STATUS REPORT ON THE FIRST SIX YEARS OF GANIL OPERATION

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ABSTRACT

The accelerator has been operating for six years, with a PIG ion source until December 1985 and with an ECR ion source since this date. Main statistical results about the running time distribution are given. Technical improvements, machine studies and beam developments made from the beginning are summarized. Three major modifications were decided in 1987 : the energy increase project which will be completed by July 1989 ; an additional beam line to continuously send medium energy beams to a dedicated experiment room (to be completed this year) ; the installation of a new ECR source on a redesigned axial injection line for increasing the beam intensity (to be completed by the end of 1990).

Concerning the experimental area facility, we describe the modification of the LISE spectrometer (LISE3 project) and the increase of the high energy beam line acceptance for secondary beams (SISSI project).

STATISTICS OF OPERATION

The accelerator has been operated with a PIG ion source from January 1983 to December 1985 and with a ECR ion source since this date.

Fig 1 shows how the total running time (27920 hours) has been shared between physics and industrial applications, initial settings and beam tunings, machine studies and new beam developments. For a total time of 19678 hours devoted to users, 15700 hours have been effectively used on target, 3306 hours are accounted for equipment failures and beam retuning, and 672 hours have been spent for maintenance and ion source changes (PIG source and then ECR source when operating with solid sample).

The operation efficiency has been regularly progressing : from 56% the first year of operation to 91% in 1988 (fig 2).

Beam Setting up

Despite efforts made up to now the initial setting mean time decreased only from 46 hours in 1983 to 26 hours in 1988. This progress is mainly due to improvements in beam diagnostics systems, power supply stability, automatic beam tuning computer programms but also to ECR ion source operation since 1985 and to the know-how of operator teams.

Progresses in beam diagnostics signal processing and particularly in computer control systems are the main conditions for achieving the accelerator tuning from a standstill situation within a 15 hours span. Six beam changes have been worked out in 1988 in such way as to keep all magnets from the ion source to the stripper at their previous parameters. So the spared time is about 10 hours per beam set up. This method can obviously be extended to only a limited number of beams depending on user's requests.

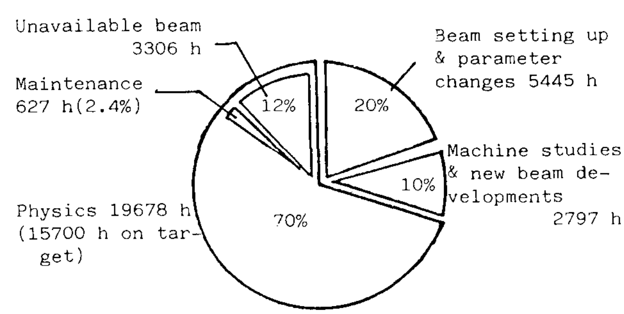

Figure 1 : Division of GANIL cake from 1983 to 1988

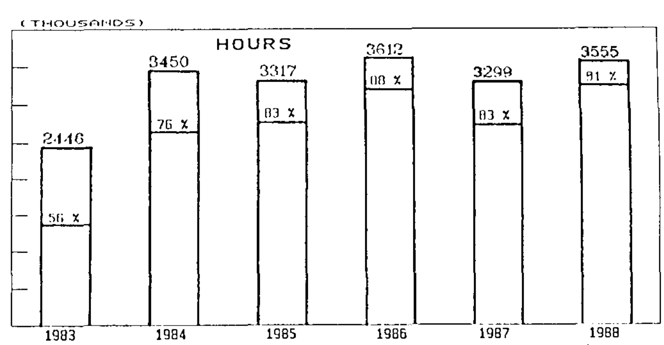

Figure 2 : Scheduled (hours) and effective (%) beam time on target from 1983 to 1988

Fault Distribution

Table 1 gives the breakdown time per year and the retuning time which corresponds to the time needed after a breakdown period or the time required for refining parameters after a few days of continuous beam on target.

% of the scheduled time for physics	1983	1984	1985	1986	1987	1988	
	41	8,2	7,9	5,3	5	4,6	break down
		14	7,6	5,9	4,5	4	retun.

Table 1 Beam unavailability evolution from 1983 to 1988

Physics

The number of experiments completed has been 236 for physics (97.6%) and industrial applications (2.4%) with 54 different beams of elements from ^{12}C to ^{132}Xe and their isotopes at an energy range going from 95 MeV/amu down to 3.6 MeV/amu. The intensities on target have been in the range from 2.10^{12} pps ($^{13}O^{8+}$ at 60 MeV/amu) to 7.10^{9} pps ($^{132}Xe^{35+}$ at 27 MeV/amu) i.e. from 2.5 eμA down to 40 enA.

IMPROVEMENTS AS SEEN BY THE USERS

Beam Characteristics (table 2)

They have not changed since the operation beginning, except for a few points :

a) Beam intensity :

The replacement of the PIG source by an ECR source has resulted in more intense beams of higher charge state ions, a perfect beam stability and a continuous mode of operation.

b) The long term beam stability has been bettered by about a factor of ten after adding servo loop systems locked on beam phase variations[1].

c) Several channeling experiments needing an angular divergence as small as 0.15 ± 0.05 mrad, in both the horizontal and vertical directions have been performed with Ar at 60 MeV/amu and Xe at 25 and 27 MeV/amu.

d) The important problem related to the beam pulse length reduction has finally been partially solved by using special tuning method of SSC2 combined with beam emittance reductions (beam intensity divided by 20). Under those conditions we get short bunches, less than 500 ps wide, which are not enlarged by remaining tail. Great care has to be taken to routinely adjust such a bunch length.

Beam Intensity Modulator[2]

It enables us to operate a time sharing of the beam between two experiments and also to set the intensity at the appropriate value with a maximum intensity ratio of 100.

Beam Energy Degrader

Carbon plates of different thicknesses which can be rotated from 0° to 45° are placed at the object point of the high energy spectrometer for :

- slowing down the beam without retuning the whole machine (a few hundred micrometers foil thickness) ;
- changing the final charge state of ions (~ 2.5 micrometers foil thickness) ;
- getting secondary beams for detector calibrations or long time of flight measurements (particle identification coupled with "SPEG" spectrometer).

Beam intensity	(A < 40) (A > 40)	10^{12}pps 10^{10}à 10^{11}pps
Emittance	horizontal vertical	5 πmm.mrd
Beam spot	diameter divergence	5 mm 4 mrd
Bunch length	intensity : normal reduced	 0,9 à 1,5 ns ⩽ 0,5 ns
Total energy spread		10^{-3}

Table 2 Beam characteristics on target

Pulse Suppressor [3]

A first model has been installed in 1986 in order to select down to one bunch with a maximum duty cycle of 1.4%. It works with a combination of continuous and pulsed voltages put on parallel plates (vertical deflection). The time interval between two successive pulses being too long for some experiments (⩾ 70 RF periods), a second device has been designed[4] using sine wave and DC high level voltages. It will transmit one pulse in two, three or four depending on the requested time interval (200 to 450 ns).

MACHINE IMPROVEMENTS

The most important steps have been the introduction of sophisticated beam diagnostics, the replacement of the PIG source by an ECR source and a general effort to make all equipments more reliable, easier to control.

Current Transformers

Transformers have been developped[5] in 1984 to measure small beam currents in the lines without intercepting the beam. Their resolution is around 1 to 10 enA depending on the background noise. That is obtained by using synchronous detector locked on beam chopper pulse (10% beam off).

SSC Turn Counter System

The turns being well separated in SSC1, the counting of their number is easy but takes a long time and interrupts the beam (use of a movable probe). Moreover that method cannot be used in SSC2, orbits overlapping each other.

A new non interceptive method[5] based on cross correlation function computation has been routinely in operation since 1986.

Capacitive Beam Position monitors[6]

Capacitive probes have been recently designed for permanent measurement of the beam position along the beam lines. Some of them are installed in the transfer line leading the beam from the injector cyclotron to the first SSC. These probes are non interceptive and although they give only the radial position of the beam center of gravity, they will advantageously be placed as a substitute for many beam profile monitors.

Special Devices Recently Developped

- An accurate bunch length measurement system using X ray emission from a thin aluminum target,
- A tomographic head installed at the end of the injector cyclotron probe (orbits being well separated).
- A magnetic field measurement system. All bending magnets (beam lines as well as cyclotrons) are now automatically controlled by a dedicated NMR measurement system fully controlled by a microprocessor under the main computer dependence.

Computer Control System

In the beginning the computer control system behaved almost like a huge multiplexer. More than 120 programs have been written up to now for helping the beam tuning procedure. In 1986 more powerful computers : MITRA 625 for the machine control and MITRA 725 for sofware developments took the place of the first type MITRA 125.

Part of the work is done locally by CAMAC controllers using microprocessor such as INTEL 8080 and MOTOROLA 68000 since 1987.

Moreover, 25 programmable controllers relieve the central computer from functions involving equipment safety, vacuum and RF systems handling, etc...

The computer control system[7] is working satisfactorily. Due to the present machine developments the number of parameters to be handled increases more and more, and this is an incitation to install a more efficient computer control system with modern distributed architecture, work stations and VME bus. That project is going to be approved and will be progressively implemented. The complete take over is expected in a few years.

MACHINE STUDIES

Table 3 shows the part of the operating time devoted to machine studies since 1983. The various topics are classified in three sections : theoritical investigations, reliability and tuning procedures, tests of new equipments.

	1983	1984	1985	1986	1987	1988	
hours	384	422	36	49	159	25	New
% (*)	10	8,4	0,8	1	3,5	0,5	beams
hours	336	216	495	246	144	238	Mach.
% (*)	6	4,3	10,4	5	3,2	6	studies

(*) % of the operating time

Table 3 New beam developments and machine studies evolution from 1983 to 1988

Beam Dynamics Investigations

Much time was devoted to classical topics like parameter checking and general beam behaviour study into the three cyclotrons as well as in the beam lines (transversal and longitudinal motions, emittances, matching, correlations, etc...).

The following topics were programmed, the final goal being to make easier the machine tuning :

- Choice of the orbit number in SSC1 at different energies in order to be in beam line L2 as close as possible to the computed parameters.
- Determination and adjustment of the orbit precession in SSC2 seen as a way to increase the turn separation at the ejection radius.
- Correction of magnetic perturbations at injection radius or of small field differences between sectors. That last work resulted in a very convenient computer program which determines trim coil correcting currents when strong unexpected radial oscillations are detected.
- During the last two years, we were looking for the possibility to slightly change the beam energy without retuning the whole machine. Two methods were tried. The faster one consists of a change of the extraction deflector position in SSC2. The maximum energy variation obtained does not exceed ± 0.5 %.
- Diminution of beam losses all along the beam path.
- In 1987, April 1st, a major breakdown occured in SSC2 : a vacuum leak appeared in one RF resonator due to a water cooling pipe overheating. We made original study [8] for three weeks to achieve normal operation in that cyclotron with one RF resonator on instead of two.

Reliability and Tuning Procedures

Those topics summarize all works related to software development (more than 120 tasks are now operational), to parameter drift evaluation, to the design of the four servo loop systems locked on to beam phase detectors.

Moreover we mention here :

- the great effort made for reducing the effect of electrical mains fluctuations on beam stability[9]. The beam time lost due to this inconvenience has regularly decreased : starting from 10% of the scheduled time for physics in 1983 down to 6% in 1984 and finally to less than 1% in 1988,
- the tests scheduled to make easy the beam tuning method at constant beam rigidity.

New Equipment Tests

The design of new beam diagnostic systems needs numerous tests with beam.

In 1988 some time was alloted to solve technical problems involving very sensitive diagnostics. The goal is to make possible the machine tuning when the beam intensity is as small as a few enA.

NEW BEAM DEVELOPMENTS

They are essentially related to ions produced from solid material. Until the end of 1985 the PIG source was operated with ions obtained by the sputtering method ($^{40}Ca^{5+}$, $^{58}Ni^{5+}$, $^{100}Mo^{7+}$).

Since the installation of the ECR source, two methods have been investigated. The first one used an oven electrically heated and introduced radially in the second stage of the source ; the second one consists of a rod of solid material or of a crucible containing the material (pure or composite), axially introduced and heated by the plasma itself. $^{48}Ca^{6+}$, $^{58}Ni^{7+}$, $^{100}Mo^{7+}$ and $^{181}Ta^{20+}$ have been routinely produced by this last method.

MAJOR MACHINE MODIFICATIONS

ECR Ion Source Evolution

Since the installation of the first ECR source on the machine (ECR1), three other ECR sources have been progressively developped[10] with the collaboration of PADSI's laboratory at GRENOBLE :

a. ECR1 has been routinely operated from December 1985 to December 1988. This source (MINIMAFIOS type) was initially designed for gazeous ion production and a rod mechanism has been added in 1987 in order to produce also ions from solid materials by adding a rod mechanism.

b. ECR2 (FERROMAFIOS type) has been designed for both metallic and gazeous ions. It has been delivered and subsequently installed on a test bench. It has been used for beam tests from April 1987 to December 1988. Its own advantages are : less electric power consumption, better emittances and higher beam intensity for gazeous ions. The on line ECR1 source running well enough with metallic ions, the ECR2 source was not installed on the machine.

c. ECR3 (CAPRICE 2B type) has been made at GANIL from the PADSI specifications and was operational in October 1988. Owing to an increase of the magnetic field in the extraction region, the beam current is three time higher for gazeous ions. First tests show that the source efficiency is also better for metallic ions. This source, now installed on the axial injection of cyclotron C02, has been satisfactorily operating for two months. ECR2 type source will be modified to become quite similar to ECR3 type, which will make it possible to develop new ions requested without interfering with the operation of the accelerator.

d. ECR4 has been entirely designed at GANIL. Combining an optimization of its axial magnetic structure with an increase of the exciting frequency (14.5 GHz instead of 10 GHz), this source will be able to produce heavy ions with higher charge states. Its completion is expected by the end of this year.

Energy Range Increase

The machine is undergoing a series of important modifications since the beginning of the scheduled six months shut down, in December 1988. This project, called "OAE", has been elsewhere described[11]. The energy range of the accelerator will be enlarged for heavy ions (A > 40). Recent ECR source developments push for a better use of higher charge to mass ratio, which led us to lower the stripping ratio from 3.5 to 2.5. This choice implies a series of technical modifications on the machine :

a. The installation of a more performing ion source (CAPRICE type).

b. The almost complete transformation of the injector cyclotron C02[12]. Its pole pieces have been removed and new ones with spiralled sectors have been installed (now the radial field law is isochronous), the dee has been replaced by a 180° angle dee driven by the existing RF resonator (acceleration on harmonic 3 instead of 4), the extraction radius has been extended by 23 mm to remain compatible with the injection radius of SSC1.

c. The modification of the buncher R1 (beam line L1). The distance between its two gaps has been reduced from 96 to 51 cm corresponding to a half period transit time.

d. The post-stripper part of the beam line L2 has a higher magnetic rigidity (multipled by 1.4) and the voltage applied on the stripper ranges from -150kV to +150kV.

e. The injection radius of SSC2 has been extented from 0.857 to 1.2 m, according to the new stripping ratio (2.5). All the magnetic components of the injection channel have been redesigned. The sharpest problem has been the design of the magnetic septum SMI3 which gives a maximum average field of 2.18 T with a maximum peak value of 2.33 T in its center. Two injection magnets, MI2 and especially MSI3, induce field perturbations on the first orbits path. A three month campaign of magnetic field measurements has been made on the four sectors of SSC2 to determine the shimming and the trim coil compensations.

The main work is yet finished. First beams ($^{120}Xe^{18+}$, $^{16}O^{2+}$) have already been accelerated by the injector cyclotron and then sent into the beam line L1. Results are presented on a dedicated paper (these proceedings).

New Medium Energy Beam Facilities[13]

A new beam line installed downstream of the stripper will divert part of the unused ions toward a new experiment room dedicated to non-nuclear physics. The corresponding modifications (intra-mural part) are now completed : analysing dipoles ; septum magnet, set of Qpoles are in place. The whole line will be operational by the end of this year.

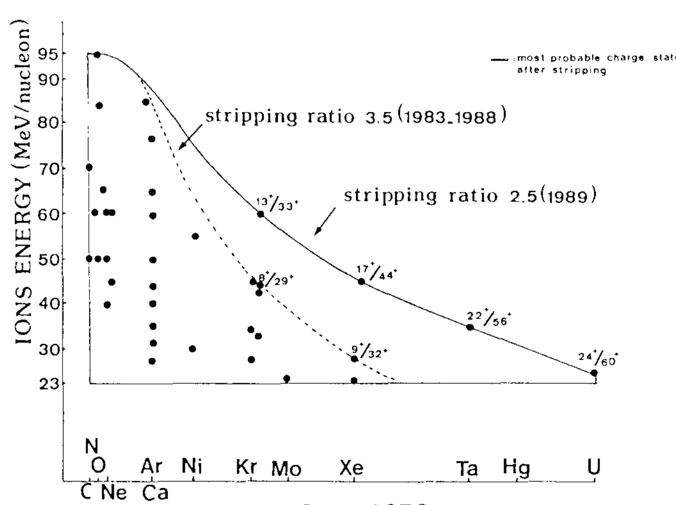

Figure 3 : Maximum energies expected at ejection of SSC2 with stripping ratio 2.5 (dots on solid line). Beams obtained up to 1988 (others dots).

Beam Intensity Increase (O.A.I project)

The beam intensities delivered by the injector cyclotron are presently limited by two factors : space charge effects and non-optimal beam matching in the axial injection system. The first problem will be solved by using an improved ECR source (ECR4) at higher potential (100 kV). The second problem, related to the axial injection design has been subject to specific studies[14)15)].

Ion type	$^{16}_{8}O$	$^{40}_{18}Ar$	$^{84}_{36}Kr$	$^{129}_{54}Xe$	$^{181}_{73}Ta$
Charge states	4^+-8^+	7^+-18^+	14^+-33^+	17^+-44^+	22^+-55^+
Energy (MeV/amu)	95	77	60	44	36
Beam intensity on target (pps)	$2\ 10^{13}$	$3\ 10^{12}$	$5\ 10^{11}$	$1.5\ 10^{11}$	$2.4\ 10^{10}$

Table 4 Beam intensity on target expected by the end of 1990

EXPERIMENTAL AREA

The experimental area facility will be improved by two projects : LISE3 (to be completed this year) and SISSI (not still approved).

LISE3 project

The LISE spectrometer analyzes exotic nuclei by means of two systems : magnetic selection (law in Av/Q where A is the atomic mass, Q the charge state and v the ion velocity) followed by an energy slowing down selection (law in A^3/Z^2 where A is the atomic mass and Z the atomic number).

The third stage will be composed of a WIEN filter (velocity selection) followed by a dipole analyser (A/Z selection). LISE3 will be operational this year with the WIEN filter only.

SISSI project

The maximum high energy beam line acceptance is 35 πmm.mrd. Secondary beam are routinely produced from a target put on the object point of the high energy monochromator. A solution to increase the angular acceptance of the line downstream of the target is to have a beam spot as small as possible on it. The SISSI project consists of two superconducting solenoid lenses, the target being in between. The transmission factor should be ten times higher. Both the SPEG spectrometer and LISE spectrometer should take advantage of this improvement (better mass resolution). Studies are just beginning.

CONCLUSION

GANIL is going to resume operation for physics with extended capabilities : heavy ions will be provided at higher energies next July and at higher intensities next year. Non-nuclear users will take benefit of permanent medium energy beams.

A reflexion group has been constituted to think about possible proposals. Taking advantage of future high intensity beams, a SSC3 booster could enlarge the field of nuclear physics investigations.

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