S.A.R.A. - GRENOBLE STATUS REPORT

M. LIEUVIN

INSTITUT DES SCIENCES NUCLEAIRES
I. N2. P3.
Université Scientifique et Médicale de Grenoble
53, avenue des Martyrs
38026 - GRENOBLE CEDEX - FRANCE

Abstract. - *S.A.R.A. : "Système Accélérateur Rhône - Alpes" is a two stage accelerator situated at the Nuclear Science Institute of Grenoble (I.S.N.). The first stage is a compact Cyclotron K = 90 running since 1968 ; in this paper we describe the second stage which is a 4 separated sectors cyclotron K = 160 and is now under completion.*

I - INTRODUCTION

S.A.R.A. is a two stages heavy ions accelerator. The first stage, the I.S.N. - Grenoble compact cyclotron, is running since 1968 ; the second stage (Post-Accelerator) is a 4 separated sectors cyclotron. The beam from the post-accelerator is injected in the switching magnet and transported to experimental areas using the existing beam lines (figure 1). S.A.R.A. is a common realization of I.S.N. Grenoble and I.P.N. Lyon. The project was first presented in 1976 and definitively accepted in 1977 ; it consists of the construction of the Post-Accelerator itself, the beam lines between the first cyclotron and the post-accelerator (injection line) and between the post-accelerator and the switching magnet (extraction line). An important characteristic of the project is its relatively low cost ; it was estimated to 7.4 MF (1,5 M$) in 1976 not including the laboratories technical staff salaries. This low cost implied that nearly all the items of the new machine would been done at the labs including main coils, correcting coils, power supplies, probes, magnets, cooling system, control system... Only the parts too large to be machined at the laboratories workshops (magnets yokes, vacuum chamber) were done by factories.

From 1976 some modifications to the original project have been done. The most important was the change in the injection system.

In the 1976 project, the ions were stripped on the post-accelerator first orbit. This way had a lot of advantages : very simple injection line and injection system, variable energy gain by variation of the injection radius ; but a very important drawback was that the stripping ratio had to be of the order of 2, excluding acceleration of ions heavier than Argon and use of new sources like ECR or CRYEBIS. In 1979 it was decided to strip the ions in the injection line. That involved a lot of modifications : a more sophisticated injection line, a different central region of the machine, new injection elements, a different RF range.

An other important modification was to add a flat-topping RF cavity running on the third harmonic of the main resonators in order to keep separated turns and to rise the extraction efficiency.

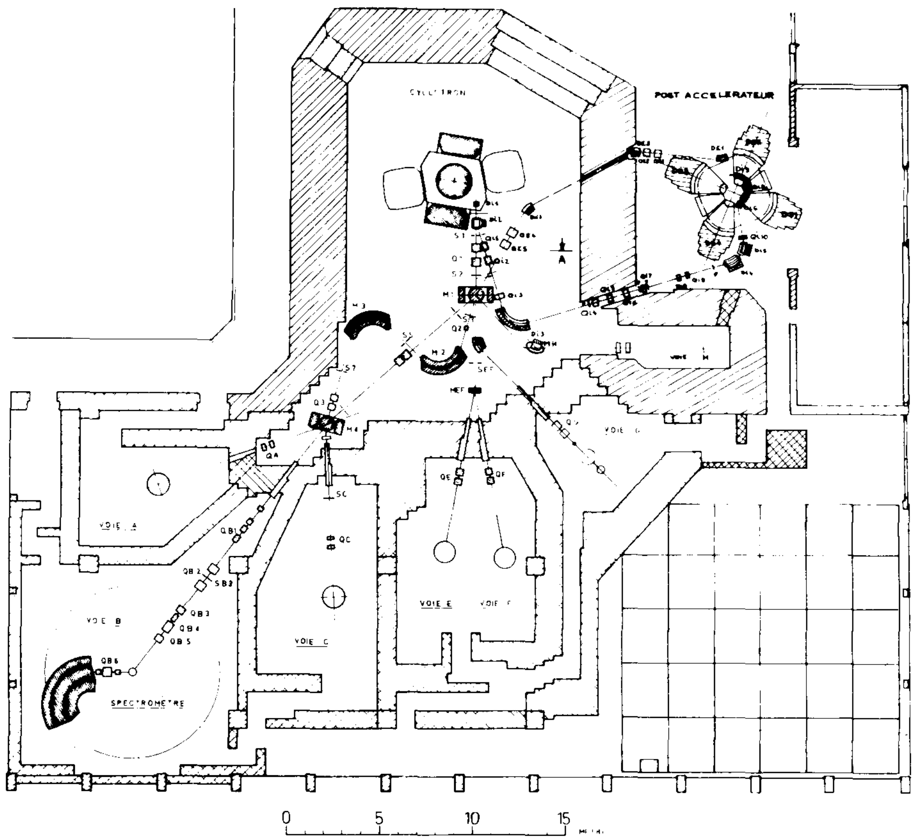

Figure 1 : General layout of S.A.R.A.

II - GENERAL DESCRIPTION OF S.A.R.A. FACILITY

The first variable energy cyclotron is a compact one with K max = 90 ; it was designed by CSF for 60 MeV protons. Acceleration is done by two 80° dees, the dee voltage up to 60 KV, frequency range from 10.5 to 20 MHz, used harmonics : 1, 2 and 3. The Livingston ion source was replaced in 1971 by an internal PIG heavy ion source which enables to accelerate ions up to Argon with energies from 2 MeV/AMU to 7.4 MeV/AMU.

Since 1973 an external PIG source and a new axial injection system allows us to accelerate ions like Be..

The post-accelerator has a K max = 160 ; the energy gain is 5.4 Acceleration is done by two 34° dees with a frequency range from 21 to 32 MHz, harmonic numbers are 4 or 6. A flat-topping cavity running at 3 times the main frequency with a 13° dee gives an energy gain per turn which is constant on 40° phase range within $\pm 10^{-3}$.

Ions at the exit will have an energy between 11 MeV/AMU (Frequency limit) and 40 MeV/AMU (K limit).

In 1982 the first cyclotron will be equipped with an ECR type source : MICROMAFIOS developped by R. GELLER. Ions from the source will be injected using the existing axial injection.

Table 1 gives for some ions and some energies the maximum intensities (in part/s) and figure 2 shows the energy - mass characteristics. This figure demonstrates clearly the interest of using ECR source.

	E/A = 40 MeV	E/A = 30 MeV	E/A = 20 MeV	E/A = 15 MeV	E/A = 11 MeV
			PIG SOURCE		
^{12}C	$1.1.10^{12}$	5.10^{12}	5.10^{12}	5.10^{12}	5.10^{12}
^{16}O	.15	3	5	5	5
^{20}Ne	.01	.2	1.2	2	2
^{40}Ar	--	--	.0015	.01	.3
			ECR SOURCE		
^{20}Ne	$1.5.10^{12}$	2.10^{12}	2.10^{12}	2.10^{12}	2.10^{12}
^{40}Ca	.03	.03	.1	.1	.3
^{40}Ar	--	.03	.1	.1	.3
Kr	--	--	--	.005	.01

Table 1 : Expected intensities for some ions at different energies.

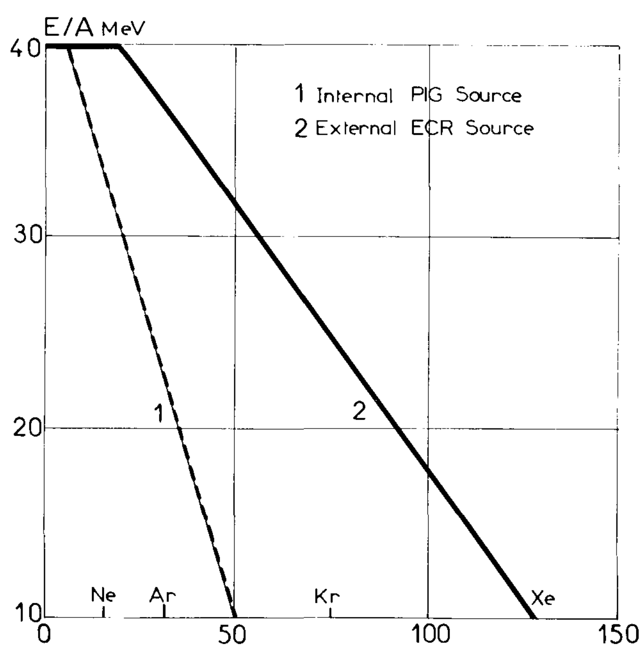

Figure 2 : Energy characteristics

In the next chapters we will describe in more details the post - accelerator ; the first cyclotron being essentially unchanged.

MAIN MAGNETS

Main magnets have been described at the Bloomington conference [1]. Table 2 gives their characteristics.

Sector angle	48°
Spiralisation	0°
Gap	60 mm
Nominal field (K = 160)	1.65 T
At	95 000 At
Magnetic radius	
- Injection	480 mm
- Extraction	1 122 mm
Maximum beam radius	
- Injection	900 mm
- Extraction	2 110 mm
Total weight	4 x 100 t

Table 2 : Main magnets characteristics.

The poles are machined from laminated low carbon steel (.06 % carbon) and surrounded by a welded stainless steel flange which supports the vacuum seal.

Pole face and correcting coils are in vacuum. The Yoke is made from 140 mm thick laminated steel plates welded together and machined. Each main coil has 64 turns of 14 x 14 mm^2 copper conductor with a Ø 7 bore for water cooling, insulation is done by epoxy impregnated fiberglass.

Shimming

Magnets have been shimmed in order to obtain the synchronism without corrections for particles of q/m = 1/2 accelerated up to 32 MeV/AMU. Shimming is done on the pole axis : a slot 120 mm wide x 25 mm depht was machined along the pole axis and filled with steel shims which height is calculated in order to obtain the required mean field along each trajectory (figure 3).

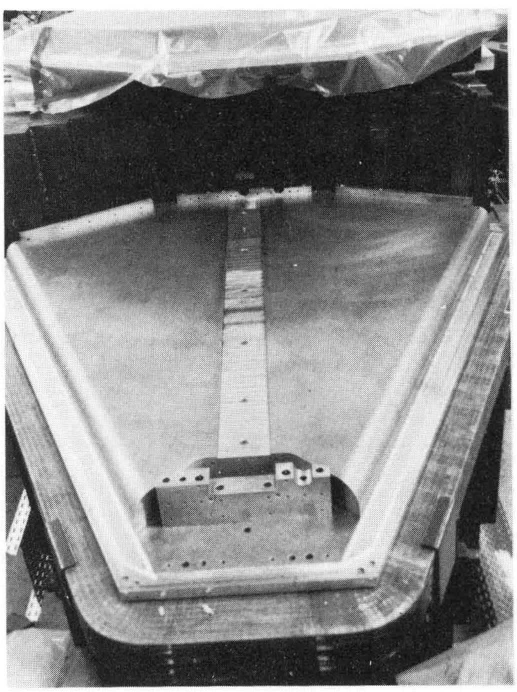

Figure 3 : View of the radial shim.

Correcting coils

Each magnet has 15 correcting coils except D2 which receives injection and extraction elements and have only 12 correcting coils. One correcting coil consists to a unique copper conductor laying on the pole face along the trajectories (figure 4) the turn is closed at the rear of the pole. The maximum current in one coil is 200 A giving ΔB = 75 G.

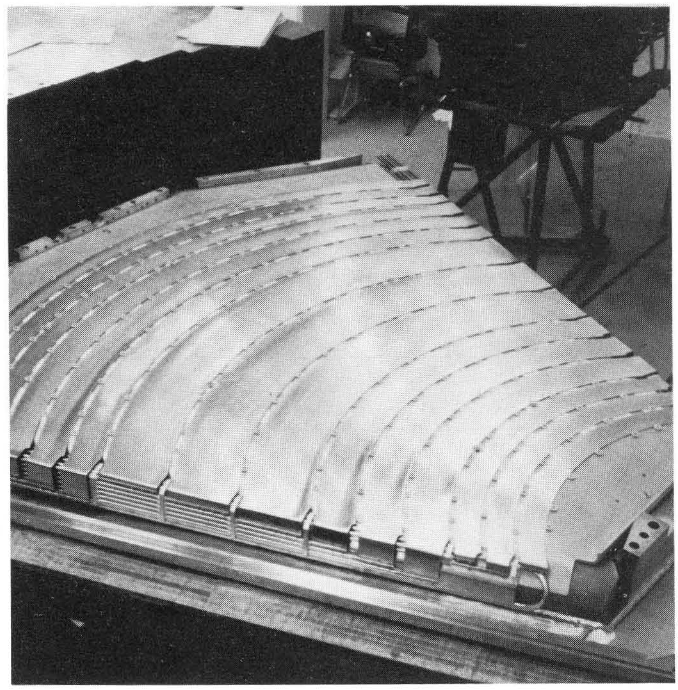

Figure 4 : View of the correcting coils.

Harmonic coils

In magnet D4, the first and second correcting coils are coupled in order to produce an harmonic 1 field bump in the injection region and coil 15 will be used to create a field bump at the extraction radius.

Field measurements

Each sector has been individually measured at different fields, in polar coordinates, 45° on each side of the axis, using 27 hall probes 2 cm spaced. The field between two sectors has been measured in the same way. Field defects due to injection elements have been measured and compensated by symmetric iron pieces (for more details see other contributions at the conference).

RADIOFREQUENCY

Acceleration is done by two identical RF resonators of Indiana type. The dee is supported by two vertical stems which act like $\lambda/4$ coaxial lines with fixed short circuits. Tuning is done by two symmetrical movable panels driven by hydraulic jacks (figure 5).

The main RF characteristics are summarized on table 3.

Dee angle	34°
Dee vertical gap	3 cm
Tuning range	21 - 32 MHz
Peak RF voltage	70 - 100 KV
Q factor	5 000 - 7 000
Phase regulation	1°
Amplitude regulation	10^{-4}
Power (1 resonator)	60 KW

Table 3 : RF characteristics.

Each resonator is driven by an independant regulation loop as shown in figure 6 ; the last amplification is done by a water cooled tetrode (Siemens RS 1082 CW or Philips YL 1010) which maximum anode dissipation is 30 KW. In order to protect the tube, RF is pulsed untill the resonator is tuned.

The coupling is capacitive and variable (max. 10 pF). The pre-amplifier is a 1 KW tuned tube for the tests but we are working on a wide band transistor amplifier.

Each resonator has been tested for more than 2 000 hours and the voltage along the dee measured (figure 7). The absolute calibration has been done by X - rays method.

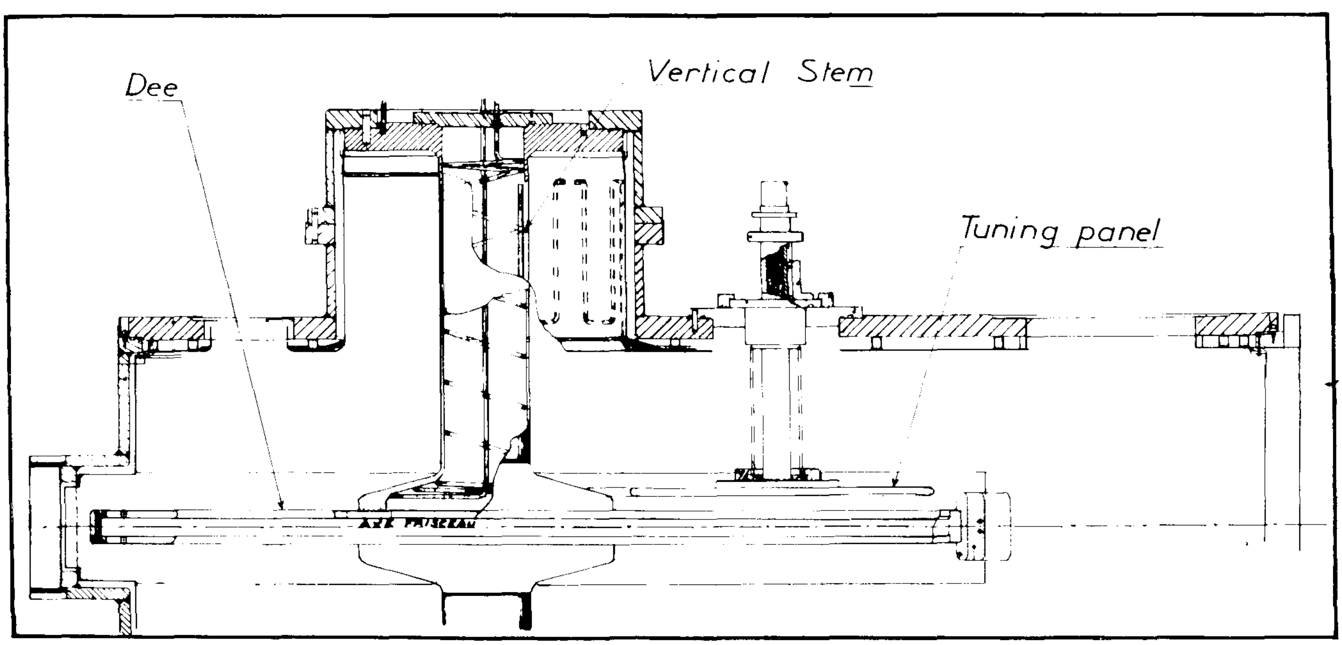

Figure 5 : The main resonator structure

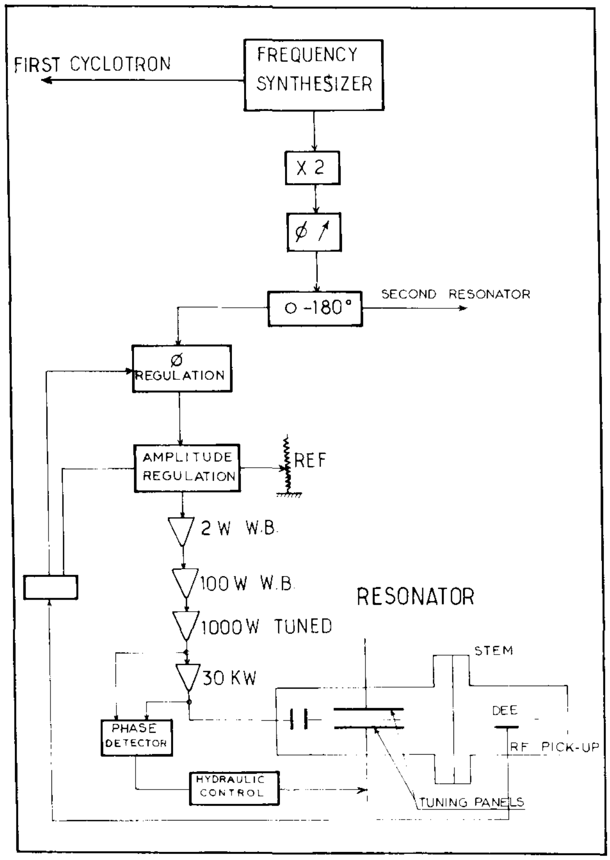

Figure 6 : Schematic of RF loop regulation

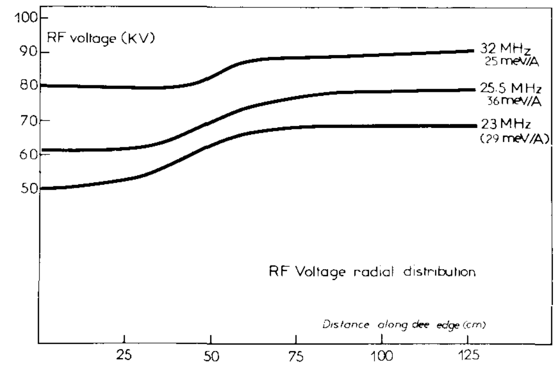

Figure 7 : RF voltage distribution.

III - INJECTION ELEMENTS

Injection is done using 2 magnets DI6 and DI8, one magnetic channel DI9 on the pole tip of D2 and one electrostatic channel EDi (figure 8).

Table 4 and 5 summarize the characteristics of these elements.

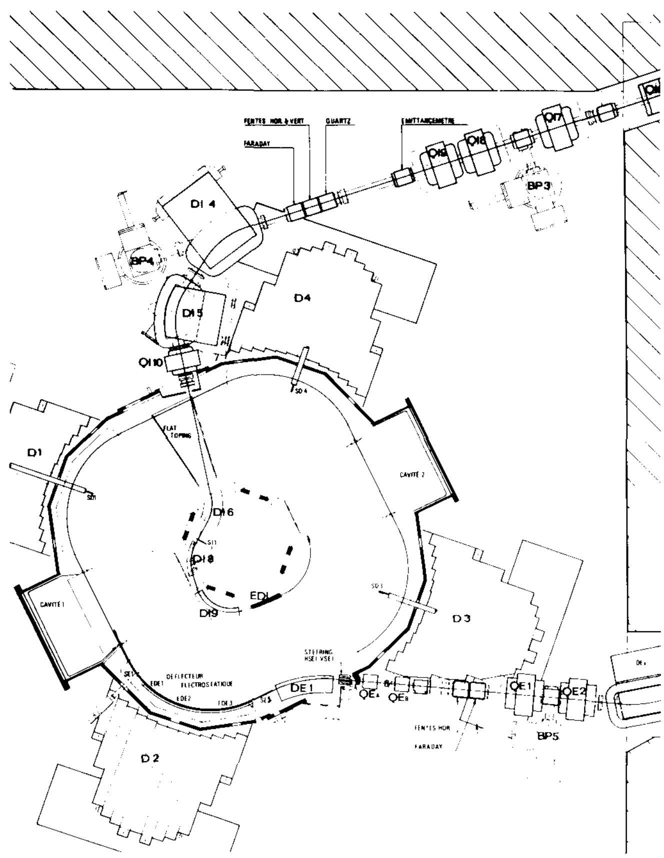

Figure 8 : General view of the post-accelerator.

	DI6	DI8	DI9
Magnetic radius (mm)	515	500	400
Angle (°)	42	45	95
Gap (mm)	15	15	14
Max. Field (T)	1.54	1.64	B_M+.3
At (At)	20 000	21 000	4 000

Table 4 : Magnetic injection elements characteristics.

Maximum electric field	52 KV/cm
Horizontal gap	11,5 to 9,5 mm
Maximum voltage	55 KV
Deviation	2.5°

Table 5 :Electrostatic channel characteristics.

IV - EXTRACTION ELEMENTS

Extraction is done by an electrostatic deflector in the gap of the sector magnet D2 and a septum magnet DE1 which is into the vacuum, in the valley between D2 and D3 (see figure 8). The electrostatic deflector is in 3 parts (EDE1, EDE2, EDE3) which may have different electric fields to compensate for light magnetic field defects in the extraction area. One can move independently the exit of the electrostatic deflector, the entrance and the exit of the septum magnet.

The main characteristics of these elements are summarized on table 6.

Electrostatic deflector :	
- Total length	1 460 mm
- Maximum electric field	36 KV/cm
- Gap	9.5 to 11.5 mm
- Maximum voltage	35 KV
- Deviation	1.93°
Septum magnet	
- Magnetic radius	1 469 mm
- Angle	28.5°
- Gap	15 mm
- Maximum field	1.256 T
- At	15 000 At

Table 6 : Extraction elements characteristics.

V - DIAGNOSTICS AND CONTROLS

In this section we describe briefly only the diagnostic elements for the post - accelerator.

Injection

Fixed horizontal and vertical slits at the entrance of DI6, horizontal slits at DI8 exit, DI9 entrance and DI9 exit ; and a retractable interceptive probe with 5 vertical fingers at the entrance of DI8.

Acceleration

3 interceptive probes on the axis of the magnets D1, D3, D4. Each of these probes can be moved radially in all the acceleration region and have a main finger and 3 differential fingers in order to see vertical oscillations of the beam.

10 capacitive non interceptive phase probes in the valley between D2 on D3 in order to set the isochronism .

Extraction

At the extraction radius a retractable probe with 64 vertical wires will give a pattern of the last 10 turns, we have also interceptive movable probes at the entrance and the exit of the electrostatic deflector and at the exit of the septum magnet.

All the probes are controlled by microprocessor and their currents are displayed on CRT screen. (See other contribution at this conference).

VI - BEAM TRANSFER LINES

The beam line between the first cyclotron and the post-accelerator (injection line) is made up of 4 dipole magnets (18°, 90°, 37°, 45°) and 10 quadrupoles. The line was calculated in order to be achromatic and to match the beam emittance to the acceptance of the post-accelerator. Beam properties at the exit of the cyclotron are summarized on table 7.
The beam line at the exit of the post-accelerator is made up of 2 magnets (32°, 32°) and 6 quadrupoles, it was calculated in order to match the beam to the existing beam lines. Elements of this line may be setted in order to have an achromatic or chromatic transfer. In this last case the energy resolution is 2.10^{-3}. More details in the transfer beam lines are given in an other contribution at this conference.

Beam from the cyclotron	
- Horizontal emittance	20 π mm mrad
- Vertical emittance	21 π mm mrad
- Δp/p	$\pm 1.3.10^{-3}$
Beam from the post-accelerator	
- Horizontal emittance	10 π mm mrad
- Vertical emittance	10 π mm mrad
- Δp/p (without flat-topping)	$\pm 2.5.10^{-3}$

Table 7 : Optical properties of beams at the exit of the cyclotron and the exit of the post - accelerator.

VI - VACUUM

The monolithic stainless steel (NS22S) post-accelerator vacuum chamber is closed by the RF resonators and the magnet poles. Its overall dimension is 5.3 m and its weight 7 000 kg. Vacuum is obtained very classically by 6 x 5 000 l/s oil diffusion pumps, seals are viton O - rings, the residual pressure would be better than 1.10^{-6} Torr.

VII - PRESENT STATUS

The aim was to have a first beam accelerated at the beginning of this year. Unfortunatly, this was not possible, mainly because of a long delay in the vacuum chamber machining which was delivered only on last August. Nearly all the other elements of the new machine have been made and tested, including the transfer lines which have been assembled and aligned precisely. We are now in the last assembling phase and we hope to accelerate a first beam in the next few months.

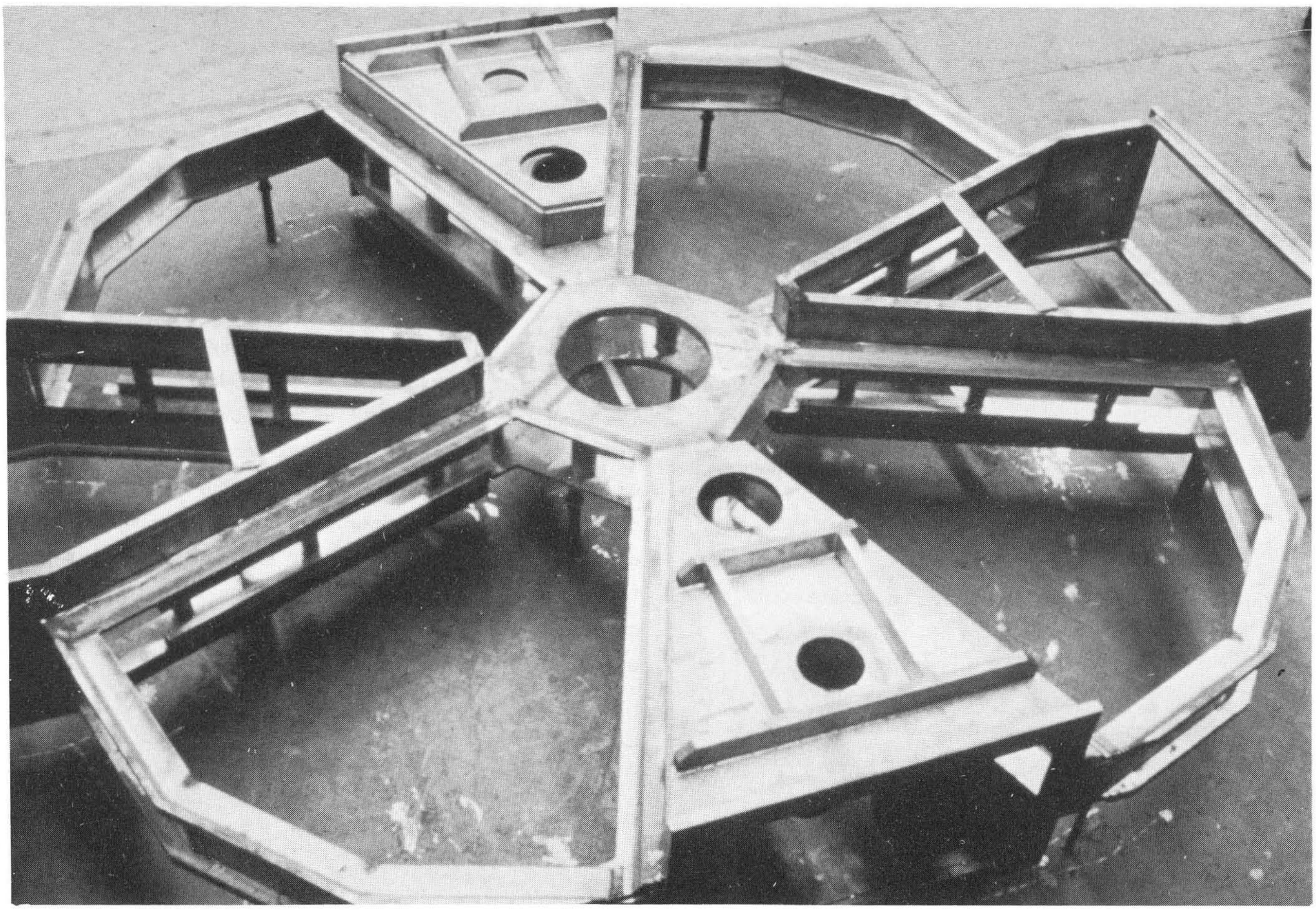

Figure 9 : The vacuum chamber.

REFERENCE

1) J.L. BELMONT, M. LIEUVIN, J.M. LOISEAUX - IEEE, Vol. NS-26, n° 26, April 1979.

" DISCUSSION "

Y. JONGEN : In the first design of S.A.R.A., you had a very simple injection scheme using stripping. Later on, you turned to a more classical design. What is the reason for that ?

M. LIEUVIN : The main reason was that, using internal stripping, we must have a stripping ratio of the order of 2 and this excludes the use of high charge state sources like ECR or EBIS.