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STATUS REPORT ON GANIL

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Abstract.- The parameters of the three accelerators Col, SSC1 and SSC2 of the GANIL system are recalled with a special emphasis on those which have been modified since the beginning of the construction ; furthermore consequences of theoretical works which were made in order to obtain a beam with small energy dispersion ΔW/W are given. The current status of the project is then described : the Col injector is already in operation, as well as the first part of the line L1 (from Col to SSC1) which is used to analyze the beam coming from Col ; magnets (with their trim-coils) and chamber (vacuum tested) of SSC1 are completely assembled ; routine magnetic measurements are in progress whereas the first resonant accelerating cavity is on a special test bench ; magnets and chamber of SSC2 are installed and vacuum tests are under way.

1. Introduction.- The construction of the GANIL laboratory on the site of CAEN was decided and funded in September 1975 ; the completion of the facility is planned for Autumn 1982. The different phases of the construction appear on figure 1.

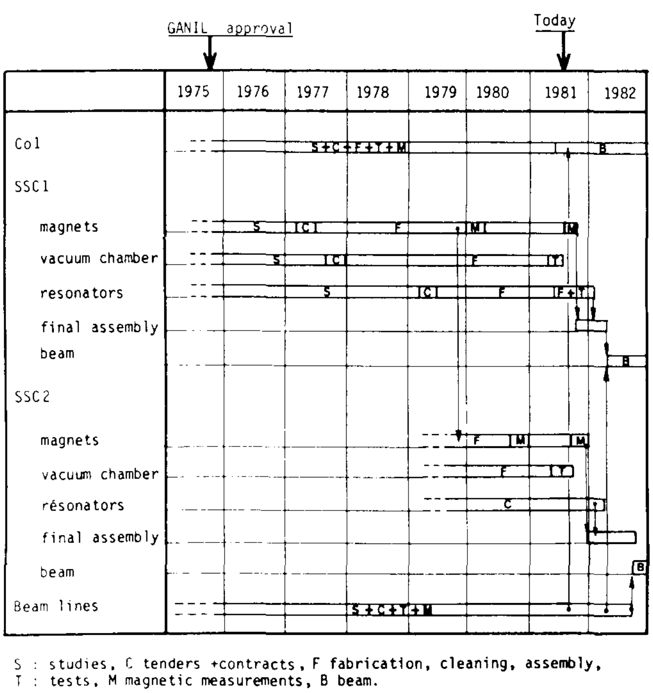

Fig. 1 : GANIL time schedule (main components).

The GANIL scheme has been described in previous publications[1-2] ; let us however recall the main goals :

- acceleration of all ion species from carbon to uranium with a maximum energy of about 100 MeV/A for light ions and 10 MeV/A for the heaviest ;
- beam intensities in the order of 10^{12} to 10^{10} pps
- energy resolution $\frac{\Delta W}{W} \simeq 10^{-3}$

In order to fulfil these beam conditions an accelerator complex was chosen which is composed of three cyclotrons : a compact injector cyclotron Col (actually, for reliability there will be also a second one, Co2 : this one will probably be equipped with an axial injection line and an ECR source), a first separated sector cyclotron SSC1 and a second identical machine SSC2. Between these two large cyclotrons a stripper foil provides higher charge states (optimum value $q_2 = 3.5\ q_1$), the high energy beam coming from SSC2 passes through a monochromator and then enters the experimental area (see fig.2).

The purpose of this report is :
- first to examine the parameters which have been changed since the beginning of the construction and also to give the present ideas on the future operation of the machines and the expected beam characteristics ;
- second to give a short conceptual description of the various sub-systems and to describe the present state of their construction and tests.

2. Theoretical results on future operation.-

2.1 General parameters

They are given in the following table.

	Col	SSC1	SSC2
$\bar{R}_{in}$ m	-	0.814	0.857
$\bar{R}_{out}$ m	0.465	3	3
Harmonic number h :			
HE operation (high energy : energy ⩾ 20 MeV/A)	4	7	2
LE operation (low energy : energy ⩽ 20 MeV/A)	8	14	4
Energy gain		13.6	12.25

Table I

*presented by M. Gouttefangeas.

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Two comments have to be made on this table :

- although $\overline{R}_{in}$ is slightly different in SSC1 and SSC2, these two machines are actually the same, only individual adjustments have to be done ;

- it must be recalled that the value of the injection radius in the initial proposal[1] had to be modified owing to economical and technological reasons (necessary room for injection elements in the central region of accelerators). The increase of $\overline{R}_{in}$ from .75 meter to the present values led to a change from 4 to 3.5 in the optimum stripping factor.

2.2 Future operation and beam characteristics.

As it has been already shown in previous papers and as it will be reported at this conference[3-4-5-6], the requirements concerning the beam quality (mainly the energy resolution) lead us in particular to use the following devices or at least part of them :

Co

. separated turn ejection

SSC1

. a buncher in the injection beam line to compensate for the effect of longitudinal drift resulting from the energy dispersion of the beam

. chromatic correlations at injection[4]

. bunch length compression[5] by a factor of about 2 or phase selection via energy spread by a moving target ($\Delta W_2 \simeq 0.3 \ \Delta W_1$ for $i_2 \simeq 0.5 i_1$)

. compensation for R.F. stopband (for LE operation only[7])

. separated turn ejection

SSC2

. chromatic correlations at injection[4]

. bunch length compression by a factor of about 3

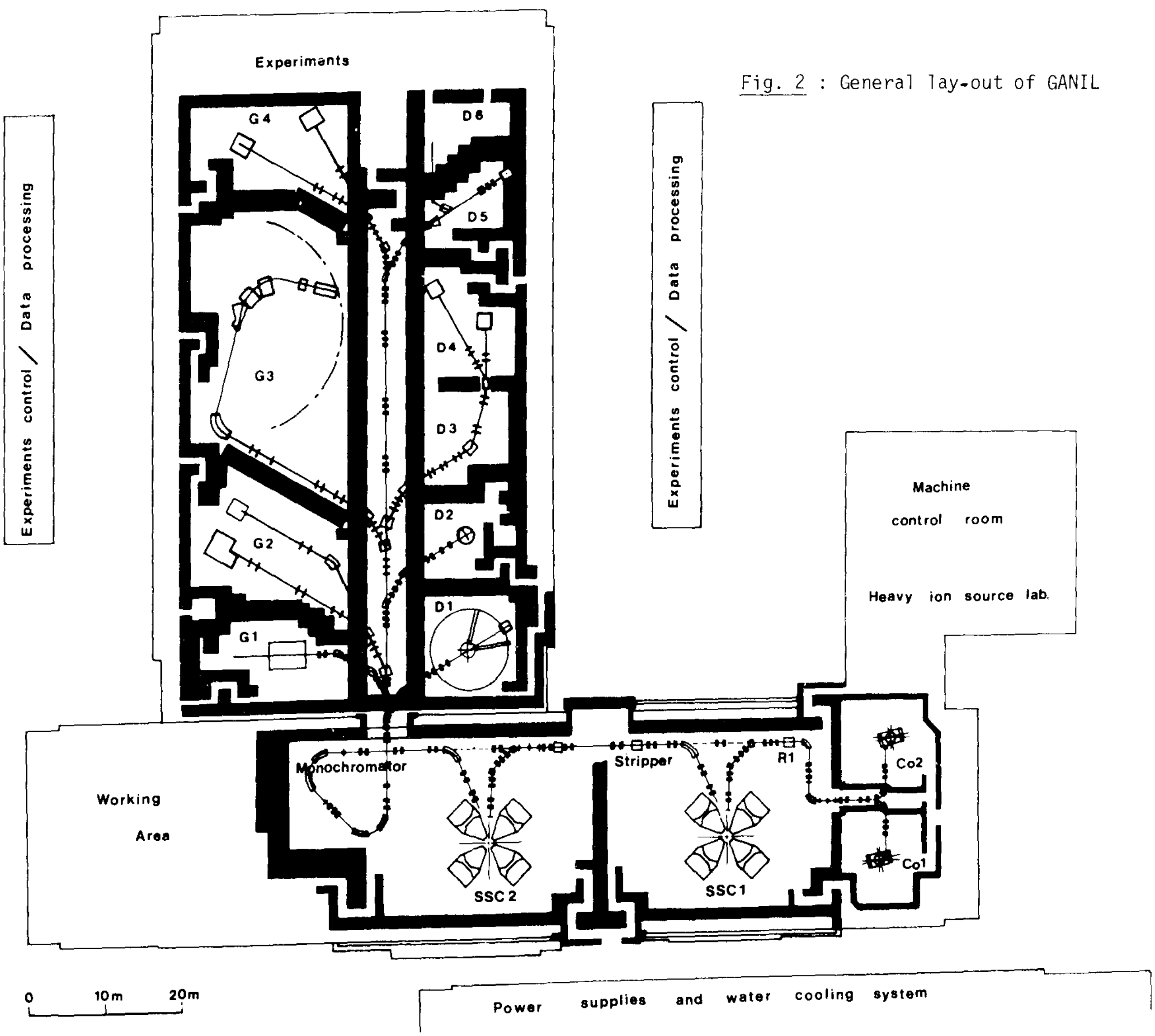

Fig. 2 : General lay-out of GANIL

and consequently for this high energy machine precessional injection (there is no buncher between SSC1 and SSC2

. separated turn ejection.

Moreover, at the output of SSC2 an on-line monochromator (the so-called α spectrometer) the parameters of which are : relative energy resolution $\pm$ 2.5 10^{-4}, relative filtering power $\pm$ 5.10^{-4}. This monochromator is used for tuning the two SSC and also to ensure in any case the delivery unto the experimental area of a beam with good energy spectrum.

The expected beam characteristics at the output of SSC2 are shown on table II. The data are based on theoretical performances of the Co1 cyclotron. However preliminary measurements on this injector seem to be in agreement with theory.

	Flux p.p.s.	Energy resolution ΔW/W	Emittances πmm.mrad H	V
HE operation (A < 40)	10^{11} - 10^{12}	$\pm$ 5.10^{-4}	5	5
LE operation	10^{11} - 10^{12} (A < 40) 10^{11} - 10^{9} (A > 40)	$\pm$ 10^{-3}	8	5

Table II : GANIL beams.

3. Description and present situation of the main sub-systems.

3.1 Injector and source.

The design of the first injector Co1 has been already reported(8) ; let us only give again the most important features of the machine : Co1 is a flat pole cyclotron with K = 30 ; it has to be operated in anyone of four different harmonic modes : 4 and 8 routinely (See Table I) and also 1 and 2 in solo mode (Co + SSC2 in cascade). The dee shape differs with harmonic and the suitable dee has to be connected to the central conductor of the accelerating cavity ; the PIG type source is inserted radially.

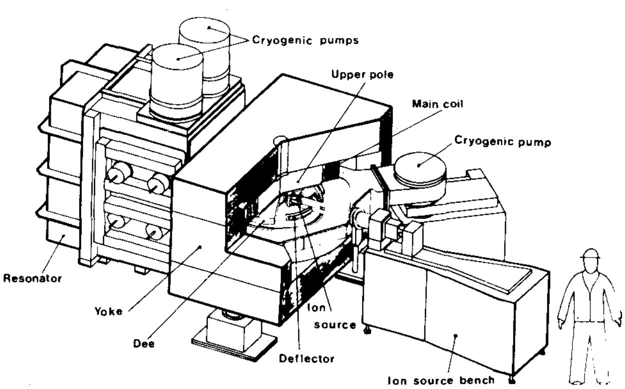

Fig.3 : Co1 injector.

Previously the source has been tested on an experimental bench with D.C. operation and emphasis was put on the production of metallic ions by sputtering and on the lifetime of the cathodes. Tables III and IV give respectively the mean operational current and the emittance of the source, as they were measured on the test bench, with D.C. extraction, the source being tuned for an expected lifetime of about 15 hours.

Element	Gas dynode	Mean Operational current (10^{13} pps) 1^+	2^+	3^+	4^+	5^+	6^+	7^+	8^+	9^+
C	Co^2	310	260		6.7					
N	N^2	290	130							
Al	Xe/Al		13	2.5	0.18					
Ar	Ar	77	120	160	67	23	7	2.4	0.4	
Ca	Xe/Ca			12	4.7	1.5				
Fe	Xe/Fe			6	5.3	2.2	0.37			
Cu	Xe/Cu					2.5	0.9	0.4		
I	Ar/NaI+C			0.83	0.63	0.83	0.97	2.3	1.5	0.6
Xe	Xe			22	19	18	17	15	10	3.3
La	Ar/La			3.7	3.2	4.7	4.7		5.3	4.7
Yb	Ar/Yb_2O_3+C					0.73	1.5	2.6	3.2	
Au	Ar/Au						4.3	5.3	5	3
Hg	Ar/Hg+Ag+Cu						8	6	1.8	0.6
Pb	Ar/Pb						3.7	5.3	6	5

pulse length : one millisecond every four milliseconds (duty cycle = 25 %)
Mean operational current = 0.3* x duty cycle x I_{peak} (gas)
" " = 0.7** x 0.3* x duty cycle x I_{peak} (sputtering)

*This factor 0.3 is introduced to take into account the intensity decrease during the source lifetime (about 15 hours).
**This factor 0.7 is introduced to take into account the shape of the pulse.

Table III : Mean operational currents.

Ion	Duty cycle %	Mean current (10^{13} pps)	Extraction voltage kV	Emittance 80 % of the beam πmm.mrad H	V
C^{2+}	25	550	40	188	
Ar^{4+}	25	160	20	105	
	25	100	20		140
	25	60	20	80	
Ar^{4+}	100	160	20	65	
	100	80	20		93
Fe^{5+}	25	8	20		180
Xe^{7+}	100	8	20		130
Pb^{7+}	25	3	20	230	
	25	2	20		180

The values of the current are different from those of table III. They correspond to the actual values observed during the instant of the measurement of the emittance and are not affected by the coefficient .3 from Table III.

The emittance seems to be independent of the age of the source.

Table IV : Emittances.

The first injector Co1 is in operation since May 1981(10) on the 4th harmonic mode, the measurements have been carried out successively with C^{2+} and N^{2+} beam at f_{rF} = 10 MHz then with a Ar^{4+} beam at f = 9.52 MHz (this beam will be used for the first tests on the other cyclotrons).

They have shown a well-centered beam, in good agreement with computations:for example, radial width at half height is 2 or 3 mm. We nevertheless found a vertical coherent oscillation of 4 mm amplitude, the reason of which has not yet been understood.

Measurements of radial emittance and phase extension have been made internally on the last turn before ejection, then resumed and completed in the beam line which leads to SSC1. Typical values are summarized in Table V :

IONS	Internal beams			External beams		
	flux 10^{12}pps	r.m.s. horizontal emittance πmm.mrad (97%)	r.m.s. phase extension (degrees, total)	r.m.s. horizontal emittance πmm.mrad (97%)	r.m.s. vertical emittance πmm.mrad (97%)	r.m.s. energy spectrum 10^{-2}
N^{2+}	7.5	17	11.5	-	-	-
"	13.5	23	14.5	-	-	-
Ar^{4+}	0.5	27	-	-	-	-
"	1.2	29	13	-	-	-
"	3	40 *	-	50 *	30	± 0.3
"	7	50	-	-	-	-
Cu^{6+}	0.23	40	-	-	-	-

*the methods of emittance measurement for internal and external beams are not the same.

Table V : Co1 first measurements.

The second injector Co2 will be mainly used in conjunction with Co1 when the schedule of the GANIL will request more flexibility for changing the type of accelerated ions. It will be almost identical to Co1, nevertheless provisions will be made for future axial injection system with probably the use of an ECR source.

3.2 Magnet.

Each cyclotron has four separate sector magnets of 52°. Each sector weighing 425 tons has been divided into 10 pieces by horizontal cuttings[11-12].

The eight pieces of the yoke are made of pre-crushed laminated iron whereas the two pole pieces are fabricated from forged iron.

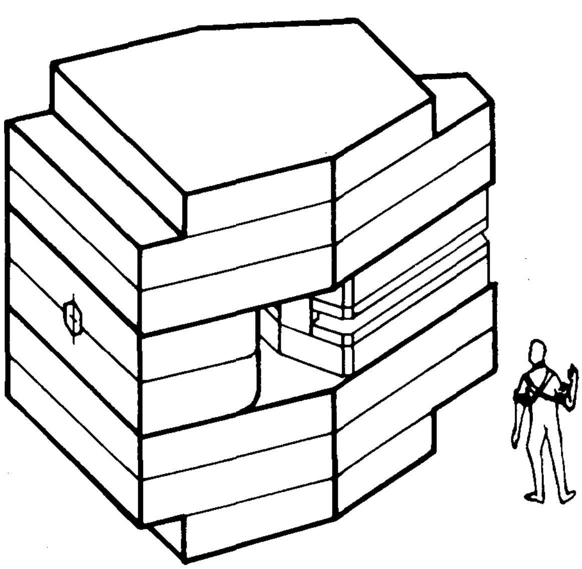

Fig.4 : GANIL magnet.

The assembly of the magnet is a simple stacking of the ten pieces, without bolts, the cohesion of which is given only by weight and magnetic forces. This construction technique was possible on account of the very good accuracy of the machining of the surfaces. A carefull measurement of the height H has been made before the introduction of the pole complex. Adjustment of the mechanical shims which define the damping gap were made taking into account the measured values of H. (See fig. 5).

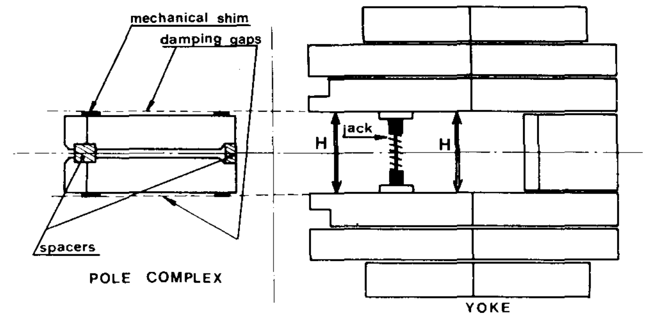

Fig. 5 : Magnet mechanical adjustment.

The useful gap itself is defined by three stainless steel spacers which ensure quite parallel pole surfaces.

As the main coils are located in the vacuum chamber (See 3.3) each of them is enclosed in a vacuum tight stainless steel box which has been welded after epoxy impregnation. The box sustains the internal atmospheric pressure.

In the gap are located 2 pole face windings. Each one is composed of 32 coils following the hard-edge theoretical ion trajectories. They are made with mineral insulated hollow copper conductors. These trim-coils (See 3.3) are enclosed in vacuum tight stainless steel boxes with atmospheric pressure or preferably rough vacuum inside. Theses boxes are composed of a thick base plate with grooves for the conductors and a thin cover plate. These plates are tightened together by spot welding.

Today the eight magnets of the two SSC are completely assembled, with their vacuum chambers ; preliminary magnetic measurements have been made on both machines and final measurements on SSC1 are in progress.

The computed mechanical behaviour - with excitation current - has been verified : with B = 1.7 T the forces in the spacers have been measured (2.10^3kN in the front spacer and 2.5 10^3kN in each of the two rear spacers) ; likewise have been verified the gap deformation ($d \leqslant 0.15$ mm) and the radial displacement of the upper nose ($\Delta r = 0.2$ mm).

Field shapes in the four sectors of a machine are the same but absolute levels are slightly different : for example, in SSC1 we have for a main field of 16000 G :

Sectors	A	B	C	D
ΔB	- 43 G	+ 77 G	- 15 G	0

therefore the measured ΔB are in the order of 5.10^{-3}, half of this value is coming from steel properties dispersion and half from gap mechanical dispersion. An auxiliary coil in each magnet compensates for this effect.

Magnetic field mapping without injection elements gives very good field shapes : the average field deviates by less than 20 gauss from the theoretical isochronism law for which the pole side profiles were designed (γ = 1.00 for SSC1, γ = 1.05 for SSC2) (See fig. 6).

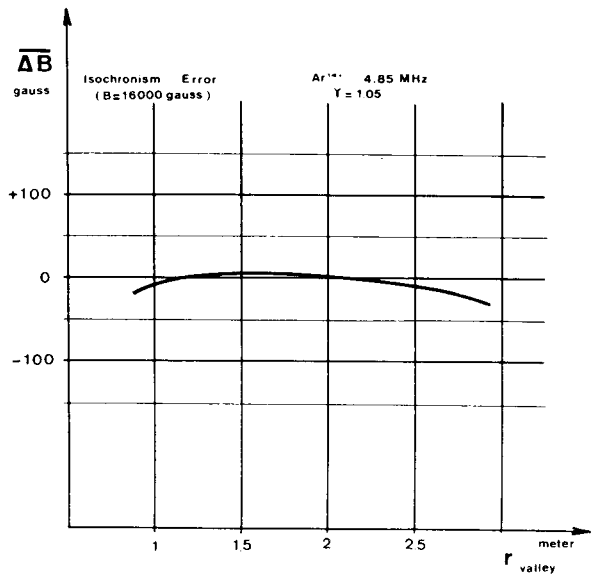

Fig. 6 : Field quality, SSC2.

Magnetic field mapping of the four sectors of each machine with their injection elements (See 3.4) has then been made[12]. Taking into account the results of the measurements it was decided to correct locally the field effects of Mi2 and SMi3 (See 3.4) by a special trimming of the poles profiles close to Mi2 (in SSC2) and with iron shims installed on SMi3 (in SSC1 and SSC2).

3.3 Vacuum chamber and pumping system.

The vacuum chamber of both SSC which is a 316 L stainless steel monolithic vessel has been previously described[13].

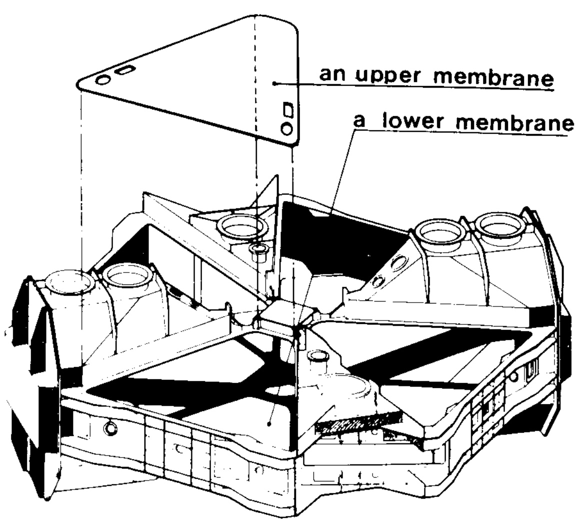

Fig. 7 : GANIL chamber.

It is a large mechanical structure (diameter 9 m, height 4.3 m, weight 55 T) which was entirely computed by a finite elements method and then was fabricated as a welded assembly. The different parts of the vessel were electrode welded and then fit together by electron beam welding ; finally the large vacuum flanges were machined on the whole vacuum chamber.

Concerning the vacuum tightness of the vessel one has to recall that the pole pieces and their spacers, the main coils and the trim coils are located inside the vacuum chamber ; the continuity of the vessel is then achieved by thin membranes. The lower membranes

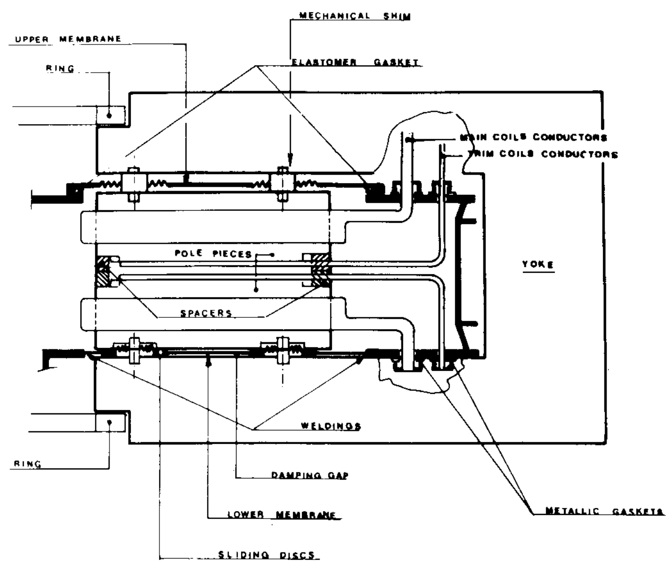

Fig. 8 : Vacuum tightness of the chamber.

are welded to the chamber, the upper ones are equipped with elastomer gaskets (these are the only elastomer gaskets on the chamber, all the other gaskets are metallic). Such membranes allow differential movements between magnet and vacuum chamber, in particular vertical and horizontal displacement of the upper nose of magnets when the magnetic field is setting up.

The monolithic body of the vessel is supported mainly by very strong vertical struts on the sides of the sectors and also by a pair of iron rings at the noses of the sectors which are radially independent of magnets deformation and strenghten the chamber in the radial and axial directions.

Today the vacuum chambers of SSC1 and SSC2 are put in place, completely cleaned and firmly fastened to the magnets and rings ; the vacuum tests of SSC1 have been completed and they are in progress on SSC2. It has been possible to measure the deformation of the body under atmospheric pressure and the thermal gradient forces : we found on flanges a maximum value of about 0.05 mm.

The pumping system of each SSC is composed of 4 turbomolecular pumps and 8 cryogenic pumps (operating without liquid nitrogen) ; provisions are made for mounting 8 cryogenic panels[14] and 2 additional cryogenic pumps.

The vacuum tests which were carried out in SSC1 were performed with the 4 turbomolecular pumps and only 5 out of the 8 cryogenic pumps ; after suppressing some leaks coming from the metallic gaskets, the pressure finally reached was 8.5 10^{-6} Pa (6.4 10^{-8} torr), this is a satisfactory value very close to the requirements. Unfortunately this was achieved after too long a time (290 hours), it seems that the reason for that is a saturation of the cryogenic units due to a too high starting pressure.

3.4 Injection and ejection systems.

The original designs of both systems[15-2] are still valid : nevertheless two new developments have to be considered.

The first one is the introduction of phase compression in both machines (See 2.2) which reduces the energy gain per turn and therefore the turn separation of the beam[5-6] on the first orbits. In SSC1, in order to face this reduction one can energize again the electro-static deflector ESi5 and suppress SMi4, but

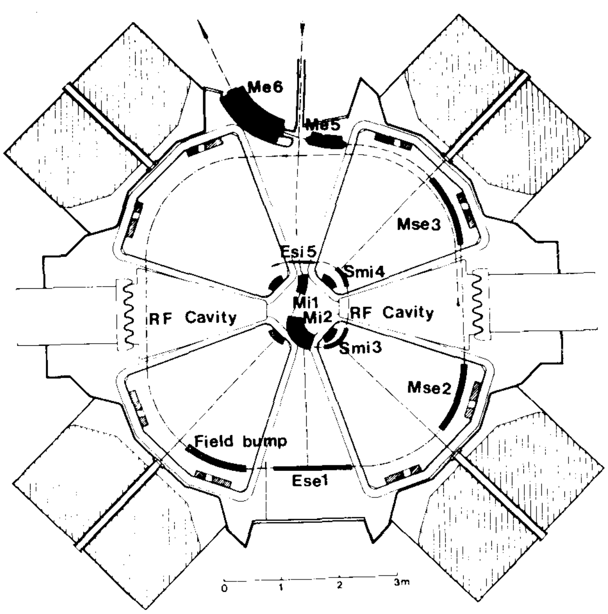

Fig. 9 : Injection and ejection (in SSC1 SMi4, Field Bump are not to be installed.)

this is a non-optimum process as $\gamma_r \simeq 1$; nevertheless it will be possible to operate with a relatively low voltage in this deflector (V ≃ 15 kV). In SSC2, the normal turn separation being small, it would be necessary to adopt a precessional injection scheme (See 2.2)

The second new development is coming from the effects of injection and ejection elements on the main field (mainly from Mi2, SMi3 and, to a lesser degree from Me5). These effects are rather serious for large harmonic numbers (LE operation) ; we had to compensate for them by magnetic shimming (See 3.2).

3.5 SSC Acceleration system.

The GANIL SSC resonators are of the delta-type, tuned by a variable capacity. Their parameters are summarized in Table VI :

Number (per SSC)		2
Δ angle (middles of gaps)	degree	34
Tuning	variable capacity (movable panel)	
Frequency range	MHz	6.4 - 13.8
Max. Voltage (peak)	kV	250
Max. Q		14.000
Max. Power Dissipation	kW	90
Coupling system	inductive loop	

Table VI : SSC resonators parameters.

The resonators were previously described[16] ; let us only recall of the main characteristics of their mechanical and electrical conceptual design :

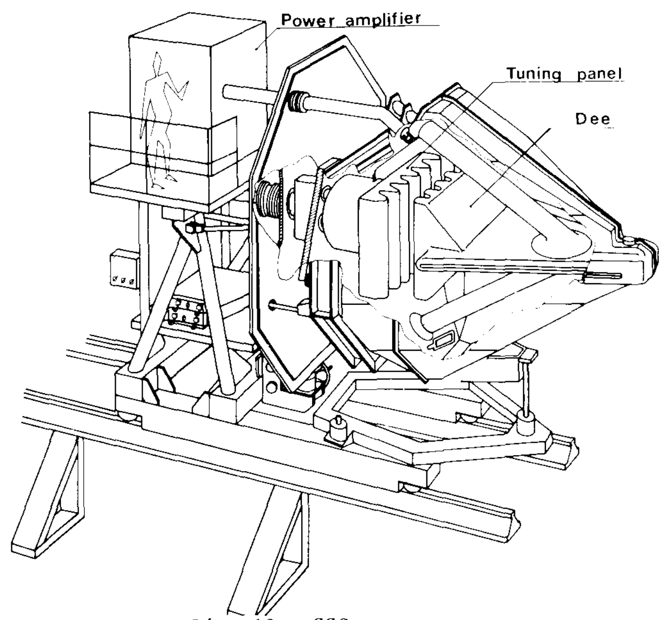

Fig. 10 : SSC resonator.

. compactness having regards to the frequency range of the structure : height 4 m ;

. no deformation due to atmospheric pressure forces since the resonator is entirely located inside the vacuum chamber ;

. very easy positionning since it is movable forward and backward on rails as a whole (with the power amplifier and the chamber cover plate) whereas in operation it is supported by 3 jacks which are independent from the vacuum chamber ;

. increasing voltage as a function of radius for any frequency. This is an important feature for separated-turn ejection.

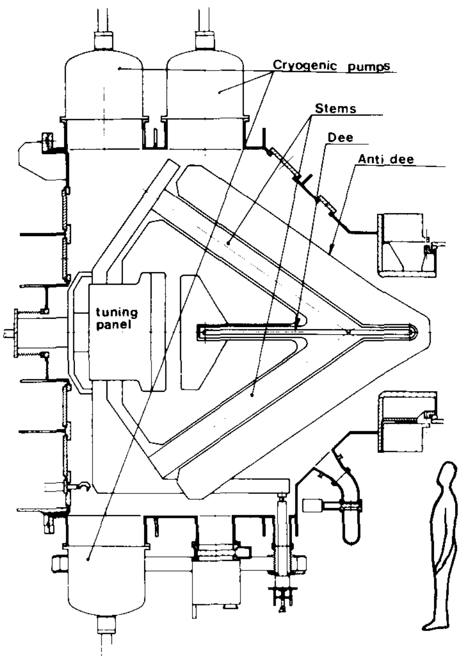

Fig. 11 : Resonator section

Today, the first cavity completely assembled, has been put inside a special vacuum vessel. Radio-frequency tests with full power (all the amplifiers are already available) and with control loops are in progress[17].

Amplitude and phase regulations of the accelerating voltage are necessary conditions in order to obtain at the output of the three cyclotrons a good beam quality : $\pm$ 5.10^{-5} and $\pm$ 0.15° are respectively required for voltage stability and phase regulation.

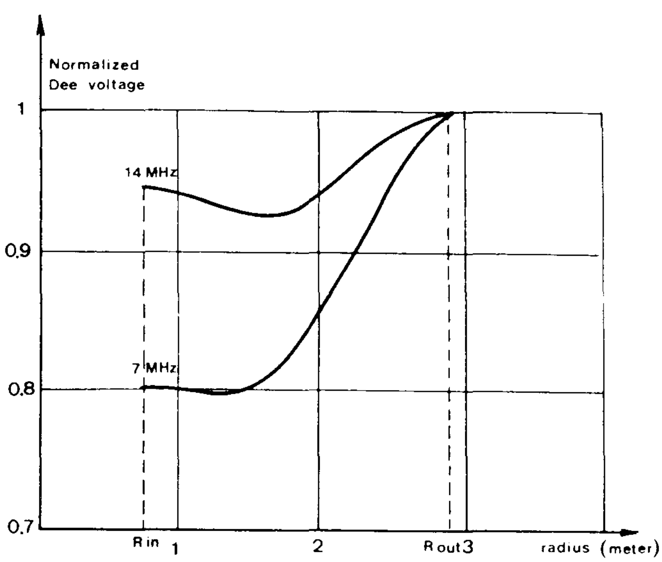

Fig. 12 : Radial voltage distribution

Two kinds of servo-systems are used for the frequency tuning of the cavities : a movable panel (coarse adjustment) and a rotating loop (fine adjustment ([17-18])). For the phase regulation there is a classical phase shifter which has a good amplitude rejection and for the amplitude feedback an amplitude modulator which has a very small parasitic phase effect.

All these loops were tested in a model cavity at nominal power-level. Typical performances measured at 14 MHz are given on Table VII.

Tuning system		
a) movable panel		
electrical resolution (1 step)	Hz	15
mechanical resolution (1 step)	µm	1
b) rotating loop		
electrical resolution (1 step)	kHz	0.07
small signal open loop gain		
1 Hz		60
small signal unity gain bandwidth	Hz	2.5
Phase regulation		
small signal open loop gain		
300 Hz	dB	40
600 Hz	dB	34
small signal unity gain bandwidth	kHz	11.5
signal to noise ratio	dB	> 80
Amplitude regulation		
small signal open loop gain		
300 Hz	dB	57
600 Hz	dB	51
small signal unity gain bandwidth	kHz	12
signal to noise ratio	dB	> 90
relative thermal drift	per °C	< 10^{-5}

Table VII : Control loops preliminary results.

3.6 Beam lines.

The main purposes of the beam lines([19]) which are installed in the machine building are :

. to measure and to limit the vertical and horizontal emittances and the energy dispersion of the beam (spectrometer resolution $\pm$ 0.5 10^{-2}) at the output of Co ;

. to compensate for the phase spread depending on the energy spread ;

. to achieve the chromatic correlations required for an optimized injection into both SSC's(See 2.2) ;

. between SSC1 and SSC2, to increase the charge state of the ions (optimum multiplication factor 3.5) by using a carbon foil stripper. Notice that for line adjustments of the particle energy the foil is DC biased (V_{max} = 120 kV) ;

. by the means of the spectrometer located between SSC2 and the experimental area to measure the energy resolution and to limit the energy spread (down to $\pm$ 2.5 10^{-4} and $\pm$ 5.10^{-4} respectively).

On the experimental area the transport lines have two important characteristics :

. all beam path from the output of the spectrometer to the beam images in the experimental caves (including the deviations) are achromatic ;

. the beam can be time-shared between two users in two different caves (therefore the deviation magnets will be pulsed).

Finally, we have to emphasize the fact that all the line sections (machines + experimental areas) have separated functions : accordingly we hope that the adjustments will be fast and easy.

Fabrication or assembling are now in progress. The first part of the lines at the output of Co1 (See 3.1) is already in operation.

3.7 Beam diagnostics and control system.

Diagnostic probes will be used in the SSC to measure the beam position and intensity during injection and ejection and also the radial position, the central phase and the phase extension during acceleration[20].

The radial beam position will be measured along three radii by classical differential probes with three fingers moving continuously along the axis of three magnets and having a good vacuum design (no moving gaskets only bellows are used).

The central phase of the particle bunches will be measured by 15 fixed capacitive probes which are located along a radius in a valley ; their electronics is operating on the second harmonic of the RF accelerating frequency in order to have a sufficient rejection efficiency.

The phase extension of the beam will be measured by a secondary-emission probe mounted on one of the three radial position probe arm and consequently radially movable but destructive.

In the beam lines[19], besides classical and coaxial Faraday cups, we will have wire detectors giving the horizontal and vertical profiles of the beam and a central phase detector to provide the phase feedback of the machines.

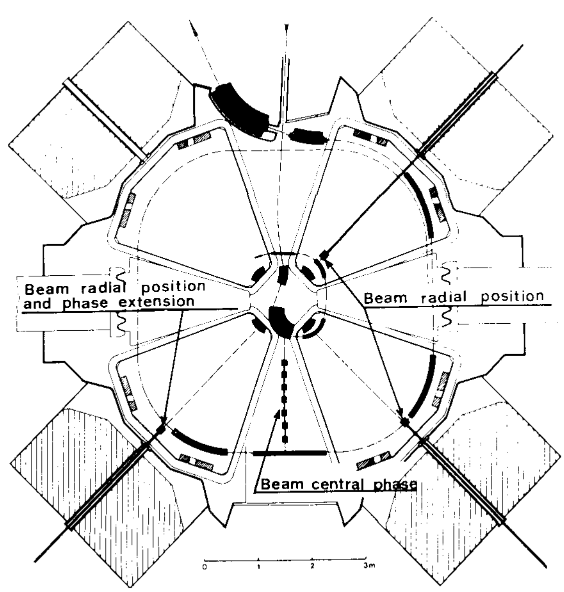

Fig. 13 : Diagnostics for acceleration.

All these beam diagnostics are constructed or being assembled. Some of them were tested in other laboratories with heavy ions or electrons beams on operating accelerators.

The control system [21-22] is mainly based on two MITRA 125 computers, 15 microprocessors (actually autonomous Camac crate controllers driven by microprocessors) and 15 programmable controllers. All these processors are linked together via Camac data links and interfaced to the GANIL process through a parallel Camac branch handling the main console and two serial Camac loops.

The main characteristics of this system are :

. The first computer (equipped with 128 K 16 bits words) is in charge of controlling the accelerator, the second one (192 K words) is devoted to ancillary tasks, software development and to back up the control computer in case of failure.

. Microprocessors are used for running local and repetitive tasks in order to save the main computer time. There are console microprocessors and process microprocessors. Process microprocessors either are in charge of local equipments or perform computation on data coming from beam diagnostic devices (such as tuning RF cavities, phasing cavities between themselves, measuring the central phase of the bunches,...)

. The console system is composed of a main console located in the control room and 4 movable consoles which can be connected at some points along the serial loops for controlling equipments which require local attention.

. The specific software of the control system - named GANICIEL - is written in LTR, a structured high level real time language similar to PASCAL.

The control computer has no safety tasks concerning the protection of people or the safeguard of the equipements. These tasks are assumed either directly by local circuits, or if necessary by programmable controllers. However, in case of incident, the control computer is kept informed by the means of an interrupt signal sent by the corresponding programmable controller.

Our computers have been in operation for a few years. During this period they have been more specifically used for on line (magnetic field measurements and various correlative computations,....) and to write and test the system software.

The main part of the microprocessor software written in assembly language is completed and presently under test.

Some programmable controllers are already in operation : for example, programmable controllers for the vacuum pumps of SSC1 and SSC2, for the RF and the vacuum pumps of Co1.

The console system is partially equipped : a priority has been given to the completion of the movable consoles which are more useful during the construction and tests period.

On the whole the first operation tasks which are required from the control system (for instance testing the first injector Co1 and its beam) are being prepared ; as the construction of accelerators makes progress new equipments are connected to the control system.

Acknowledgements

Many other works have been done at GANIL or are under study and development (for example See([23]) concuring into full operation of the accelerators by fall 1982.

This status report summarizes the activity of a number of engineers and workers from the french and european industry and of about 200 enthusiastic people from GANIL or from other french laboratories which are taking part into the construction of the facility and have made valuable contributions to the project.

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" DISCUSSION "

H. BLOSSER : Would you give more details on the expected schedule for operating the GANIL cyclotrons ?

M. GOUTTEFANGEAS : The time schedule of the 3 GANIL machines is :

- Co 1 already in operation since May 1981
- CSS 1 in operation at Spring 1982
- CSS 2 (and full operation of accelerators) in operation at Autumn 1982

G. DUTTO : Can you expand on the project of using precessional injection for the second stage, and tell us how it will work with various types of particles ?

M. GOUTTEFANGEAS : Certainly you will have the answer to your question in Dr LAPOSTOLLE's report (this conference).