting plate fastened to a gimbal ring connected to a valve on an extraction port by means of a stainless steel bellows.

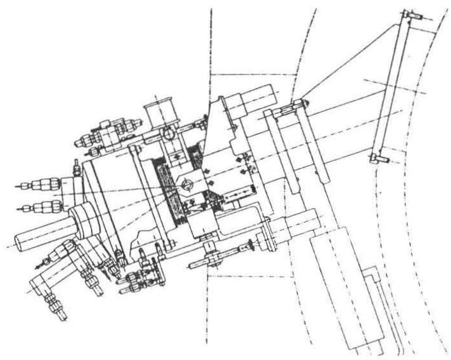

Fig.5 Target Changing Mechanism

Two computer controlled motors on the two axes of the gimbal rings can be used to rotate the assembly through an angle of 30 °to allow all of the extracted beams from 13 MeV to 19 MeV to be used. If a target needs to be serviced the system can be valved off from the cyclotron vacuum tank.

5 System Performance

The cyclotron was tested by placing a quartz plate at the position of the cross over point of the extracted beams and varying the energy of the extracted beam by moving the extraction probe radially. The azimuthal position of the extraction probe was adjusted until the cross over point was positioned in the middle of the quartz plate. The motion of the cross over point was less than 3 mm over the entire energy range.

The quartz plate was replaced with one made of aluminum with a 6 mm diameter water cooled channel behind the center of the plate. A focussed beam of 100 μAmps was extracted for a period of 10 hours as a durability test. Although the Aluminum plate was cooled the power density was sufficient to melt a small hole in the surface of the plate.The melted spot was approximately 3 mm in diameter corresponding well to the measured shape of the extracted beam at low current.

The centering of the beam was measured by extracting two simultaneous beams of 50 μAmps on two aluminum beam stops positioned in the two opposing beam lines for 10 hours. As before, the beam melted the surface of the aluminum. A photograph of the melted spot on the surface of the aluminum is shown in Figure 6.

The water cooling channel was approximately 10 mm away from the impact point of the beam The size of the melted spot was a little less than 3 mm. The Aluminum beam stops were subsequently replaced with Ag plates 3 mm thick directly cooled on the backs of the plates. There was no visible damage to these stops at the maximum current extracted.

Fig.6 Melted Spot in the Surface of the Water Cooled Aluminum Beam Stop with a 50 μA Beam at 15 MeV.

The position of one extractor was set to 15 MeV. The extraction radius at this energy was 477 mm. The total current was set to approximately 11 μAmps and the extractor on the other side of the cyclotron was moved to measure the energy spread of the beam in the cyclotron by measuring the currents as a function of the motion on the two extraction probes. The results of the measurement are given in Table 1.

Motion(mm)	Probe1(μA)	Probe2(μA)
0	1.8	9.6
1	2.3	8.0
2	4.1	7.1
3	5.0	6.2
4	5.9	5.3
5	6.7	4.4
6	8.0	3.3
7	8.8	2.4
8	9.7	1.6
9	10.4	1.0

Table 1. Measurement of beam energy spread

Since the energy gain per turn in the cyclotron is 200 keV the radial gain per turn of a particle at 15 MeV is 3 mm. The half width of the beam in the cyclotron at 15 MeV is 5.5mm.

The magnet tune was measured with the two probes set to the same energy with equal currents being extracted. At 15 MeV the beam current remained constant as the current in the magnetic field was varied over a range of 0.5 Amps at a current of 467 Amps. 10% of the beam was still extracted when the current in the magnet was changed over a range of 1.0

Amp corresponding to a 0.2% change in the magnetic field. The beam split ratio remained constant over most of the variation in the field indicating that the beam was reasonably well centered. The quality of the extracted beam was excellent as demonstrated by its size at a current of 100 μAmps.

REFERENCES

[1] B.F. Milton et al. "A 30 MeV H^- Cyclotron for Radioisotope Production", *Proc. 12th Int'l. Conference on Cyclotrons and their Applications*, p 145, Berlin, 1989.
[2] K. Erdman et al. "Operation of the TR30 Industrial Cyclotron", *Proc. IEEE Part. Acc. Conf., Vol. 3*, p 1733, Washington, 1993.
[3] R.E. Laxdal et al. "Beam Measurements on a Small Commercial Cyclotron", *Proc. 4th European Part. Acc. Conf., Vol. 1*, p 545, London, 1994.
[4] Jayamanna et al. "The TRIUMF Compact DC H^-/D^- Ion Source", *Proc. 2nd EPAC,* p 647, Nice, 1990.
[5] Kuo et al. "On the Development of a 15 mA DC H^- Multicusp Source", *Rev. Sci. Inst.* 67(1996), p 1314.
[6] M.P. Dehnel et al. "Measurements of Beam Emittance, Accelerated RF Phase Band, and Centring in a 1MeV Test Cyclotron", *Proceedings of this Conference.*
[7] M.P. Dehnel et al. "Measurements of Injected Beam Deflections at the Exit of a Cyclotron Inflector as a Function of Applied Field or Beam Energy Perturbations",*Proceedings of this Conference.*