A New Design for an EMIS - CYCLOTRON System, for Direct Production of Gaseous PET Radioisotopes

Henrik AYVAZIAN
Ion Beam Applications Laboratory
Nuclear Research Center for Agriculture and Medicine
P.O.Box 4395, Karaj 31585, Iran

Abstract

A new scheme for direct production of $^{11}C(T_{1/2}$=20min) and $^{15}O(T_{1/2}$=2min) for medical purposes is studied as a future plan in IBAL. A broad sheet beam of separated stable isotopes (120x10mm) is converted into an almost cylindrical synchronous bunched beam of high intensity (100mA) and is accelerated in a low energy single cavity RF accelerating unit, in order to lengthen the Mean Free Path (MFP) of the separated ions. The resulting beam is directed into a special Target Ion Source (TIS) and is exposed to a cyclotron beam of protons (deuterons) with relatively high intensity (500μA). The bunching unit is in-tune with that of the cyclotron injection device, in order to achieve effective results of radioisotope production. The high concentration of produced radioisotopes are extracted and directed into a strong analyzing magnet to prevent transportation of target gas and/or undesired impurities into medical areas. The beam line, including focusing magnets, apertures, the special ion source and vacuum system are explained in brief. Finally a comparison is given between the conventional and the new design.

I. INTRODUCTION

The main idea of going for the new system comes from the problems that usually occurs when a radiochemical lab becomes a necessity in short lived medical radioisotope production sites. Eliminating this, and offering a direct gaseous usage of the main PET radioisotopes, viz. ^{11}C and ^{15}O, seems to be a method with a reasonable cost, since in the new method, except for the TIS, all neutron polluted areas are omitted.

In a typical Electro-Magnetic Isotope Separator (EMIS) designed for separation of light elements, ion currents higher than 100 mA is available for highly abundant isotopes, and for those of lower abundance, a minimum of 1mA is a reasonable figure. If the separated beam is cut into intense bunches of ions, then each bunch is regarded as a time-lapsed target, seen from the proton beam point of view. This requires bunching frequencies, harmonically, of the same order as the proton beam; i.e. two beams should be properly in-tune.

Outcome of this scheme is a secondary ion beam of desired radioisotopes, which is stopped in a deccelerating chamber, then pumped out with efficiencies less than 30% (^{11}C is stopped and oxidated in the same chamber).

This non-standard on-line configuration is capable of easy switching between $^{14}N(d,n)^{15}O$, $^{14}N(p,\alpha)^{11}C$ and $^{15}N(p,n)^{15}O$ reactions by applying a slight change in separator's magnetic field. This, optimises the occupancy of the cyclotron beam, and offers a selective production of ^{13}N and ^{18}F, as well, provided that ^{18}O-enriched source is used to feed the EMIS. In this case, either of $^{16}O(p,\alpha)^{13}N$ and $^{18}O(p,n)^{18}F$ reactions could be selected. This versatility is a promising factor, although drastic production rates are not expected.

II. BEAM LINE

The main beam line consists of two parts: The stable and radioactive beam sections. Optics-wise it is sected into DC and bunched parts (fig. 1), therefore, some focusing characteristics are different for quadrupoles in the latter section.

Since, delicate focusing is not required for isotope production, obviously, higher order focusing elements are omitted.

A: Beam converter

Design of a sheet-to-cylinder beam converter is the dominant focusing task in the DC part. The undesired shape of the sheet beam (mostly a bended rectangle) is transfigured, using an electrostatic set of crescent-like electrodes, followed by a rectangular slit. A series of doublet-triplet is used for reshaping the beam.

B: Bunching, Pre-acceleration

Proton (deuteron) beams in typical dedicated radioisotope production cyclotrons are bunched with frequencies up to 60 MHz. If a Harmonic frequency of 15 MHz is chosen as the bunching frequency of the separator ion beam, then each concentrated group of ions will be bombarded with 4 consecutive bunches of protons. This number can be raised to desired figures, by appropriate selection of the bunching mode.

A 15 MHz tuned single cavity RF accelerator with an energy of 100 Kev is an ideal choice for this purpose, since it is also quite easily available. Such a unit is used as a booster pre-accelerator, in order to extend the MFP of the ions before they are exposed to the cyclotron beam.

0-7803-1203-1/93$03.00 © 1993 IEEE

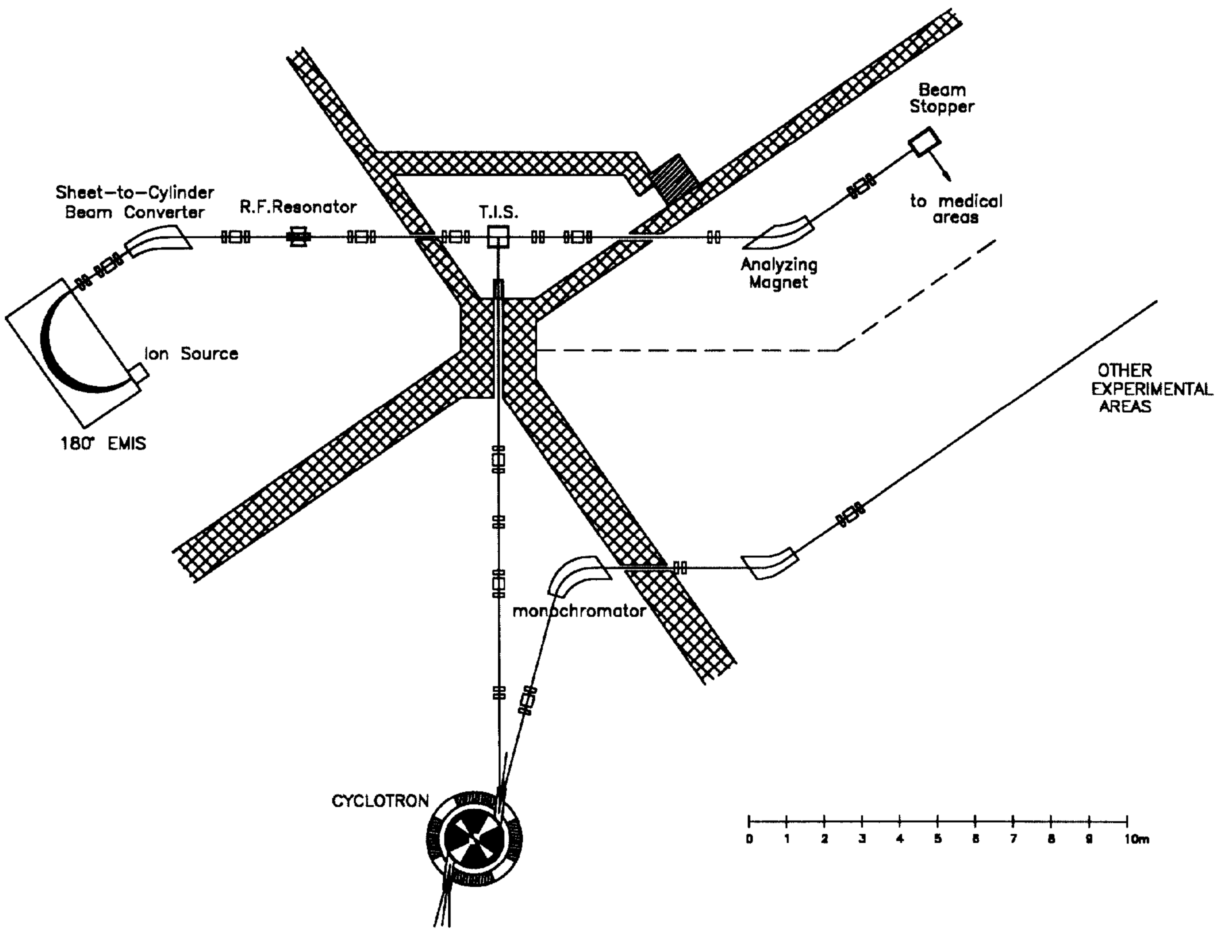

Fig.1 General layout of the new EMIS-CYCLOTRON scheme for production of PET nuclides

C: Target Ion Source

The ion-proton junction is the point where the concept of the new method is realized. A modified Jväskylä ion guide (fig. 2) is used as the TIS for the system [1,8]. In the original ion guide a skimmer is used to trim the excess of the feed gas, in the ionization chamber. In the modified version the skimmer is drawn out , since the feeding of the source is supplied from the separator beam and a skimmer will cause remarkable loss of ions. The exit hole of the primary injection stage is widened so that the beam flow is made easier and overheating of the ion guide is avoided.

A vacuum pump is attended to the proton-stopper end of the source, to collect recombined H atoms from the ionization chamber, and to maintain the pressure drop caused by the difference in the vacuum systems of the ion and the proton beam lines.

Since the element range is not varied for the separator beam, the extraction efficiency is dedicatedly upgraded to 30%, therefore, higher rates of production is achieved in this specially modified ion guide.

D: Vacuum System

The pressure gradient, caused by the difference in the vacuum systems used in three different beam lines (i.e. the DC beam, the bunched ion beam and the proton beam), has to be balanced by rather tricky methods.

Normally the gas pressure in a separator hardly goes lower than 10^{-4} Pa, where in a bunched ion beam line it should be kept lower than 5 10^{-6} Pa, at least, to obtain good beam-transport conditions. In this sense the reshaping of the DC

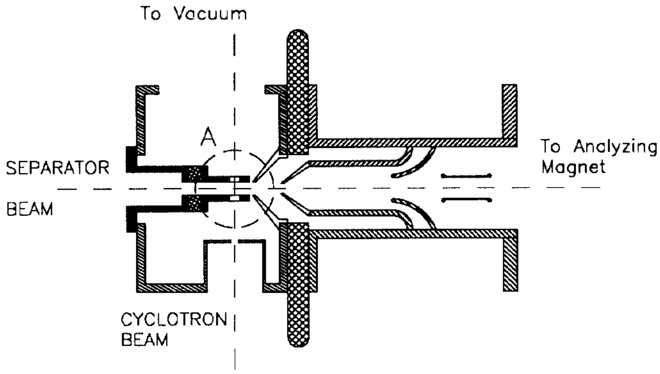

Fig. 2 Schematic drawing of the modified Jväskylä ion guide used as the special Target Ion Source.

beam doesn't help much, since the beam area remains unchanged. The entrance and exit slits of the RF resonator are functioning as orifices to maintain the pressure drop in this section.

The second point of pressure drop lies in the TIS, where two beam lines of different vacuum qualities are crossing. The second trick is to chose the entrance slit of the cyclotron beam such that it acts like an orifice. However, some limitations in focusing of the proton beam in the vicinity of the TIS should be considered.

III. A BRIEF COMPARISON

The idea of consecutive on-line production of radioisotopes is not unknown, either in classic ISOL facilities [2] or in modern compact systems, recently tested for production of short lived radioisotopes for nuclear astrophysics research [3,4,5]. The production-separation sequence is common between all previous designs.

Compared to a double cyclotron arrangement for production of ^{11}O, ^{13}N, ^{15}O and ^{18}F, the production costs are reduced by replacing one of the complicated cyclotrons, with an economically designed mass separator and an RF resonator, in the present design. The production-separation sequence is reversed, in the new design, so that the neutron polluted areas are minimized, which requires lower costs for separation of the radionuclides.

Remarkable costs of radiochemical labs either in modern single-cyclotron systems [6] and in older systems, using radioisotope generators [7], are eliminated .

The special TIS is designed for limited range of radionuclides, therefore the efficiencies could be pushed to higher limits compared to conventional complicated tubular gas targets [8].

IV. ACKNOWLEDGEMENTS

I would like to acknowledge my colleagues in IBAL, specially our director Mr. M.Karbassforoushan. I express my special gratitude to Dr. K.Halbach and my brother Abraham and his Wife Helen; without their support this work would not be presented.

V. REFERENCES

[1] J.ÄRJE et al, Nucl. Instr. and Meth., **A 247**,(1986)431.

[2] H.L.RAVN, "Radioactive Ion Beams available at On-Line Mass Separators", Proc. of the 11th Int. Conf. on EMIS and technics related to their application ed. W.L.Talbert, (1986)72.

[3] M.ARNOULD et al, "Production and acceleration of Radioactive Ion Beams at Louvain-La-Nouve", Proc.of the 10th Conf. on the applications of Accelerators in research and industry, eds. J.L.Duggan, I.L.Morgan, (1988)498.

[4] Y.JONGEN et al, " A two-Cyclotron concept for the production of Radioactive Beams", Proc. of the 1989 IEEE Particle Accelerator Conf., p.1620.

[5] G.BERGER et al, " Acceleration and Mass Separation of Radioactive Ion Beams in an Isochronous Cyclotron", Proc. of the 1991 IEEE Particle Accelerator Conf., p.2610.

[6] J.R VOTAW and R.J.NICKLES, "Radionuclide Production for Positron Emission Tomography : Chosing an appropriate Accelerator", the same Conf. as ref. [3], p.1093.

[7] Y.YANO, "Radioisotope generators for short lived Positron Emitters applicable to Positron Emission Tomography", the same Conf., p.1105.

[8] R.D.HICHWA et al, " Design of Target Systems for production of PET nuclides", the same Conf., p.1110.