THREE YEARS OF OPERATION OF CYCLONE 30 IN LOUVAIN-LA-NEUVE.

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ABSTRACT

The prototype of the now famous CYCLONE 30 is installed on the premises of the Université Catholique de Louvain in Louvain-La-Neuve. Three and a half years after its first extracted beam it has now firmly established a reputation of high performance and reliability. Although in 1989 and 1990 most of its time was devoted to radioisotope production for various users, a number of developments and improvements were made with the aim of further increasing reliability, safety and comfort for the users. The most relevant improvements are presented hereafter as well as operation statistics clearly showing that a 95 % up-time is achieved at the present time.

DESCRIPTION OF CYCLONE 30

Detailed design descriptions of CYCLONE 30 appear elsewhere [1], [2], [3] and [4] and are only summarized here.

CYCLONE 30 is a fixed field, fixed frequency, isochronous cyclotron designed to accelerate intense beams of H- ions up to a maximum energy of 30 MeV.

The unusual magnet design combines the advantages of separated sector cyclotrons and solid pole cyclotrons. Energizing the cyclotron magnet requires as little as 7 kW. The magnetic field is adjusted during the manufacture by azimuthal shimming of the pole edges, providing a stable and highly isochronous field profile.

The rf system consists of two dees connected at the center and operating on the 4th harmonic of the particle revolution frequency. The half-wavelength resonators are entirely located in the magnet valleys. The total power needed to obtain the nominal 50kV dee voltage is only 5.5 kW per dee. The final stage rf amplifier, a grounded grid triode capable of delivering 26 kW, is attached to the cyclotron structure and coupled to the dees via a capacitor.

The negative hydrogen ions are produced by an external multicusp arc discharge ion source, biased at 30 kV. The axial injection system includes two 15° bending magnets to select the appropriated beam species, a steering magnet, an electrostatic "EINZELL" lens, a beam stopper, a double gap rf buncher, a magnetic "GLASER" lens located in the cyclotron yoke and an electrostatic helical inflector.

The H- ions are extracted from the cyclotron by stripping through a thin graphite foil (40 μg/cm2). Continuously adjustable energies from 15 to 30 MeV are available by varying the radial position of the foil. Two beams may be extracted simultaneously at the same energy by means of two foils on opposite sides or at unrelated energies by using a primary stripper of carbon fibres and a secondary of graphite foil.

Adequate pumping speed is provided by two oil diffusion pumps (1500 l/s per pump) and two cryogenic pumps (1500 l/s per pump). Typical operating pressure lies around 5.10-7 mbar which keeps the beam loss rate below 2%.

The control system consists of a programmable logic controller running software developed in-house. Preset beams, menus and functions keys allow unskilled operators to run the machine.

DEVELOPMENT MILESTONES.

The main steps in CYCLONE 30 development and operation were presented elsewhere [4] and are reviewed and completed hereafter.

86	**Dec**	Assembly complete.
	24th Dec	1st beam 31.5 MeV.
87	**Jan**	Extraction system assembly.
	Feb	1st extracted beam - 100%.
	Mar	170 μA.
	Jul - Aug	Final vault installation.
	Oct	285 μA - vacuum system upgrade (cryopumps).
	Dec	Stripping foil lifetime 100 hrs @ 250 μA.
88	**Jan - Jun**	Source and axial injection improvements.
	Jul	530 μA - rf regulation loop upgrade. Ion source DC supply (filament).
	Aug	30 MeV @ 450 μA for 24 hrs non-stop.
	Nov	Axial injection line vacuum improvements, injection efficiency boosted from 20 to 29 %.
	Dec	580 μA constantly.

89 **Feb**. A beam loss monitor system was implemented, increasing safety by preventing unnecessary activation of inner parts of the cyclotron.

UV light bulbs were installed in the vacuum chamber, allowing significant gain of time in resuming operation after a vacuum system shut-down.

Mar. Rf amplifier for the buncher was replaced by a capacitive pick-up in the 25 kW rf amplifier.

Mar - Apr. A new beam line with a 90° bending magnet was installed in CYCLONE 30.0 vault. This line ends on an enriched ^{13}C target at 350 μA to produce a large amount of ^{13}N (200 Ci at equilibrium) which is injected in the CYCLONE 100 of Louvain-La-Neuve by means of an ECR source. CYCLONE 30 plays a major role in the Radioactive Ion Beam Project, which is supported by the Belgian Governement and described elsewhere [5].

Apr. CYCLONE 30.0 runs unattended every night and week-end, a modem calls the duty engineer at home if the beam current decreases below a preset level.

July. A 15 kW reliable beam dump was developed and tested in which the beam passes through a 100 μm tantalum window and is stopped in water.

A main coil regulation loop was developed (in the PLC controller) to counteract thermal drifts as well as the effects of CYCLONE 100 fringe field.

Oct. A gaseous F_2 target was developed in collaboration with Erasme hospital.

Oct - Nov. Two types of Helium cooled twin windows targets were developed on the CYCLONE 30.0 for the ^{123}I production by the (p, 2n) reaction on ^{124}Xe, and for PET isotopes production chemistry on the CYCLONE 30 and baby cyclotrons.

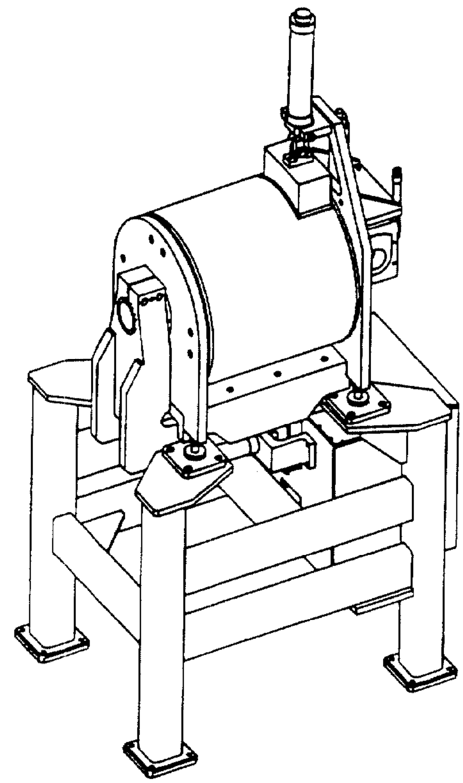

Figure 1.
57 Co automated target station.

90 Jan. A high intensity fully automated target station has been developed to produce ^{57}Co. The targets used in the station withstand a total beam current of 400 µA @ 22 MeV (8.8 kW). This equipment runs every night and week-ends to produce 3 to 4 Ci of ^{57}Co per month. Figure 1 presents the general layout of the automated target station.

Jan - May. PET target development is carried out to upgrade and optimize the targetry and chemistry performances for the new CYCLONE 10/5, 18/9 and 3D of IBA.

CURRENT STATUS.

CYCLONE 30.0 operation history in 1989 and 1990

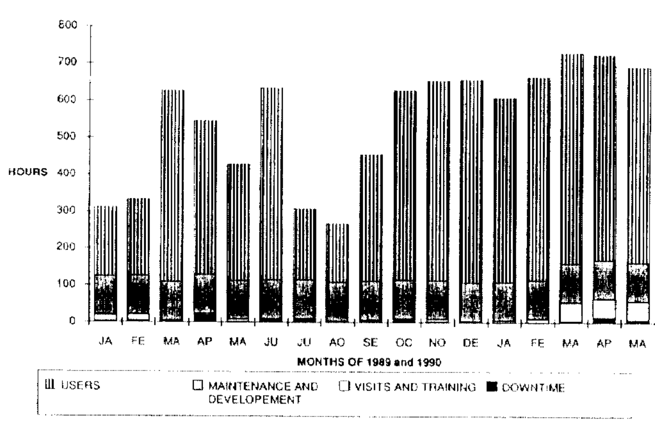

Figure 2.

Figure 2 presents the CYCLONE 30.0 operation statistics since January 89 and emphasizes the very high reliability level reached for the user benefit.

Present CYCLONE 30.0 major users are the following :
- PET radioisotope routine production for Belgian PET centers (UCL, Erasme, KUL)
- Radioactive Ion Beam Project
- ^{57}Co production
- PET targetry and chemistry developments
- CYCLONE 30 improvements and new developments in regard with IBA's new experience with other CYCLONE 30 sites
- Training : an intensive training program was undertaken in March 90 for people from the Lucas Research Laboratories in Sydney, Australia.

Future developments are planned along two axis.
Ongoing improvements such as for the ion source vacuum system, the injection line efficiency, or the cooling system simplicity and reliability, are supported. Actual new feature implementations are also undertaken. The main two of these are the deuteron option and a new ion source design.

The first project will give CYCLONE 30 users the possibility to use deuteron beams of up to 15 MeV, with 100 µA guaranteed intensity. First tests were already done on CYCLONE 30.0 with the actual injection line and central region, which show that good results may be expected with slight changes in the inflector and central region geometry. A new inflector and central region geometry were then calculated [6], which would accomodate both protons and deuterons. The magnetic field change between proton and deuteron operation will be provided by steel pieces located in the valleys and raised / lowered around the median plane by pneumatic jacks. Figure 3 presents the conceptual design of the described device.

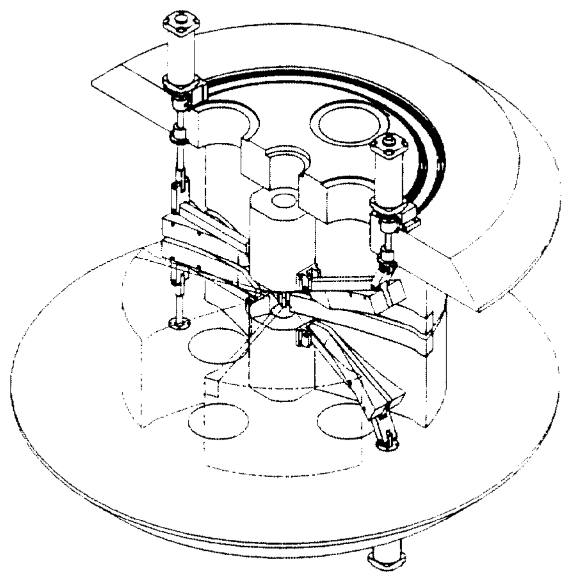

Figure 3.
Deuteron option for CYCLONE 30. Conceptual design.

The new inflector and central region geometry will be tested on CYCLONE 30.0 in August 90, and the first complete configuration will be installed in Australia before March 91.

A new H^- ion source is currently being designed. Based on IBA's large skills in H^- cusp sources and in sources in general, the goal is to design a very cost effective and simplified source with high performances, allowing CYCLONE 30 to reach 1 mA extracted beam.

Table 1. Main parameters.

	Expected	Achieved
Beam		
Type of ions		
- extracted	H+	
- accelerated	H-	
Variable energy <MeV>	15 - 30	14.5 - 31.5
Maximum intensity <μA>	500	580 at 15 MeV 507 at 30 MeV
Max. number of beam lines	4	10
Number of beams extracted simultaneously	2	
Stripping foil lifetime	20 mAh	55 mAh (peak) at 400 μA - 22 MeV
Normalized emittance <mm rad>		
- horizontal	< 10 π	~ 6 π
- vertical	< 5 π	~ 4 π
Magnetic structure		
Number of sectors	4	
Sector angle (radially varying) <degree>	54 - 58	
Magnetic induction <T>		
- Hill	1.7	
- Valley	0.12	
Coil power consumption <kW>	7.1	
Mass <tonne>		
- Iron	45	
- Copper	4	
R.F. system		
Number of dees (connected at the center)	2	
Effective dee angle <degree>	30	
Harmonic mode	4	
Frequency (fixed) <MHz>	65	
Nominal dee voltage < kV>	50	
Dissipated power <kW>		
- per cavity	5	
- beam acceleration	15	
Injection		
Type of source	cusp	
Filament power <kW>	0.5	
Arc power <kW>	2	
H2 flow rate <sccm>	5 -10	
Source bias <kV>	30	
Injected H- current <mA>	2	
Filament lifetime <h>	200	240
Total power consumption <kW>	< 100	86 at 30 MeV and 507 μA

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