# STATUS REPORT OF CYCLONE

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## Abstract

The UCL cyclotron has been in operation since 1972. Maximum energy has reached 95 MeV for protons, 110 MeV for α-particles and extracted beam power has exceeded 3 kW. Up to 10 μA of $N^{4+}$ and $O^{4+}$ has been obtained. Some operational features are outlined and future developments are briefly discussed.

## Introduction

The basic design features of the UCL cyclotron are essentially the same as those of the cyclotrons of the Faculté des Sciences, Grenoble and the University of Maryland. They have been described previously (eg. Ref. 1-3) and will be recalled very briefly here. Cyclone was guaranteed by Thomson-CSF, France (CGR-MeV now) to accelerate protons and alpha particles up to 80 MeV with maximum extracted current of 20 μA. The electromagnet is equipped with four highly spiralled (55° max) sectors that give a hill to valley field ratio of 2 : 1. Two 90° dees are driven from two separate RF amplifier chains via two panel tuned cavities. The frequency range is 11 - 23 MHz, maximum RF power is 2 x 70 kW at 50 kV. The extraction system consists of a 55° electrostatic deflector followed by a 25° weakening magnetic channel. Fig. 1 shows the general lay out of the machine and the experimental area. The beam handling system was designed and built by the cyclotron group at the University. It consists of a main line connecting the cyclotron to a switching magnet which directs the beam to one of six separate experimental areas. One of the lines is equipped with a 110° analyzing magnet and can be operated either in a monochromatic or in a non-dispersive mode.

## Operation

Cyclone has been accepted from Thomson-CSF in the summer of 1972 and has been in operation on a regular schedule of 5 to 6 x 24 hours/week for physics, chemistry and radiobiological experiments since then. At the time of acceptance all contractual performance specifications except the maximum current at maximum proton energy were met. The machine has become very quickly fully operational showing increasing reliability and versatility as the technical staff got more familiar with it. Unscheduled shutdown for failure decreased from 20 % at the beginning to 6 % one year later. Since very frequent energy changes became required (some days up to ten changes are carried out) a considerable effort was devoted to the development of new beams. So the procedure of changing energy has become very fast : our record up to now is about 7 minutes for a 10 MeV change including beam transport adjustment. The demand for higher currents and energies encouraged our trials to go beyond the original specifications. The use of the spare power in the main coil supply allowed a raise in deuteron, resp. α-particle energy from 40 to 55 MeV resp. 80 to 110 MeV. Especially the 50 MeV deuteron beam which corresponds to a very favourable operation of the machine is being used extensively for neutron beam production in radiobiological experiments. During recent tests protons of 95 MeV have been accelerated but at 100 MeV the vertical focusing becomes insufficient. Optimization of the septum geometry for power dissipation together with careful tuning of the machine yielded very high currents : 66 μA of deuterons at 50 MeV have been extracted giving over 3 kW of beam power. Table 1 summarizes contractual specifications and actual characteristics of Cyclone.

## High intensity specific problems

However, frequent operation at high intensities causes some specific problems. The running of the cyclotron becomes more critical since any misadjustment, any drift or failure of a power supply can cause the melting of some part by the beam. Therefore a few safety systems have been added : any failure of a power supply causes a fast RF switch-off. To protect the deflector septum, which is finally the most vulnerable element, a monitoring system has been designed. It consists of a series of logic circuits analyzing the video signal coming from a camera looking at the septum. When a signal is detected which has the structure of a bright spot RF, and arc are switched off.

The overall activation of the machine becomes very important. Just after a run of several hours at 20 μA of 50 MeV deuteron an ambiant radioactivity of 100 rad/h was measured inside the vacuum box and a contact dose of 1.2 million rad/h at the septum entrance. Obviously the replacement of a defective septum is quite a problem. Therefore a "plug-in" deflector has been developed allowing the replacement of the whole assembly which is located inside the vacuum box (septum and high voltage electrode) by a new or repaired set without manipulating radioactive parts.

## Heavy ions

With a maximum energy of 110 $Q^2/A$ MeV it was evident that Cyclone had some interesting possibilities in the heavy ion field. Initially heavy ion beams were developed using the radial Livingston-Jones type source and peak intensities of 1 μAe were obtained for the $4^+$ state and used for physics experiments. But here also higher currents and higher charge states were required which led us to the design of a high power source. In collaboration with the team of Alice at the Orsay Institute of Nuclear Physics we started studies at the end of 1973. A source of the Dubna type with indirectly heating cathode has been adapted to the central region geometry of Cyclone. Fig. 2 gives a view of the source and some of its components. It is inserted axially and positioned by rotating the central plug. The necessary modifications were carried out during the summer of 1974 and by that time the new power supply

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got ready. The first tests took place at the end of 1974 and currents of about 10 μAe on target were obtained for $N^{4+}$ and $O^{4+}$ with extraction efficiencies of about 30 %. Table II summarizes the performance for heavy ions of Cyclone.

## Future developments

Future developments of Cyclone will concern especially the improvement of beam quality and the increase of its heavy ion capability. Short term development concerns the ion source itself. A long term project of a heavy ion preaccelerator injecting low energy high intensity beams into Cyclone is discussed elsewhere [5].

### Improvement of beam quality

The highest possible extraction efficiency is required in order to limit the activation of the machine. However we obtain most often rather low figures (30 to 60 %) and differential probe diagrams show always an important coherent radial oscillation. This affects seriously the extraction efficiency and we expect an important increase from improving the internal beam quality. Another problem arises at extraction : measurements showed that 90 % of the beam is contained in 70 mm.mrad with a horizontal width of 8 cm at the exit of the machine. Orbit calculations showed the important dispersive effect of the magnet fringe field together with the non linear defocusing effects of the fringe gradient. The same effect had already been observed at the University of Maryland cyclotron [4]. This situation can be improved by reducing the energy spread of the beam together with a better horizontal focusing along the extraction path. Therefore the dee voltage stability will be increased, phase acceptance limited and some focusing elements will be added between the magnetic channel and the vacuum box exit.

### Heavy ion development

A radial high power source will be designed to replace the axial one. We expect a serious increase of the output capability due to better cooling of the source. The radial source can be more accurately positioned. This allows the optimization of the central region resulting in a better extraction efficiency. Heavier particles with low charge-to-mass ratio have to be accelerated in the third harmonic mode but up to now no satisfactory operation could be obtained. For this reason a new central region geometry for third harmonic will be designed.

### References


1. P. Macq et al., Proc. Fifth Int. Cyclotron Conf. (Butterworths, London, 1971) 124
2. Y. Jongen et al., Proc. Sixth Int. Cyclotron Conf. (AIP, New York, 1972) 110
3. P. Delphin, Annales de Radioélectricité (TXXIII-N° 94 - oct. 1968) 307
4. W.P. Johnson, IEEE Trans. on Nucl. Sc. NS-18, N° 3 - p. 268
5. Y. Jongen, Proc. of this Conf. N° I-33


TABLE I - CONTRACTUAL SPECIFICATIONS AND ACTUAL CHARACTERISTICS OF CYCLONE

| | SPECIFIED | | ACTUAL | |
|---|---|---|---|---|
| | ENERGY | INTENSITY | ENERGY | INTENSITY (MAX) |
| PROTON | 10 - 80 MEV | 20 μA | 10 - 95 MEV | 40 μA (40 MEV) |
| DEUTERON | 10 - 40 MEV | 20 μA | 10 - 55 MEV | 70 μA (16 MEV)<br>50 μA (33 MEV)<br>66 μA (50 MEV) |
| α-PARTICLE | 20 - 80 MEV | 20 μA | 20 - 110 MEV | 45 μA (60 MEV) |
| $^{3}$HE | 20 - 120 MEV | 20 μA | 20 - 145 MEV | |

TABLE II - PERFORMANCE FOR HEAVY IONS

| | MAX. ENERGY | CURRENT INTERNAL | CURRENT EXTRACTED |
|---|---|---|---|
| CARBON $^{3+}$ | 80 MEV | 50 μAE | 20 μAE |
| NITROGEN $^{4+}$ | 125 MEV | 30 μAE | 12 μAE |
| OXYGEN $4^{+}$ | 110 MEV | 25 μAE | 8 μAE |
| NEON $^{4+}$ * | 85 MEV | 3 μAE | 1 μAE |
| NEON $^{5+}$ | 135 MEV | 1 μAE | 0,3 μAE |
| ARGON $^{8+}$* | 175 MEV | 0,100 μAE | 0,025 μAE |

* REQUIRE 3RD HARMONIC

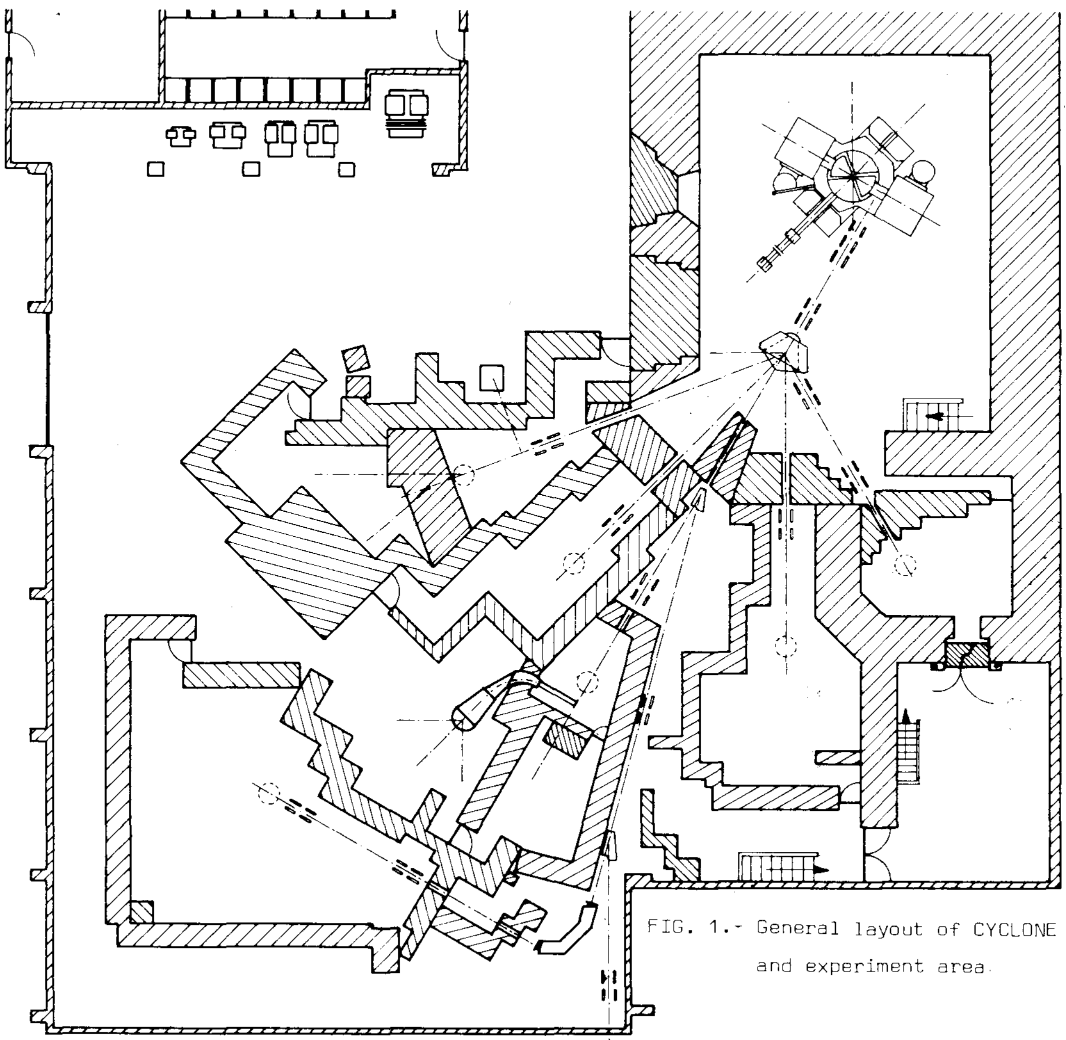

FIG. 1.- General layout of CYCLONE and experiment area.

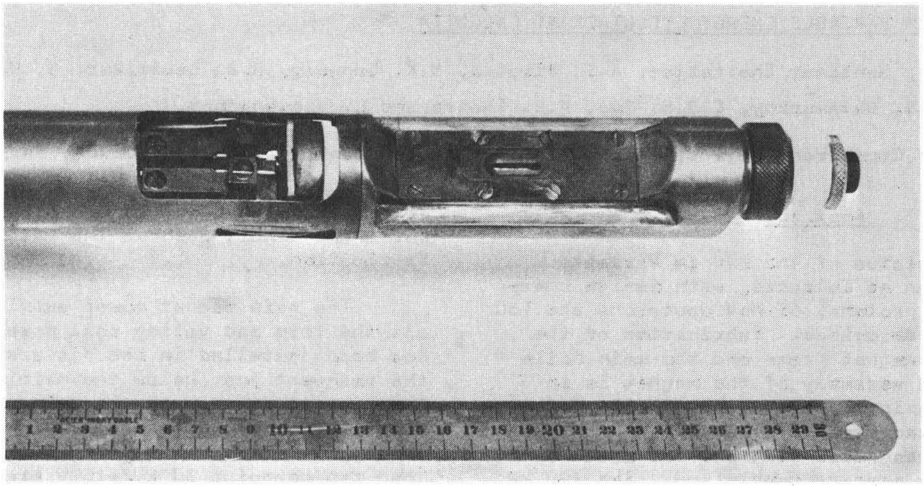

FIG. 2.a.- View of the heavy ion source (scale in cm)

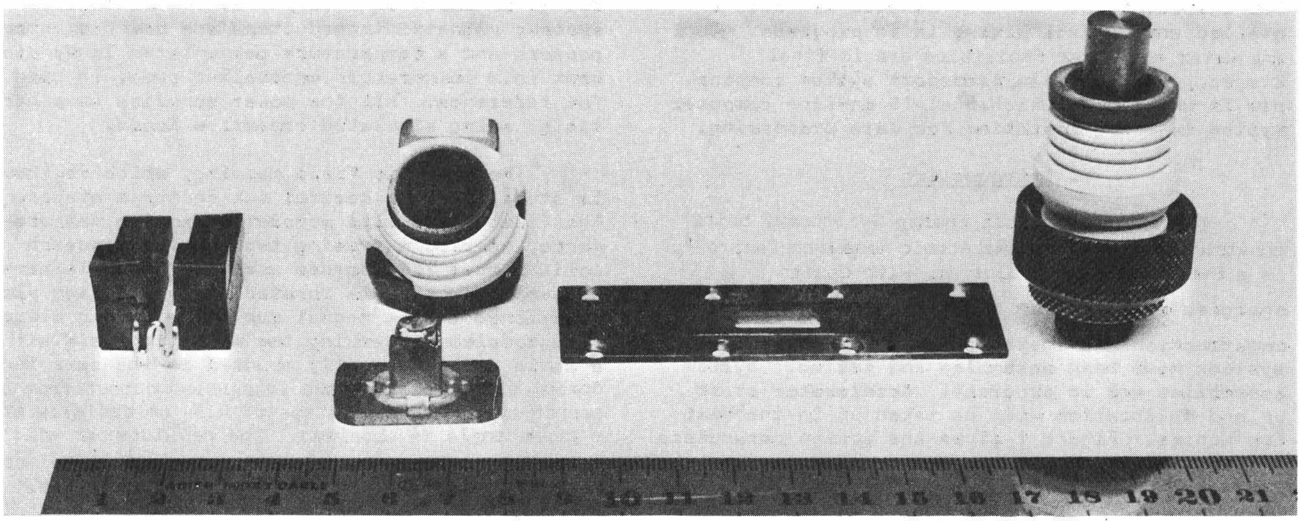

FIG. 2.b.- Some components of the heavy ion source

DISCUSSION

H. BERGER: Why did you not give intensity figures for $^3$He acceleration as you did for protons, deuterons and alphas?

G. RYCKEWAERT: We have accelerated a few $^3$He beams at maximum energy of 140 MeV as well as at 20 and 25 MeV. The reason why we did not do much $^3$He up to now is that $^3$He is very expensive, and we have no satisfactory recovery system; so experiments have been limited.

M. ZACH: Are the machine and beamlines tuned by computer?

G. RYCKEWAERT: No, that is done manually.

M. ZACH: Do you have to retune the beamlines as well?

G. RYCKEWAERT: Yes.

M. ZACH: Also manually?

G. RYCKEWAERT: Yes.