CURRENT STATUS AND FUTURE OF CYCLOTRON DEVELOPMENT AT IBA .

E. Conard, M. Abs, C. Dom, L. Hardy, Y. Jongen, M. Ladeuze, S. Laycock and T. Vanderlinden.

ION BEAM APPLICATIONS
Chemin du Cyclotron, 2 - 1348 Louvain-la-Neuve
BELGIUM.

ABSTRACT

Since the commercial success of IBA's first cyclotron, CYCLONE 30, two smaller accelerators dedicated to Positron Emission Tomography have been designed and built. CYCLONE 3D is a 3 MeV deuteron classical cyclotron and CYCLONE 10/5 is a 10 MeV proton, 5 MeV deuteron accelerator based on the "deep valley" concept used in the 30 MeV machine. Furthermore, the CYCLONE 18/9 project was started earlier this year. A conceptual design study was undertaken for a K = 230 cyclotron for proton therapy. The current status of all these projects is reviewed with emphasis on design innovations.

INTRODUCTION

IBA was established in 1986 with the purpose of commercializing its newly designed 30 MeV H^- accelerator. Two such machines are now in operation and another six are on order and are at various stages of manufacture. Meanwhile, intense R&D activity oriented towards medical applications allowed the company to develop three other models of cyclotron, dedicated to the production of PET (Positron Emission Tomography) isotopes . Moreover another very large project is now being evaluated: a 230 MeV cyclotron for a proton therapy facility. This paper briefly describes the main features of every cyclotron, concentratring on original ideas. Current status and forecasts are given for each project. Details about beam injection and extraction, RF and control systems are given in other papers [1], [2], [3], [4], [5] and [6].

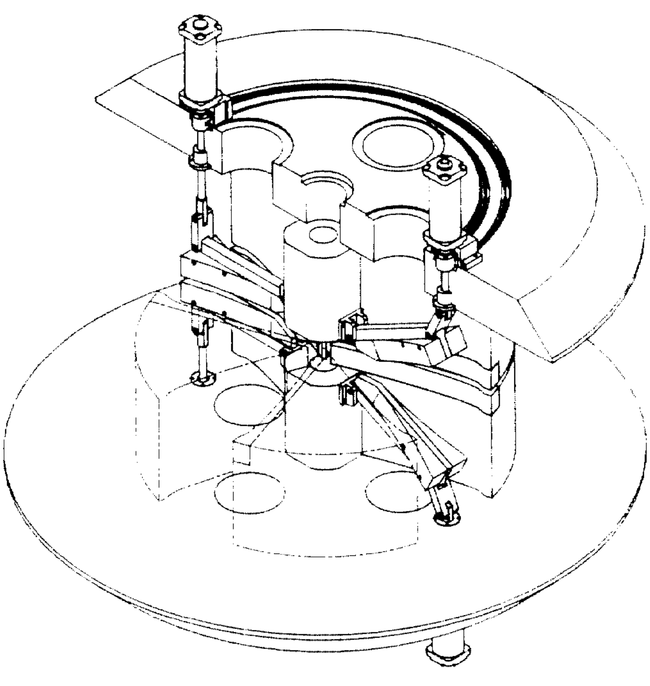

Figure 1.
Pneumatically actuated magnetic shims for field adjustment in CYCLONE 30/15 (H^-, D^-).

CYCLONE 30

Cyclone 30 is a 30 MeV H- accelerator described elsewhere [2]. It is a sturdy, field proven machine. The prototype remained in Louvain-La-Neuve and is constantly undergoing new developments aimed primarily at ever improving its reliability, its productivity and its simplicity of operation. Besides fairly heavy routine operation it is also used as a test bed for all possible improvements or modifications brought to production machines. Among these developments we may quote:

Project	Achieved	Scheduled
Beam intensity	580 µA (1988)	1 mA (Nov 1990)
Axial injection	Design of new H- ion source and axial injection line.	Manufacturing and testing of new ion source
Deuteron beam option	Calculation of a new central region and inflector for . H = 4 for H- . H = 8 for D-	Design, manufacturing and test (at low energy - Sep 90) of new central region
	Design of pneumatically actuated shims for magnetic field adjustment (Figure 1)	Manufacture of shims and magnetic field mapping (on one of the production machines - Sep 90)
Control system	Automatic call of duty engineer if target current drops	1). Data transfer for remote diagnostics (< Dec 90) 2). Remote control implementation (early 91)

CYCLONE 3 D

GENERAL DESCRIPTION

The CYCLONE 3D is an extremely compact, easy to operate system for the production of the positron-emitting radionuclide ^{15}O through the exothermic (d,n) reaction on natural nitrogen. The complete system configuration includes a 3.2 MeV positive ion cyclotron, an ^{15}O target, an Automated Chemistry Module, and gas conversion ovens. Dedicated to producing one radioisotope only, the CYCLONE 3D has been designed for ease of operation and reliability. The magnet cross-section is square, with a vertical acceleration plane, allowing the cyclotron structure to be used as shielding.

MAGNET

Since relativistic effects are negligible for 3 MeV Deuterons, the magnetic field is conveniently provided by a conventional flat pole magnet which consist of two symetrical sets of three parts. The yokes are hinged together and the whole magnet stands upright which allows it to be opened by hand, with virtually no force required (Figure 2). The magnet gap is 50 mm in order to accommodate the accelerating electrodes. The coils are wound from hollow core, square copper conductor. Owing to the "classical" character of this magnet, the excitation power required to produce the 1.8 T field is 13 kW which is somewhat higher than for the deep valley cyclotrons. The pole faces are copper plated (50 µm) to provide the necessary "skin" for RF currents.

Thanks to the rotational symmetry, magnetic field mapping was carried out very swiftly using a single Hall probe moving on a radial support.

Initial measurements were made at various angles on the poles to pinpoint any lack of symmetry due to the openings in the return yoke.
The measured magnetic field matched the calculated profile without any shimming. Only the excitation current had to be increased by 10% with respect to the predicted value. The 1.8 T field allows isochronous acceleration of D^+ up to 3.5 MeV.

BEAM EXTRACTION AND TARGET

The most challenging problem in the whole system is the target window design. 3 MeV deuterons have a very short range in matter and therefore require a very thin window if some energy is to be saved for the actual production process. Experimental work at the UCL Van De Graaf accelerator allowed to determine the best material chosen for the window and pointed out technical and physical limitations. A 4 μm thick molybdenum foil was to be used. In order to run safely, the maximum beam current density on the window must be kept below 10 μA cm^{-2}. In other words, the beam should be spread over 6 to 10 cm^2 at the target entrance. The above requirements determined the extraction scheme. A single electrostatic deflector with moderate field and voltage is placed between the dee stems while the target is located near the ion source port, 160° after the deflector. The beam thus leaves the magnet very slowly and undergoes severe radial defocusing and axial focusing. The target window is rectangular with a typical dimension of 8mm x 100 mm.

CURRENT STATUS

The cyclone 3D prototype has accelerated it first internal beam in December 1989. Maximum internal beam intensity was brought to 250 μA at extraction radius during the first 3 months of 1990. Work on extracted beam is still in progress after 55 μA have been measured on target. Development time is now shared between extracted beam improvement, ^{15}O production tests and control system implementation. The entire system is scheduled to undergo a full range of factory tests in July and to be shipped to Hammersmith Hospital in August 1990.

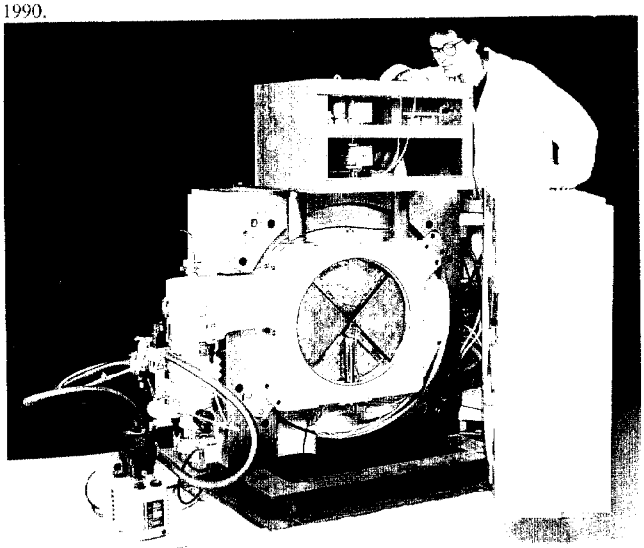

Figure 2.

CYCLONE 10/5

GENERAL DESCRIPTION

Cyclone 10/5 is a 10 MeV proton / 5 MeV deuterons cyclotron linked to automated chemistry modules dedicated to producing the most frequently used PET isotopes, i.e. ^{11}C, ^{13}N, ^{15}O, ^{18}F.
It is a compact version of the Cyclone 30 i.e. a negative ion, deep valley cyclotron. Noticeable features of the 10/5 are discribed below. (Figure 3).

FIELD MAPPING AND H- / D- ISOCHRONISM

The mapping device designed for cyclotron 10/5 consists of radial arm supporting 24 Hall probes. The arm is embedded in a solid wheel made of insulating material. Grooves are cut every 2 degrees around the perimeter of the wheel which can be remotely moved by a pneumatic ratchet.

STATUS AND PLANNING

To date, the magnetic field has been trimmed for isochronous acceleration of both types of ion. The vacuum system has been tested down to a base pressure of 9 * 10^{-7} mbar. The H^- ion source has been installed and a first discharge has been struck. All the parts are manufactured and installed and work is in progress with the RF system. First internal beam is scheduled for the end of June. Extracted beam in July. The prototype will be moved to the KUL Hospital in August and will be fully commissionned before January 1991.

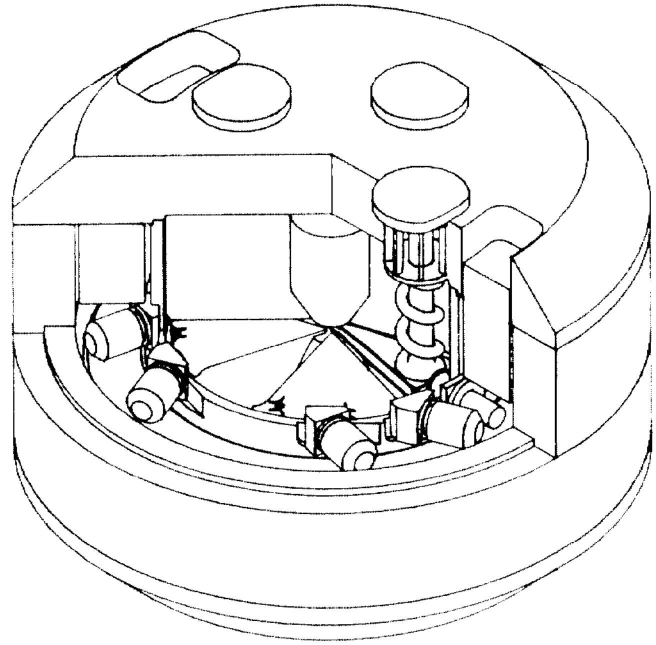

Figure 3.
Cut - away view of CYCLONE 10/5.

CYCLONE 18/9

GENERAL DESCRIPTION

CYCLONE 18/9 (18 MeV proton / 9 MeV deuteron) has been designed to meet the special requirements of radioisotope distribution centers. It is an ideal tool for research centers. CYCLONE 18/9 allows large quantity production of all radioisotopes currently used in positron emission tomography. The initial impression is that CYCLONE 18/9 is a scaled up version of CYCLONE 10/5 (Figure 4). However, the system has distinctive features on at least four aspects:

- The magnetic field profile change from H^- to D^-
- The shielding material
- The PET isotope target performances
- Generic chemistry modules and their control software.

These four points are currently the focus of a special research program supported by the local government. The first one only will be discussed here.

MAGNET.

The magnetic field profile correction may no longer be obtained by saturating the magnet steel as is done on CYCLONE 10/5. But rather similarly to the CYCLONE 30, a set of movable "wedges" will be installed inside the valleys to perform the task.

CURRENT STATUS AND PLANNING

The research grant has been approved and design has actively started. Flame cut parts of steel for the magnet are on order and the final machining drawings are being completed. Most of the long lead items have been specified and are on order. e.g. vacuum equipment, magnet p.s.u., A full size model of the RF cavity is under manufacturing. Initial planning is met. The major milestones are as follows:

- Dec 90 Magnetic field mapping
- Dec 90 Vacuum system
- Jan 91 RF system
- Feb 91 Ion sources
- March 91 First accelerated beam
- April 91 First extracted beam

The prototype will be shipped from Louvain-La-Neuve to UCLA (Los Angeles) in June 1991.

Main parameters.

		CYC 30	CYC 3 D	CYC 10/5	CYC 18/9	CYC 230
Beam						
Type of ions						
- extracted		H+	D+	H+ / D+	H+ / D+	H+
- accelerated		H-	D+	H- / D-	H- / D-	H+
Variable energy	<MeV>	15 - 30	3.2	10 / 5	18 / 9	230
Maximum intensity	<μA>	500	50	50 / 35	100 / 35	0.025
Max. nb. of beam lines / targets		10	1	8 (internal)	8 (external)	2
Nb. simult. extracted beams		2	1	2	2	1
Normalized emittance						
- horizontal	<mm rad>	< 10 π		< 10 π	< 10 π	< 15 π
- vertical	<mm rad>	< 5 π		< 5 π	< 5 π	< 10 π
Magnetic structure						
Number of sectors		4	0	4	4	4
Sector angle (radially varying)	<degrees>	54 - 58	n.a.	54 - 58	54 - 58	36 - 53
Sector spiral angle (radially varying)	<degrees>	0	n.a.	0	0	0 - 60
Magnetic induction						
- Hill	<T>	1.7	n.a.	1.95 / 1.97	1.85 / 1.90	3.09
- Valley	<T>	0.12	n.a.	0.35 / 0.354	0.35 / 0.354	0.98
- Average	<T>	1.1	1.8	1.35 / 1.36	1.28 / 1.32	2.165 (ext.)
Coil power consumption	<kW>	7.1	13	13	18.2	190
Mass						
- Iron	<tonne>	45	4	10.8	20	165
- Copper	<tonne>	4	0.5	1.35	2	26.6
R.F. system						
Number of dees		2	2	2	2	2
Effective dee angle	<degrees>	30	90	30	30	45 - 30
Harmonic mode		4	1	2 / 4	2 / 4	4
Frequency (fixed)	<MHz>	65	14	40 / 41	42 / 43.3	102.11
Nominal dee voltage	< kV>	50	30	30	30	100
Dissipated power						
- per cavity	<kW>	5	3	2	3	30
- beam acceleration	<kW>	15	0.3	1	2	6
Injection						
Type of source		cusp	Cold cath. PIG	Cold cath. PIG	Cold cath. PIG	Hot fil. PIG
Number of sources		1 (ext)	1 (int)	2 (int)	2 (int)	1 (int)
Filament power	<kW>	1	n.a.	n.a.	n.a.	1.5
Arc power	<kW>	5	1.2	1.2	1.2	0.5
H2 flow rate	<sccm>	5 -10	2	2	2	3 - 5
Source bias	<kV>	30	n.a.	n.a.	n.a.	n.a.
Injected H- current	<mA>	2	n.a.	n.a.	n.a.	n.a.
Cathode lifetime	<h>	> 200	500	500	500	> 800
Power consumption						
- stand - by conditions	<kW>	< 3	< 10	< 5	< 25	
- beam on target	<kW>	< 90	< 35	< 35	< 50	< 350

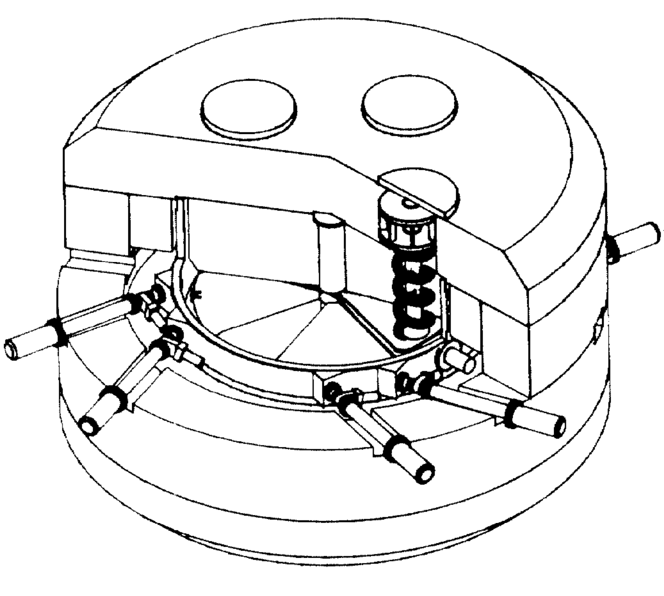

Figure 4.
Cut - away view of CYCLONE 18/9.

CYCLONE 230

Due to the growing interest in proton therapy from the medical community, a detailed feasibility study was initiated by the end of 1989. Proposed by Jongen et al [1] is an integrated design for a proton therapy facility based on a K = 230 proton cyclotron.

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