EXPERIENCES WITH THE CYCLONE 3 OXYGEN 15 GENERATOR

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ABSTRACT

The Cyclone 3 is a simple compact low energy cyclotron operated via keyboard. It generates a 50 μA beam of 3.6 MeV deuterons which strike a nitrogen gas target to produce oxygen 15 via the $^{14}N(d,n)^{15}O$ reaction. The oxygen 15 is piped 80m to a novel bedside infuser which produces ^{15}O water without the disadvantages of earlier techniques. 25 μA of beam provides an adequate supply of ^{15}O water for patient blood flow studies. The availability of ^{15}O water "on tap" is of great assistance in running the extremely full clinical research schedule at Hammersmith.

This technique has enormous potential in clinical PET programmes.

Specification

A collaborative programme was drawn up with IBA. A performance specification was agreed that would meet the current demands for ^{15}O products to support the Hammersmith PET programme.

$^{15}O_2$	30	mCi/min
C $^{15}O_2$	80	mCi/min
C ^{15}O	40	mCi/min

all of the above were for a delivery flow rate of 500 ml/min, measured 80m from the cyclotron. All products were produced in excess of specification during the factory acceptance tests in Jan 91 and the cyclone 3 shipped to Hammersmith in February of that year.

The cyclotron

The cyclone 3 was originally conceived as a classical cyclotron with plane pole faces. The pole faces were later modified to incorporate sector focussing. It was intended to have a simple 'push -button' operating system.

The plane of acceleration is vertical with the target at the bottom. The magnet yoke is hinged to allow access for servicing (Fig. 1). The weight of the cyclotron is approx 5 tonnes.

The rf system is a free-running oscillator which operates in first harmonic mode at 14.4 MHz. The dees, which are fabricated from flat copper plate are uncooled except at the dee stems. Additional rigidity is provided by dee support insulators mounted on the sides of the vacuum box. The D^+ ions are produced in a standard P.I.G. source.

A diagnostic probe measures beam intensity at extraction radius. Extraction is via an electrostatic deflector which achieves 40% efficiency.

Overall power consumption of the cyclotron is 40 KVA

Improvements to the prototype Cyclone 3

The rf system has now been redesigned by IBA to eliminate the dee support insulators . This design of rf system operates in 2nd harmonic mode and has been used in the 2nd cyclone 3 (delivered to Turku, Finland) and is to be retro-fitted in the Hammersmith machine during August '92. The redesigned rf system runs at 30 MH_z. The main magnet field has been increased also, resulting in a deuteron energy of 3.8 MeV. This increased deuteron energy has significantly increased the yield of ^{15}O from the target. The Turku machine has passed its acceptance tests at the end of June.

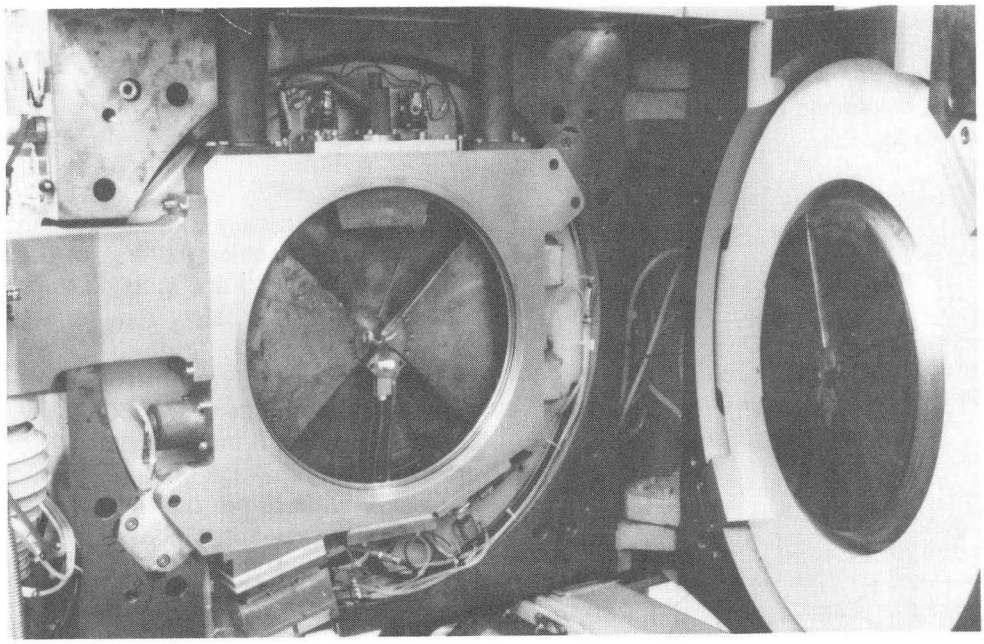
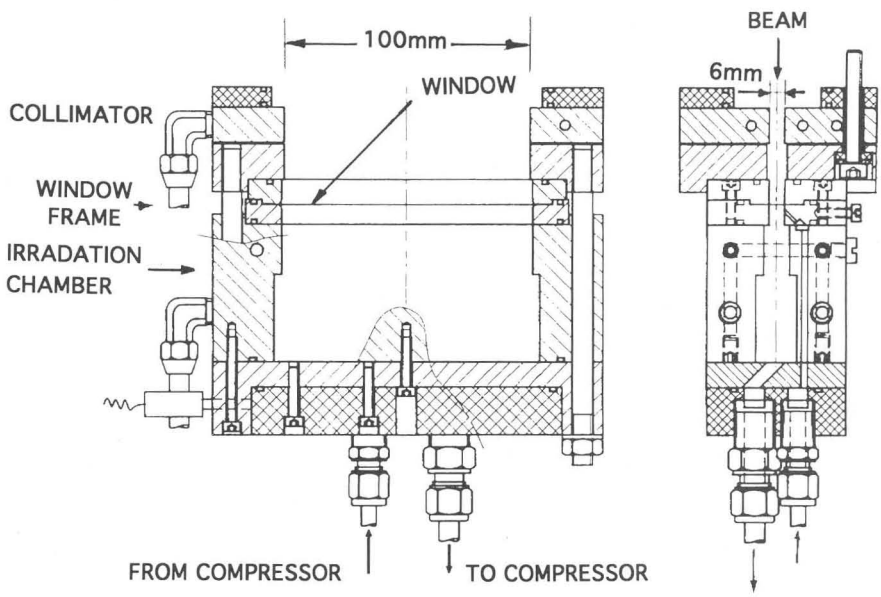


Fig 1. THE CYCLONE-3 Pole face diameter approx 480 mm

The target

The target construction is shown in Fig. 2. The target gas is dry nitrogen mixed with 1% 0_2 or 1% CO_2 at an absolute pressure of approx 1.5 bar. The cyclotron beam, having been defocussed in traversing the fringe field of the main magnet enters the target through a single thin window (currently 7.6 micron Titanium). The target gas is recirculated at 15 l/min by a ss. bellows compressor. Jets of target gas are directed on to the window, providing cooling.



^{15}O TARGET FOR CYCLONE-3

Fig. 2

The main use of the cyclone 3 so far has been to make ^{15}O water. This is done at the bedside using a novel water generator infuser.[7] A schematic of the water generator is shown in Fig. 3.

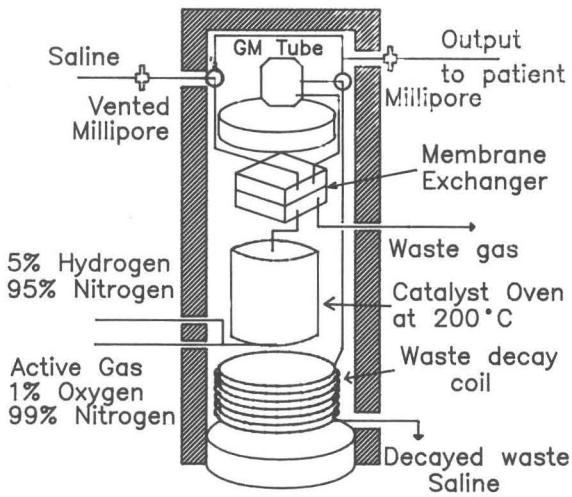


Fig. 3

The key component of the water generator is a semi-permeable membrane exchanger which introduces $H_2{}^{15}O$ into a normal saline (0.9% NaCl) infusate. (Fig. 4)

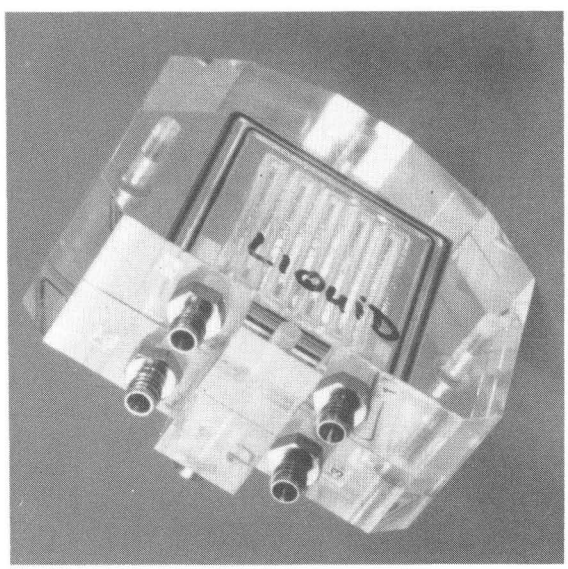


Fig. 4

$H_2{}^{15}O$ is synthesised in the gas phase by the Palladium catalysed reaction of $^{15}O_2$ with H_2 (5% in N_2)

$$^{15}O_2 + 2H_2 \xrightarrow[150°C]{Pd} 2H_2{}^{15}O$$

As the device is closely connected to the patient all the electrical controls are extra low voltage (24 volt) and isolated to comply with electromedical safety requirements.

Operation and Reliability

At high beam intensities, 50μA, the prototype cyclone 3 has continuing problems with breakage of the dee support insulators. Apart from one major water leak into the cyclotron tank, the cyclotron has run reliably at modest beam currents up to 30 μA for approx 25 hours/wk during 1992. Target window lifetime estimated to be 80 hours. Ion source service interval > 100 hours. The cyclone 3 is operated via a lap-top portable computer. Some operator intervention is required to tune in the magnet as the cyclotron warms up.In practice $H_2{}^{15}O$ water output is controlled by adjustment of cyclotron beam by altering the ion source arc conditions. Residual radioactivity in the cyclotron tank after beam off is higher than expected but not a problem.

Use of Cyclone 3 in the Hammersmith clinical programme

^{15}O water is used to carry out an average of 6 PET brain blood flow studies per week. 25 μA of beam current produces an adequate supply of ^{15}O water for these studies. The machine plays an important role in releasing the more flexible multi-particle 40 MeV cyclotron to be applied more efficiently to ^{11}C and ^{18}F PET radiopharmaceutical production.

Potential in clinical applications

The combination of the new generation of high sensitivity "septa less" PET scanners[1] and the bedside $H_2{}^{15}O$ infusion device fed with $^{15}O_2$ from the Cyclone-3[2] has provided an extremely versatile research platform for the study of small transient blood flow changes[3] in the brain of man

blood flow changes[3] in the brain of man when stimulated with a wide range of paradigms with acceptably small doses of radiation. These paradigms when carefully designed can elicit focal responses in the brain which when quantified lead to a wider understanding of normal and abnormal brain function. These "activation" paradigms range through visual (Fig.5), sound, speech, smell, movement, breathing control and cognitive processes (memory) are seen to be contributing valuable data in the "Decade of the Brain" 1990 - 2000.

$^{15}0_2$ which may be used to study tissue oxygen utilization is converted to $H_2{}^{15}0$ in vivo and the measurement of this metabolic water signal can be related to oxidative metabolism in tissue.

$C^{15}0_2$ when breathed in air is converted to $H_2{}^{15}0$ in the lung.[4,5] It has recently been demonstrated that this water can be exploited in the assessment of myocardial viability by providing a measure of regional tissue perfusion index.[6] This technique should have significant routine clinical applicability.

$C^{15}0$ binds to haemoglobin in red blood cells and thus provides a method of measuring the blood volume of organs and tissue capillaries which is often necessary as part of a PET quantitative pharmacokinetic study.

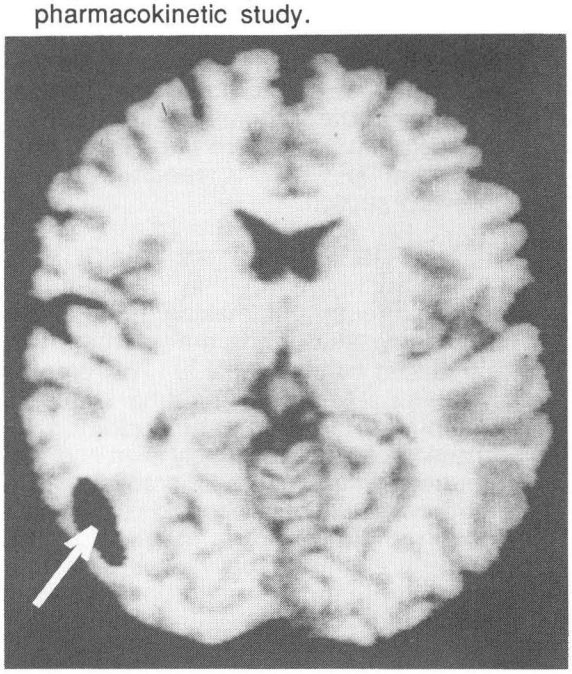


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Fig.5 Co-registered PET/MRI Images MRI Transaxial scan slices with statistically significant increases in blood flow measured using Positron Emission Tomography (PET) and Oxygen-15 labelled water (arrowed).