ECREVIS-CYCLONE STATUS REPORT*

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SUMMARY

CYCLONE is a multiparticle variable energy cyclotron capable of accelerating ions between 2.3 and 95 MeV/a.m.u. and a bending limit of 130 MeV Q^2/A. It is used for nuclear physics, isotope production and medical and technological applications. Since 1982, ECREVIS (a superconducting ECR-source) is used for heavy ion injection in the cyclotron. The most abundant charge states are roughly twice those obtained with the internal PIG-source and extracted currents of 2 μA-electrical have been achieved. Completely stripped ions of carbon, nitrogen and oxygen have been extracted. The overall efficiency between cyclotron beam on target and source intensity after charge state analysis varies between 5 and 15 % depending on harmonic mode, ion velocity and main cyclotron field. A simple two gap klystron-type buncher is used. The facility is further being extended with additional experimental beam lines, a second neutrontherapy facility and a positron-camera.

1. INTRODUCTION

CYCLONE, the isochronous cyclotron of the Catholic University of Louvain at Louvain-la-Neuve, Belgium, has been operational for almost twelve years now. Initially, the machine was designed for variable energy operation with light ions only[1,2]. The maximum energy was 80 MeV for protons and alphas but the generous design of the magnet allowed raising the K-value to about 130.

The RF- and extraction-systems and the vertical focusing limit the maximum energy at low intensity to about 95 MeV for protons and to 125 MeV for alpha particles. The interest in heavy ion physics was growing rapidly and CYCLONE was equipped with an internal heavy ion source of the PIG type[3]. Also from the beginning it was realized that although its main destination was its use for nuclear physics, other fields such as nuclear chemistry and isotope production, radiobiology, medical and technological applications had to be developed around the accelerator. The ongoing interest in heavy ion physics led the cyclotron group to search further improvements of CYCLONE's capabilities. First, an injector cyclotron[4,5] was proposed but then the construction of an external superconducting ECR source with an axial injection system was decided in 1977[6]. It was a bold decision at that time since very little was understood about ECR sources and only one prototype, SUPERMAFIOS[7], using room-temperature coils and a tremendous amount of power had been operating for a short period of time as a stand-alone source for multiply-charged heavy ions.

However, a few other labs (Karlsruhe, Darmstadt,.) followed closely on the same way. According as the performance and advantages of ECR sources became evident more and more accelerators were equipped with this type of source or are in the process of getting one (Groningen, Grenoble, Jülich, Berkeley, Ganil,..).

Now, at the beginning of 1984, the whole system ECREVIS+CYCLONE has been operating for almost two years with improving performance. Figure 1 shows the evolution of CYCLONE's characteristics from the initial light ion operation to today's operation with ECREVIS on the background of the characteristics of a few other machines.

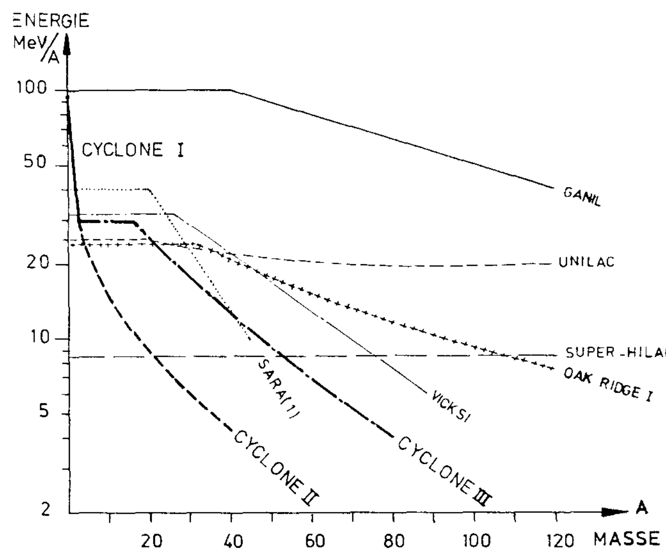

Fig. 1. Characteristics of CYCLONE and a few other machines. CYCLONE I = light ion performance ; CYCLONE II = using internal PIG source ; CYCLONE III = using ECREVIS.

Figure 2 shows how the machine time has been used over the years since the start in 1972. Figure 3 shows the evolution of heavy ion use with CYCLONE and how ECREVIS has taken over the task of the PIG-sources.

In this contribution we will further describe the latest developments at CYCLONE and the operating experience with ECREVIS as a heavy ion injector for CYCLONE.

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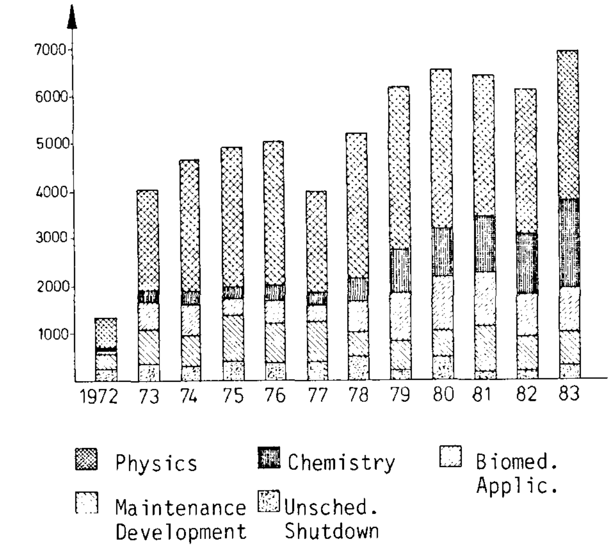

Fig. 2. Time distribution of CYCLONE.

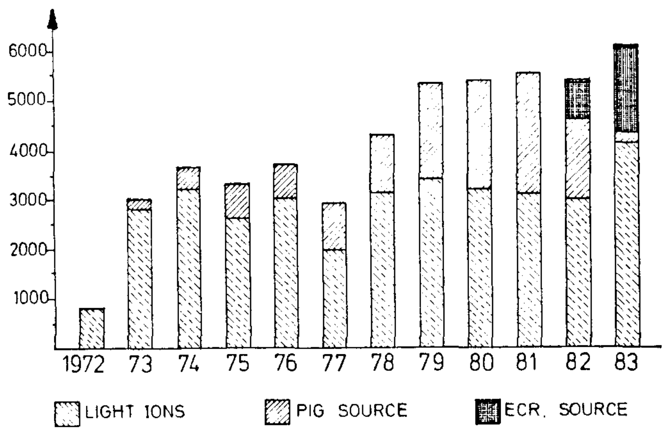

Fig. 3. Distribution of beam time with different types of sources.

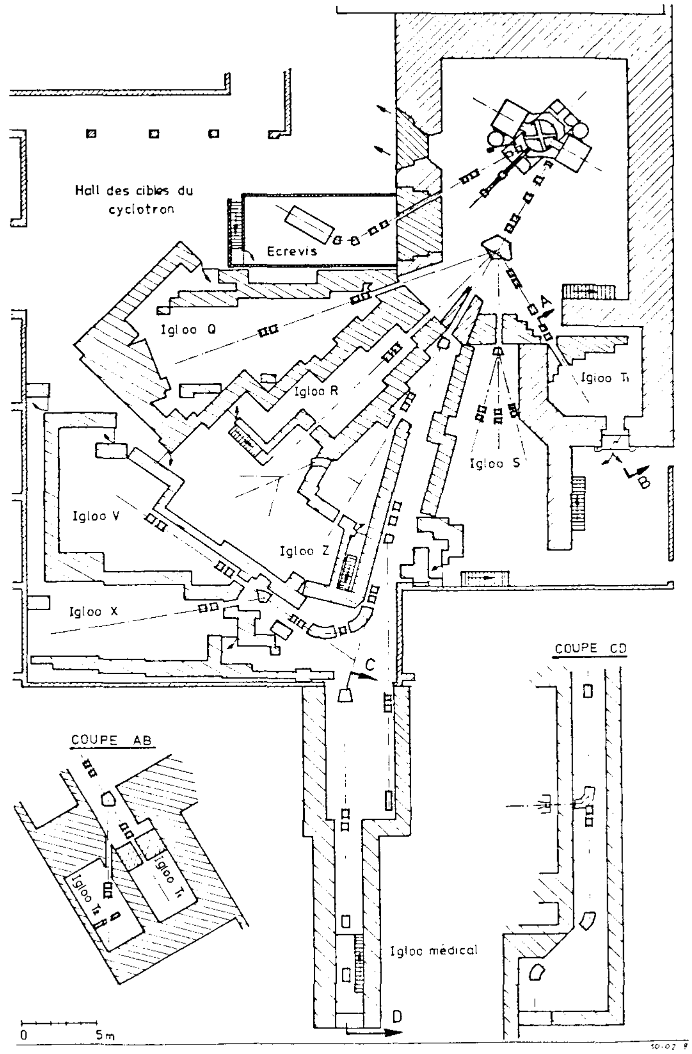

Fig. 4. Experimental area layout.

2. EXPERIMENTAL FACILITIES

2.1. New neutrontherapy unit

Figure 4 shows the experimental area layout. In the fall of 1983, the neutrontherapy programme was stopped to allow for the construction of a second therapy unit, behind the first one and equipped with a horizontal beam line. Therefore the old therapy line had to be dismantled, and the small tunnel torn down. Then a longer and enlarged vault was constructed and the old line rebuilt which is operational again since last April. The new line will consist of a switching magnet, a quadrupole doublet and a singly achromatic vertical beam shift using two 45° vertical bending magnets. The installation of this line is planned in the fall of 1984. The line will further be equipped with a neutron collimator with a continuously variable geometry using microprocessor control. Furthermore, an additional line can be equipped after the switching magnet between the two horizontal parts of the therapy lines for radiobiological experiments, preliminary experiments for protontherapy, etc...

Neutrontherapy generally uses a 65 MeV proton beam on a thick beryllium target with an intensity of about 15 micro-amps on target.

2.2. Extension of target locations on the S-line

In order to cope with the demands of several groups for additional target locations, it was decided to split the S-line into three with a 0, ± 15° switching magnet. Since this area has no specific shielding roof and to save space for experimental equipment, no shielding will be placed between the targets. These lines will be used for experiments using low intensity beams giving low radiation levels. The construction of these lines will be finished by this summer (1984).

2.3. Isotope production on the T-lines

A second vault underneath the first one has been equipped with a 30° vertical deflexion magnet and a quadrupole doublet. Both lines T1 and T2 are equipped with production targets for I^{123}. Furthermore on line T1 a rabbit system for the irradiation and handling of solid targets connects the line to a hot cell. Gas targets are installed on the end of line T2 for the production of positron emitters to be used with the ECAT III PET scanner. This positron camera is expected to be operational by the beginning of next year (1985).

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3. CYCLONE + ECREVIS

3.1. System description

Both the cyclotron and the ECR-source ECREVIS have been extensively described elsewhere[8,9]. Recently only minor modifications have been made to them. We briefly mention a few here.

The internal cryopump in the cyclotron vacuum chamber has been removed because it was situated in the way of an external target and because its liquid nitrogen filling system failed completely. Two external 3.500 l/s cryopumps have been connected through valves on external ports instead. The pumping speed in the accelerator region is considerably reduced but heavy ions are mainly injected axially now so, there is no more gas load due to the source. Besides, these external pumps can be shutdown and outgas on themselves without deteriorating the vacuum in the machine.

A new set of defining entrance slits has been placed on the charge state analysing system of ECREVIS. One 1.000 l/s cryopump has been moved from the exit 30° magnet to the slit box to pump the gas coming from neutralisation on the slits.

In the initial design of ECREVIS, the microwave feed of the 14.3 GHz to the first stage was located so that some back diffusing plasma could hit the pressure window. This caused a number of failures and was subsequently modified so that no further trouble occured.

Figure 5 shows the beam envelopes along the beam line from the source to the center of the cyclotron.

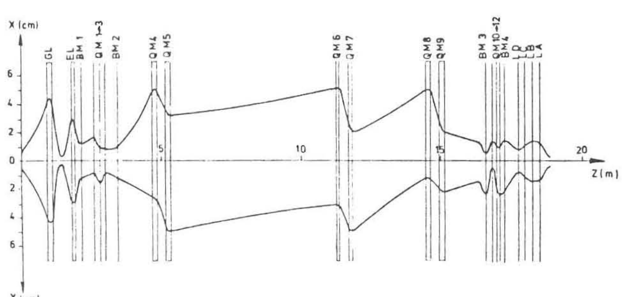

Fig. 5. Beam envelopes along the line from ECREVIS to the cyclotron.

3.2. Bunching system

An important element in the line between ECREVIS and the cyclotron is the buncher[10,11]. It will transform the DC-beam from the source into bunches, acceptable by the cyclotron RF-acceleration system. It is a two-gap klystron-type buncher located in the cube just on top of the cyclotron yoke. It will, if well adjusted, allow a theoretical gain of a factor up to 6 in intensity extracted from the cyclotron for a given source and beam line adjustment.

The buncher consists of three coaxial cilinders, in line, the outer two being at ground potential. An RF-voltage at the cyclotron frequency is applied to the central one. A few wires are fixed across the cilinders on adjacent ends to reduce the gap factor and homogenize the electric field in the gaps. The set of tubes acts as a small linear accelerator/decelerator slowing down slightly the early particles, speeding up the late ones so that they all meet at approximately the same time at the entrance into the DEE of the cyclotron. The buncher RF-voltage has to be adjustable both in phase and amplitude. Figure 6 shows the block diagram of our bunching system. A tuning circuit at the RF-electrode allows to minimize power required from the amplifier.

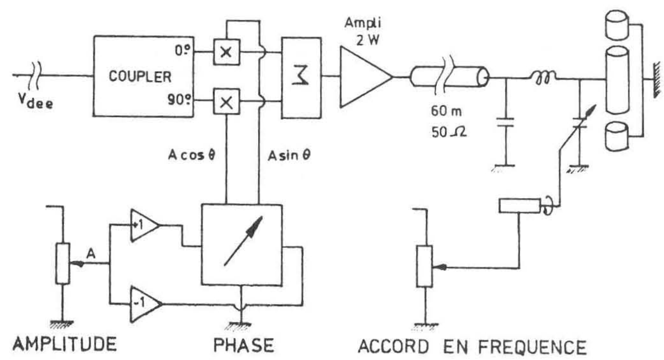

Fig. 6. Block diagram of the buncher in the axial injection system.

Table 1 summarizes the main characteristics of the buncher.

TABLE 1

Buncher characteristics :

- Excitation - sinusoidal - 2 W
- Length of drift tube = 26 mm
- Frequency range : 10.6 → 23 MHz
- Max peak voltage ≅ 200 V
- Ratio between injection voltage and peak bunching voltage :
  - . for 1st harmonic mode = 1.1 %
  - . for 2nd harmonic mode = 0.85 %
  - . for 3rd harmonic mode = 0.75 %

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3.3. Overall system performance

Table 2 shows some "typical-best" beams obtained up to now with the ECREVIS-CYCLONE combination.

TABLE 2

PARTICLE	CHARGE STATE	E_{FIN} MeV	V_{INJ} kV	HF1 W	HF2 KW	BEAM CURRENTS (in electrical micro-amps) FC1	YOKE	1st TURN	R = 20 cm	R = 92 cm	TARGET
Carbon	4	140	11.	180	2.1	24.	12.	-	3.5	3.	2.
Nitrogen	7	220	9.8	45	2.3	1.8	0.7	.15	.1	0.85	0.04
Oxygen	5	170	10.7	190	2.0	21.	16.	6.6	6.6	5.	2.5
Oxygen	6	210	11.	220	2.6	15.	8.	2.6	2.4	2.	1.0
Neon	6	140	7.3	20	2.6	6.	-	-	-	2.5	0.9
Sulphur	9	280	10.	70	3.0	19.	16.	5.	4.5	3.5	1.2
Argon	8	128	6.4	70	2.0	50.	16.	8.	5.6	3.2	1.0
* Argon	10	275	8.6	150	2.4	18.	12.	4.	-	1.	*
Argon	11	330	9.75	40	3.0	7.5	0.6	-	-	-	0.05
** Krypton 84	15	305	8.1	160	2.8	0.8	-	-	0.18	-	0.008

* Q/A = 1/4 Ar^{10+} + Ne^{5+} + O^{4+} + C^{3+} : I_{target} = 0.5 μA of Argon + 0.8 μA of Oxygen + 0.3 μA of Carbon

** Krypton isotopes 82, 84, 86 are transported together and accelerated during first few turns.

FC1 = Beam stop after analyzing system.

4. CONCLUSION

Almost two years of operation of ECREVIS both as stand alone ion source and as a heavy ion injector for CYCLONE has shown how reliable and reproducible an ECR source is. The output beam is stable over long periods (several days) and the intensities of the most abundant charge states are comparable with those of PIG sources. However, reliability, charge-state distribution, emittance and dispersion are far superior to that of PIG sources.

Further improvements to the system are a large acceptance charge state selection system with better matching to the source and an improved and more economic first stage design.

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