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AN INJECTOR CYCLOTRON FOR CYCLONE

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SUMMARY.- A heavy ions facility for CYCLONE (Belgium) is described. It consists of an injector cyclotron, able to accelerate heavy ions to a K value of 70 MeV Q^2/A, with an upgrading possibility of 100 MeV Q^2/A. Expected intensities are large. Some design aspects are described, allowing the cost of the project to be quite low.

CYCLONE is a variable energy isochronous cyclotron operating in Louvain-la-Neuve (Belgium). Maximum proton energy is 95 MeV and for heavier ions K = 110 MeV Q^2/A. Extracted beam intensities are quite large, varying with energy to give a roughly constant maximum beam power somewhat above 3 kW. The cyclotron is most often used in the 1 kW beam power region for physics experiments, isotopes production and neutron therapy.

There is a proposal to extend the possibilities of the machine in the heavy ions field, keeping the high energy and intensity characteristics.

It is planned to build near CYCLONE a heavy ions injector cyclotron injecting through the median plane to an internal stripper. The K value of the injector will be 70 MeV Q^2/A, with an upgrading possibility to 100 MeV Q^2/A, which means for the given mass to charge ratio range (from 7 to 17) an injection energy between 0.25 and 1.5 MeV/nucleon. Injected beam intensities should be large : 6 10^{14} particles/second for the low charged "light" heavy ions.

In figures 1 and 2 the expected maximum energies and intensities versus atomic number are compared to some accelerators existing or in project.

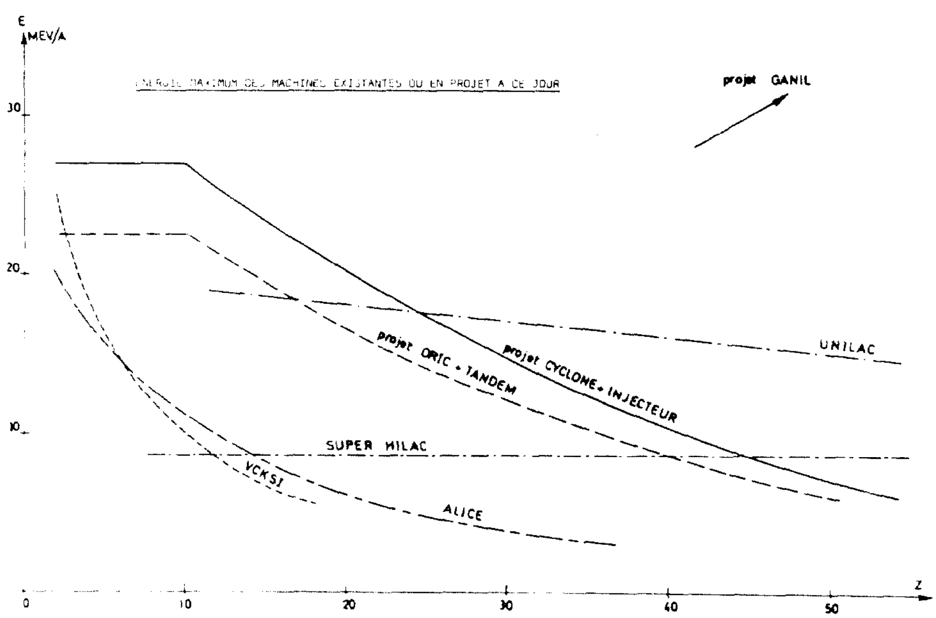


Figure 1

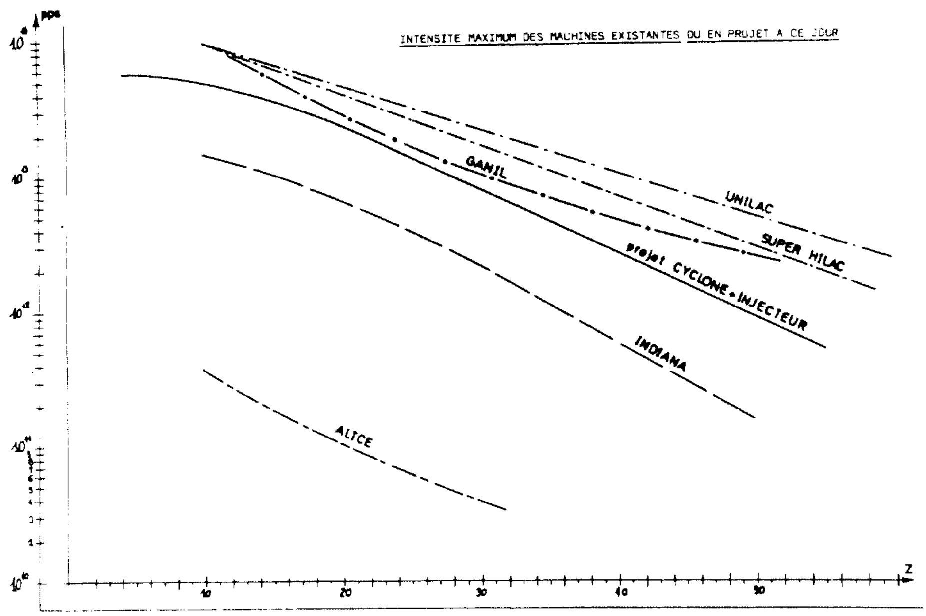


Figure 2

However, the most difficult specification to meet is not coming from physics considerations : there are now, at least in Belgium, serious problems to get money for a new nuclear research project. So, to have a chance to be accepted, the injector cyclotron has to be really cheap.

To succeed in such an enterprise, a really economy-minded design is required. Some aspects of this philosophy are developed here.

For a given magnetic rigidity there is an economical optimum for field and size. Minimizing the sum of the iron, power supply and energy costs and considering the small gap and flutter required, an optimum field of 16 kG was found, giving a pole diameter of 1.72 m. This, combined with a mean gap of 12 cm results in a magnetizing power of only 60 kW. Furthermore, there is the possibility in the future to reach 19 kG just by doubling the current in the main coils. The whole design is made compatible with this possibility.

To keep the possibility of an isochronous field, a small amount of flutter is required. This flutter is provided by two times four sectors of 1 cm thickness, strongly spiraled.

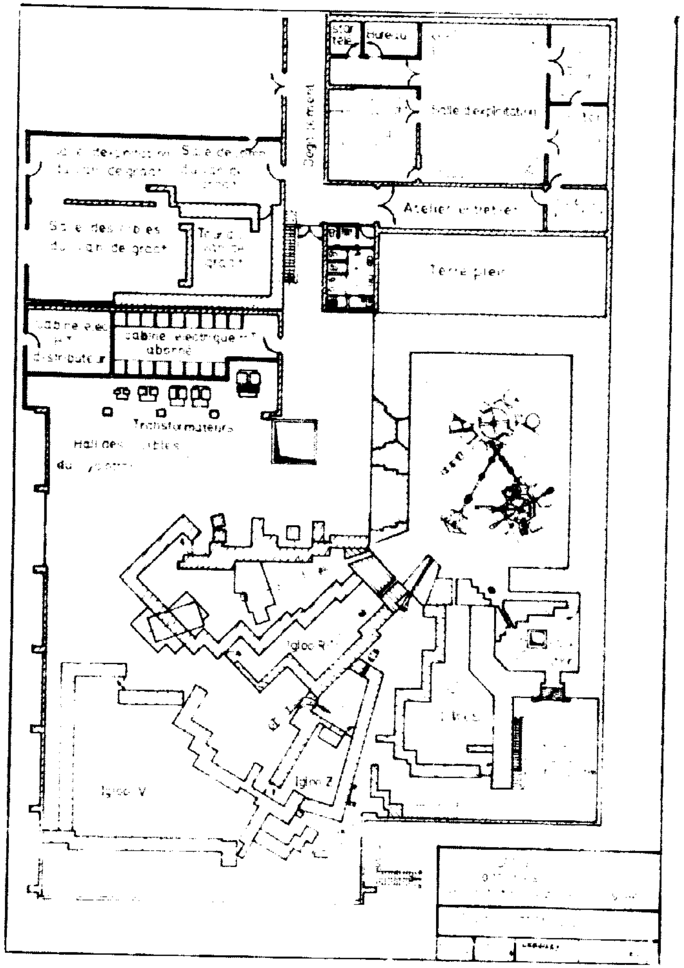
To get a rigourously uniform magnetic field for the heavy ions P.T.G. source, a 20 cm diameter flat region is provided in the center, with no axial hole. This is allowed by the large radius of the first orbit.

Magnet technology is classical, with a yoke made of thick iron plates. The effects of mechanical inaccuracy of yoke is minimized by the use of homogeneizing gaps and careful shimming after completion. Optimum injection energy being inaccurately fixed by stripping considerations, exact value of magnetic field is fixed by the necessity to have a simple ratio between injector and main cyclotron R.F. : computations show that a minimum field of 14 kG is enough to fill the R.F. range without any hole. For this reason, some trimcoils and harmonic coils are provided requiring low power due to this small excursion of the field.

Radio-frequency system design is complicated by the fact that orbital frequencies are very low : from 1.2 to 3.7 Mc/s. At such low frequencies, coaxial lines and panel type cavities are unpractically large. A solution would be to use very high harmonic modes but then the phase acceptance at the center becomes very small and the only way to reach the high beam currents required seems to use a biased source. This is a very complicated and expensive solution.

So it has been decided to go to a more conventional structure : two 90° dees, connected together at the center and working always in second harmonic mode. The frequency range becomes then 2.5 to 7.5 Mc/s. To tune the dees, two short helicaly wound lines at atmospheric pressure are provided. The realization of a movable short on an helical line seeming difficult, it has been decided to use 5 sets of different coils, easy to exchange. Intermediate tuning is done by two large coaxial capacitors under vacuum.

Maximum dee voltage will be 35 kV which corresponds to a maximum power of 30 kW. This power is fed from a home made R.F. power amplifier based on an inexpensive tetrode tube. Frequency is coming from the main cyclotron through suitable multiplying/dividing and dephasing modules.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Terre plein
Transformateurs
Igloo V
Igloo 2

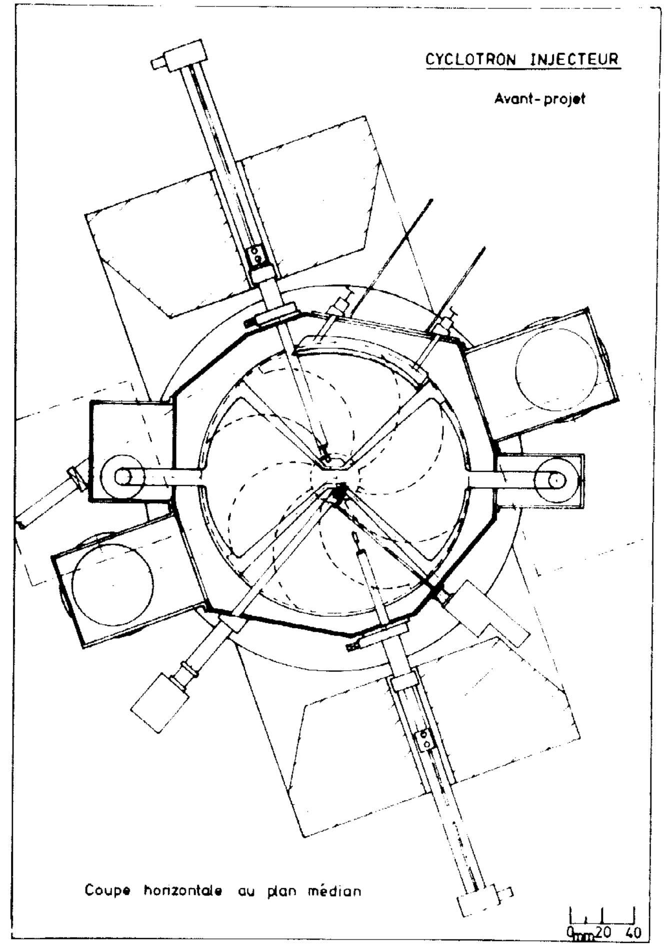
CYCLOTRON INJECTEUR
Avant-projet
Coupe horizontale au plan médian
0 mm 20 40

Figure 4

Source is a P.I.G., hot cathode, source of the Dubna type. It will be introduced radially. Sputtering and furnace models are also foreseen. Vacuum system and extraction are classical and don't need further comments.

The injector cyclotron is designed in such a way that most of the elements can be realized in the institute shops, and only the largest parts are subcontracted in the industry. In such case it is possible to realize the cyclotron within a budget of only 25 millions Belgian Francs (approx. 600.000 $). This doesn't mean that it represents the true price of the cyclotron because the use of the manpower and facilities of the actual cyclotron laboratory are not included.

Concerning the operating costs, the small total electrical power (< 200 kW), the use of inexpensive consumable components and the fact that the operation and maintenance team is the same as for the main cyclotron allows to hope that the cost of one hour of injector will be lower than a fifth of the cost of one hour of the main cyclotron (roughly 100 $ in 1975).

Finally, let's point out the fact that this design appeared to be successful at least on a first but important point : the required budget has received a first official agreement and it is expected that the construction will start in the beginning of 76. If it does, first injector beams are expected in 78 and high energy beams in 79.

INJECTOR CYCLOTRON PROVISIONAL DATA

1. Performances

energy limits
- 54 to 70 MeV x Q^2/A (basic version)
- 54 to 100 MeV x Q^2/A (upgraded)

mass to charge ratio
- $7 \leq A/Q \leq 17$

intensity limit
- $6\ 10^{14}$ p.p.s.

2. Magnet

number of sectors		4
height		2,0 m
width		1,84 m
length		4,1 m
weight		110 Tons
pole diameter		1.72 m
extraction radius		.775 m
valley gap		13 cm
hill gap		11 cm
useful gap	center	11 cm
	other	10 cm
minimum mean field		14 kG
maximum mean field	normal	16 kG
	upgraded	19 kG
ampere turns	normal	190.000
	upgraded	342.000

3. Radio-frequency system

number of dees (connected together at the center)	2
aperture	90°
frequ. range	2.5 to 7.5 Mc/s
type of cavity: short helical line at atmospheric pressure	
tuning: coarse : exchange of helix	
fine : variable capacitor under vacuum	
max dee voltage	35 kV
max R.F. power	30 kW
freq. stability	better than 10^{-6}
ampl. stability	better than 10^{-3}

4. Ion source

P.I.G., hot cathode, Dubna design
radially introduced

5. Extraction

electrostatic deflector
passive gradient corrector
3 quadrupole magnets
2 steering magnets

6. Vacuum system

Oil diffusion pumps	
number	2
speed	2 x 12.000 l/s
baffle	freon-cooled
roots pump	450 m^3/h
pump down primary pump	100 m^3/h
normal use primary pump	30 m^3/h
sas primary pump	12 m^3/h