GANIL STATUS REPORT

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Abstract

The GANIL facility (Caen, France) is dedicated to the acceleration of heavy ion beams for nuclear and non nuclear physics. The production of radioactive ion beams represents the main part of the activity. Since September 2001, SPIRAL, the Radioactive Ion Beam Facility at GANIL, delivers radioactive species produced by the ISOL method. The operation and the running statistics of GANIL are presented, with particular attention to the first SPIRAL beams. The recent developments for increasing stable beam intensities, up to a factor 13 for Argon, are presented. Considering the future of GANIL, SPIRAL II projects aims to produce high intensity secondary beams, by fission induced with a 5 mA deuteron beam into an uranium target.

OPERATION STATISTICS

The GANIL accelerators are operated 34 to 35 weeks (5500 hours) per year. The operation statistics, over these last three years, are given bellow.

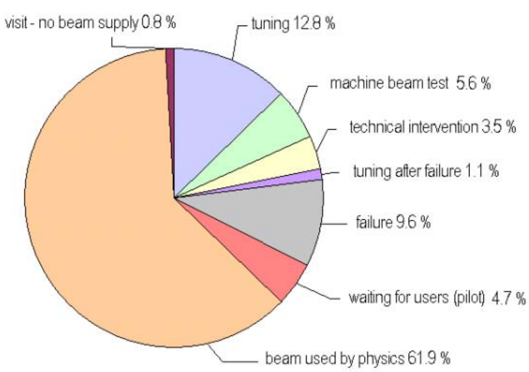

Figure 1: Operation statistics in years 2001-2003

Despite a greater number of beam changes and beam studies, due to operation of CIME cyclotron, the time available for physics experiments is slightly increasing. Indeed, beam tuning or machine studies with CIME cyclotron are scheduled in parallel of experiments with the other cyclotrons. The inverse is also possible. The available beam time is shared between different user categories : nuclear physics (85% of available beam time), atomic physics, radiobiology and material irradiation. In addition to experiments using high energy beams, the Intermediate Energy Exit (SME, Fig.2), working simultaneously with the main beam, uses about 1400 beam hours per year for atomic physics. While IRRSUD beam line allows the use of low-energy beams for material irradiation. This low-energy beam is provided, since 2002, by an injector cyclotron (C01 or C02) offline for high energy.

The main activity concerns production of radioactive ion beams for nuclear physics. In addition to the in-flight fragmentation method, with the SISSI device, the ISOL method is used since 2001 (SPIRAL).

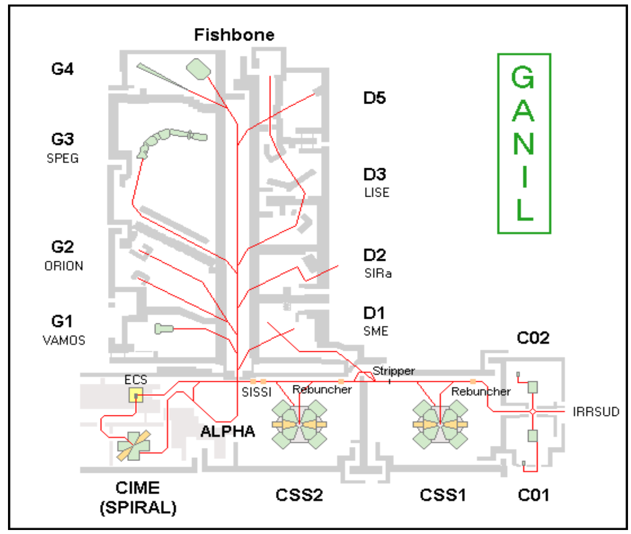

Figure 2: Plan of GANIL showing accelerators and experimental areas. C01 and C02 are compact cyclotrons (E<1 MeV.A); CSS1 (E<13.7 MeV.A) and CSS2 (E<95 MeV.A) separated sectors cyclotrons.

SECONDARY BEAMS

SISSI beams [1]

Secondary beams are routinely produced in SISSI device. Composed of a set of 2 super-conducting solenoids with a target in between, placed at the entrance of the alpha spectrometer. These beams are usually purified through an achromatic degrader, before being sent to the experimental lines. Their characteristics are the following:

$\varepsilon_{H,V}$: limited to 16π.mm.mrad (transport line geometric acceptance)

ΔW/W: limited to ±1% by alpha spectrometer acceptance.

SPIRAL beams [2]

The heavy ion beams of GANIL are sent onto a target and source assembly. The radioactive atoms produced by nuclear reactions are released from the target, kept at high temperature, into an ECR source. After ionization and extraction from the source (extraction voltage < 34 kV), the radioactive beams are accelerated up to a maximum energy of 25 MeV/A by the compact cyclotron CIME.

The list of radioactive beams produced and accelerated with SPIRAL from September 1st , until April 4th are given in table 1. Up to now, the primary beam power on SPIRAL targets has been limited to 1.4 kW for thermal and safety reasons. A new target, designed for 3 kW of ^{13}C, is about to be used.

SPIRAL BEAMS		
Ion	Energy (MeV/A)	Intensity (pps)
$^{6}He^{1+}$	3.2, 5	$3 \times 10^{+7}$
$^{8}He^{2+}$	15.4	$2 \times 10^{+4}$
$^{8}He^{1+}$	3.4 to 3.9	$8 \times 10^{+4}$
$^{18}Ne^{4+}$	7	$1 \times 10^{+6}$
$^{24}Ne^{5+}$	4.7, 10	$2 \times 10^{+5}$
$^{26}Ne^{5+}$	10	$3 \times 10^{+3}$
$^{74}Kr^{11+}$	2.6	$1.5 \times 10^{+4}$
$^{76}Kr^{11+}$	2.6, 4.4	$6 \times 10^{+5}$

Table 1 : SPIRAL beams until april 2004

CIME cyclotron as post-accelerator

The cyclotron CIME has an axial injection system. Two different injection centres are needed to accelerate ion beams from 1.7 to 25 MeV/A at the RF harmonics[1] H=2,3,4 and 5.

The low-energy beams, from 1.7 to 6.2 MeV/A, are injected at a radius R=45 mm, using a Pabot-Belmont inflector complemented by an electrostatic quadrupole, and accelerated on RF harmonics 4 or 5.

The high-energy beams, from 4.9 to 25.4 MeV/A, are injected at a radius R=34 mm, using a Muller inflector and accelerated on RF harmonics 2 or 3.

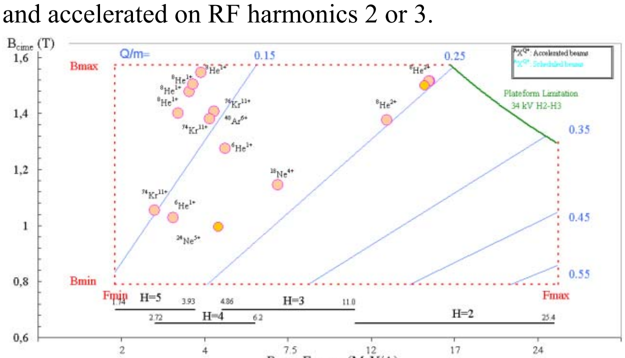

Figure3 : CIME working diagram including accelerated beams (April 2004)

However, several beams have been accelerated in (H=3 and R=45 mm) or (H=4 and R=34), so that it is possible to avoid interventions on CIME to change the centre region.

[1] Radio-Frequency Harmonics : ratio between the frequency of the accelerating cavities and the ion revolution frequency in the cyclotron.

CIME cyclotron as separator[3]

Stable contaminants can dominate by several orders of magnitude the intensity of radioactive ion species of interest. Thus, a very clean separation is needed.

For a given ion, with a mass M_1 and charge Q_1, the synchronism condition is fulfilled:

$$f_{rev} = \frac{Q_1}{2\pi M_1} \frac{B(r)}{\gamma(r)} = f_{RF} / H \qquad (I.1)$$

Where f_{rev} and f_{RF} are the revolution and the RF frequencies, B (r) the magnetic field and γ the relativistic factor.

For another ion, with a different mass to charge ratio (M_2/Q_2), the synchronism condition is not fulfilled, the relative phase ϕ_2 with the RF system evolves up to ϕ_2=90°, and then these ions are not accelerated anymore (figure 4).

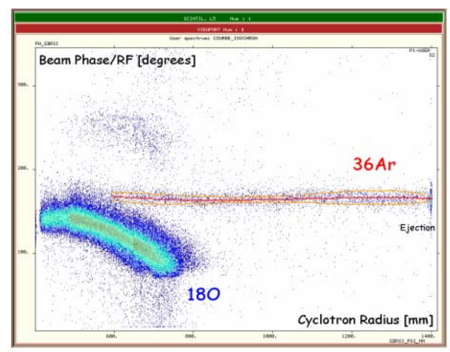

Figure4 : Synchronism condition. Phase measurement as a function of the radius in CIME using a 300 µm silicon detector. Test realised on harmonic 3.

The condition to eliminate an undesired ion corresponds at first order to:

$$\left[\frac{M_2}{Q_2} - \frac{M_1}{Q_1}\right] \Big/ \frac{M_1}{Q_1} > \frac{1}{2\pi\ H\ N_{turn}} \qquad (I.2)$$

where N_{turn} is the number of turns. Hence the mass resolution of a cyclotron is defined as $R = 1/2\pi\ H\ N_{turn}$. Depending on the harmonic, the mass resolution of CIME can reach 1.6 10^{-4}.

Tuning method of SPIRAL secondary beams

The initial tuning of CIME is realised with a stable isotopic beam delivered by the ion source. The intensity available with this stable element allows the tuning of each accelerator section with classical diagnostics.

Then, considering equation (I.1), there is two strategies to shift from one ion (M1,Q1) to another (M2, Q2) : a magnetic field (B) or RF frequency (f_{RF}) shift. Depending on the strategy chosen, and due to evolution of γ with acceleration, the synchronism condition may not be strictly respected at any radius. Nevertheless, as the γ factor at the exit of CIME is low, and as the (Q/M) ratio of stable and of radioactive beams are close, both methods may be convenient.

INCREASE OF BEAM INTENSITIES

The intensity increase in GANIL (THI project) started about 10 years ago [4], and some high intensity beams have been produced in operation and for machine studies (table 2). This intensity increase has been possible, mainly, due to developments in three domains : ECR sources (metallic ions), beam dynamics in CSS2 and increase of RF voltage and instrumentation.

Table 2: Example of primary beam intensities

Beam	Energy (MeV/A)	Available intensity (CSS2 exit)
$^{13}C^{3/6}$	75	18 μA- 1.9 10^{13} pps
$^{36}Ar^{10/18}$	95	26 μA- 9 10^{12} pps
$^{36}S^{10/16}$	77	6,3 μA[2] - 2.5 10^{12} pps
$^{58}Ni^{11/26}$	74	5 μA – 1.2 10^{12} pps

ECR sources development [5]

The MIVOC method (Metal Ions from Volatile Compounds) developed at Jyväskylä has been used at GANIL, since 1999, for the production of iron and nickel beams. 50 μA of $^{58}Ni^{11+}$, to get a 5 μA $^{58}Ni^{26+}$ on SISSI production target, have been produced several times.

Developments with natural Calcium, used under the metallic form, have enabled to get a relatively high intensity with $^{48}Ca^{10+}$ (enrichment 56%) : in June 2001, an average beam intensity of 15 μA of $^{48}Ca^{10+}$ was obtained during three weeks, with a good stability and a rather low consumption(≤ 0.1 mg/h).

After production tests with Germanium, it has been discovered that it was possible to recover germanium condensed on the plasma chamber, using a chemical reaction with SF_6 . Since then, this effect is used to get a high intensity (8.5 μAe) of $^{76}Ge^{10+}$at the exit of CSS1.

Operation with THI beams[3]

In the years 2001-2003, several improvements were made to facilitate the operation (tuning and supervision) of THI beams for use with SISSI and SPIRAL targets. These improvements concern the security of equipments, the beam stability, and the instrumentation needed to measure the beam characteristics. In addition, the project was extended to the possibility to send a THI beam directly to the experimental areas (LISE3/LISE 2000 spectrometers). The routine operation of THI began at the end of 2001, and was pursued these last two years, with several accelerations of $^{13}C^{6+}$, 1.4 kW of beam power, to use with the SPIRAL target-source (production of ^{8}He and acceleration with CIME), and the first THI beams in LISE 3/ LISE 2000.

Acceleration of a 5 kW ^{36}Ar beam[3]

Initially, the goal of the THI project was :
2.10^{13} pps for ^{13}C at 75 MeV/A limited for safety reasons
6 kW for ^{36}Ar at 95 MeV/A limited for thermal reasons

After the first studies, it appeared that, when ion beam powers were increased up to several kW, space charge effects appeared in SSC2 , mainly due to turn overlap. Thus, an increase in the dee voltage, since then operated at 170 kV (@13.45 MHz), was required. A detailed study of the SSC cavities was done, which confirmed that voltages as high as 250 kV could be reached.
A first beam test was realized in December 2001, with a 95 MeV/A Argon beam, and a RF voltage of 200 kV. The overall transmission of the cyclotron was equal to 97%, and the ejected beam intensity equal to 26 μA, corresponding to a thermal power of 5 kW.

SPIRAL II PROJECT

Compared to SPIRAL I, SPIRAL II project aims to produce heavier (80<A<150), higher intensity secondary beams, by the ISOL method. A Linac driver will deliver a 5 mA, 40 MeV deuteron beam [6]. This beam will bombard a converter, producing neutrons which will induce up to 10^{14} fissions/s in an uranium target. The radioactive beams will be extracted from a source in a mono-charge state. A separator will allow the use of one beam at low energy, and the acceleration, through a 1+/N+ charge breeder, of another by CIME. The radioactive ion beams which will be produced by SPIRAL II will be accelerated up to 6 MeV/A, and sent to existing experimental areas.

CONCLUSION

GANIL is now producing routinely secondary beams, with fragmentation (SISSI or LISE) and ISOL (SPIRAL) methods. Primary beams intensity has been increased, up to 26 μAe (5 kW) for ^{36}Ar at 95 MeV/A. A new irradiation facility (IRRSUD) is operational since November 2002, which enables the delivery of three simultaneous beams, at low, medium and high energy.
In the future, SPIRAL II would deliver high intensity secondary beams up to 6 MeV/A.

REFERENCES

[1] A. Savalle et al, The SISSI facility at GANIL, EPAC 96, Sitges, Spain, June 96.

[2] M. Lieuvin et al., Commissioning of SPIRAL, the GANIL radioactive beam facility, Proc. of the 16th Int. Conf. On Cyclotrons and their Applications. East Lansing , Michigan (2001)

[3] Technical Report on operating accelerators 2001-2002, Ganil report 03 02

[4] E.Baron et al., High intensity heavy ion beams for exotic nuclei production at GANIL, 16th Int. Conf. On Cyclotrons and their Applications.

[5] P. Leherissier et al, Status report on ECR ion source operation at GANIL, to be published in the proc. of the 10th int. conf. on ECR Ion Sources, Dubnia, Russia, 2003.

[6] A. Mosnier, SPIRAL II : a high intensity deuteron and ion linear accelerator for exotic beam production, PAC 2003, Portland, Oregon, 2003.

[2] ^{36}S enrichment: 63,4%