COMMISSIONING OF SPIRAL, THE GANIL RADIOACTIVE BEAM FACILITY

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Abstract

SPIRAL, the Radioactive Ion Beam (RIB) Facility at GANIL, Caen will use the high intensity, heavy ion beams of GANIL for the production of radioactive species by the ISOL method.

The Radioactive Beams produced by the target and source assembly, will be accelerated up to a maximum energy of 25 MeV/u by the new cyclotron CIME. Preliminary tests of CIME with stable ions were presented in the previous cyclotron conference at Caen in 1998. Since then, important progress were made in the commissioning of CIME. They are presented in this paper as well as the present status of the delivery of the administrative authorizations which are needed for the production of the first radioactive beams by the facility.

1 INTRODUCTION

The French research organisms : IN2P3/CNRS, DSM/CEA and the Regional Council of Normandy funded the SPIRAL [1, 2] project at GANIL in December 1993. A large collaboration between laboratories in France and Europe was established in order to construct and develop SPIRAL. The project is based on the ISOL technique for production of Radioactive Ion Beams (RIB) with post acceleration.

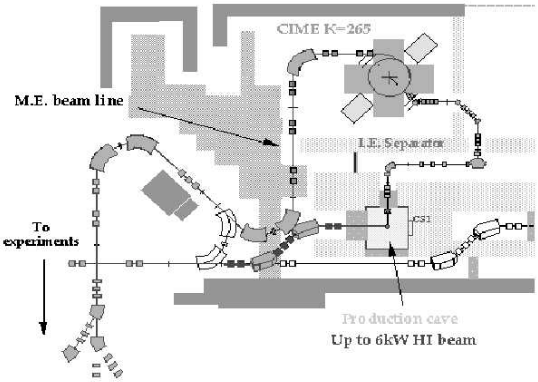

Fig 1. SPIRAL layout

Today GANIL produces beams with intensities reaching $6x10^9$ to $2x10^{13}$ pps for ions from ^{238}U to ^{12}C at energies from 24A to 96A MeV (THI project) [3]. The primary beam accelerated by the GANIL cyclotrons bombards a production target located inside a well shielded area beneath ground level in the machine building. The radioactive atoms produced by nuclear reactions are released from the target kept at high temperature (~2300 K), and pass through a transfer tube into a permanent magnet ECRIS. The radioactive atoms are ionised up to charge over mass ratio ranging from 0.09 to 0.40. After extraction from the ECRIS, the low-energy RIB (acceleration voltage from 7kV to 34kV) are selected by a relatively low resolution separator (dm/m = $4x10^{-3}$) and injected into the new K=265 (Br=2.344Tm) compact cyclotron CIME. The corresponding energy range extends from 1.7 to 25A MeV. After acceleration, the RIBs are directed to the existing experimental areas.

As the authorization to produce RIBs at GANIL is not yet obtained, this paper presents the results of the production tests of RIBs on the test stand SIRa and of the acceleration tests of stable ion beams by CIME. Plans for future extension of RIBs production at GANIL are also presented.

2 TESTS OF RIB PRODUCTION

Since 1993, a test stand called SIRa has been installed in one of the GANIL beam lines. Since then, SIRa was extensively used for the development and test of the target and source system which will be used at SPIRAL. A solution based on an external carbon target linked to the ECR NANOGAN-III source by a short and cold transfer tube has been chosen. This simple system will deliver the first noble gas radioactive ion beam for SPIRAL. The carbon target has been chosen due to its excellent release properties, low atomic number and high sublimation temperature. This target guarantees the production of noble gases with reasonable yields and can be used with high power primary beams. This requirement has necessitated a special target design, which can withstand high power load while keeping fast release properties. From the production point of view, the temperature of the target should be as high as possible and its profile should be as uniform as possible, in order to minimize the delay time between production and release. The temperature profile is related to the properties of the Bragg peak, which is particularly pronounced in the case of heavy ions. Therefore, a special conical design, which distributes uniformly the power density over the target volume has been developed.

A specific target divided into two parts due to the long range of He in carbon, was developed for the $^{6,8}He$ production (figure 2). The ^{13}C primary beam only heats the first part (production target), while the second one (diffusion target) stops the fragmentation products, and is heated by an electric current through the axis.

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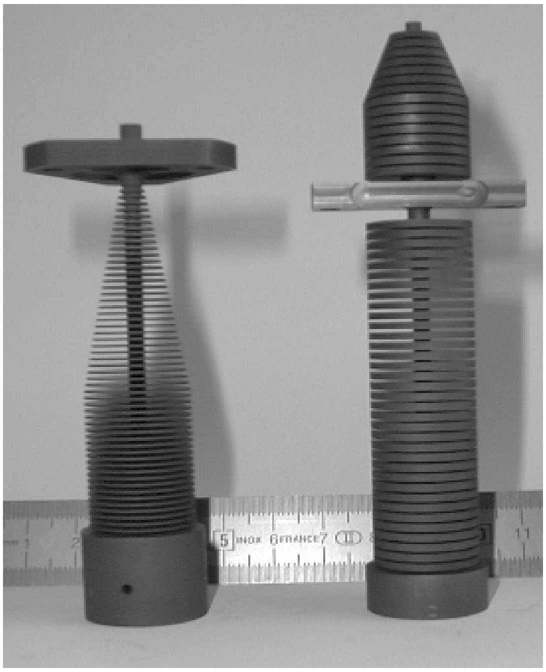

Fig 2. Carbon targets for Ne/Ar (left) and for He production (right)

NANOGAN-III [4, 5] (Figure 3) is a compact full permanent magnet ECRIS developed for the first phase of the SPIRAL project. The magnetic circuit consists of a sextupolar magnetic structure for radial confinement and of two axially and one radially magnetized permanent magnet rings. This ion source has been designed for operation with a 10GHz transmitter. Its power consumption is of 200W when tuned for the best performance. NANOGAN-III is an evolution of the previous model NANOGAN-II, which worked at 14.5GHz. The ion source is linked to the carbon target by a cold and short transfer tube. This allows efficient production of noble gas elements with reasonable suppression of condensable contaminants. The overall efficiency of the system for the production of ^{35}Ar (8+) is better than 10%.

The ionisation efficiency - all charge states - of Ar ions has been measured to be better than 95% when NANOGAN-III is tuned in order to maximise the 8+ charge state. The comparison between the off and on-line charge state distributions, attests that the ion source is almost insensitive to the heating and to the presence of the beam on the target.

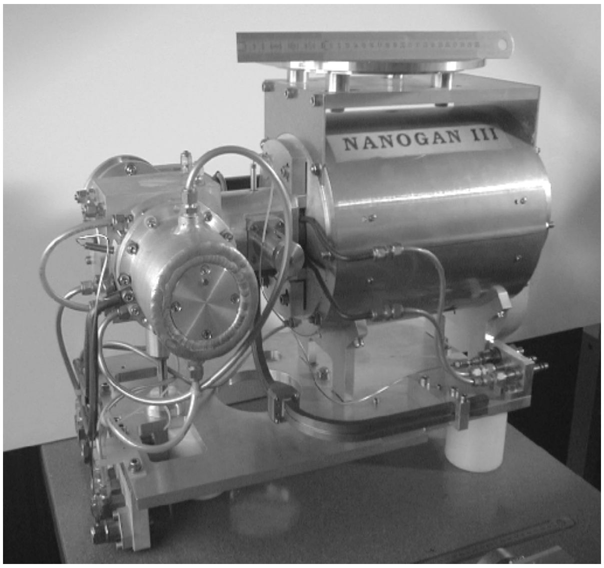

Fig 3. The target and source assembly

Most of the radioactive beams which will be soon available at SPIRAL with a primary beam power limited to 2 kW are listed in Table 1. This list will be extended gradually as soon as new target-ion source developments will be available.

Table 1. RIBs produced at SIRa

Beam	Charge state	Intensity before acceleration (pps)	SPIRAL Energy min/max (A MeV)
^{6}He(0.8s)	1+ 2+	1.0 x 10^{9} 8.0 x 10^{7}	2.7/7.2 6.8/22.8
^{8}He(0.12s)	1+ 2+	3.0 x 10^{6} 3.6 x 10^{5}	2.7/4 3.8/16.3
^{17}Ne(0.11s)	+(3-6)	1.5 x 10^{5}	2.7/24.3
^{18}Ne (1.7s)	+(3-6)	1.5 x 10^{7}	2.7/22.9
^{19}Ne (17s)	+(3-6)	2.5 x 10^{8}	2.7/21.6
^{23}Ne (37s)	+(3-6)	6.0 x 10^{7}	2.7/17.7
^{24}Ne (3.4m)	+(3-6)	2.0 x 10^{7}	2.7/16.4
^{25}Ne (0.61s)	+(3-6)	5.0 x 10^{5}	2.7/15.1
^{32}Ar (98ms)	+(6-8) +9	2.3 x 10^{3} 1.1 x 10^{3}	2.7/16.4 4.8/19.2
^{33}Ar (0.17s)	+(6-8) +9	1.7 x 10^{5} 8.0 x 10^{4}	2.7/15.4 4.6/18.6
^{34}Ar (0.84s)	+(6-8) +9	1.2 x 10^{7} 6.0 x 10^{6}	2.7/14.5 4.3/18
^{35}Ar (1.78s)	+(6-8) +9	3.0 x 10^{8} 1.5 x 10^{8}	2.7/13.7 4.0/17.3
^{72}Kr (17s)	+(15-16)	8.0 x 10^{1}	2.7/12.9
^{73}Kr (27s)	+(15-16)	2.0 x 10^{3}	2.7/12.6
^{74}Kr (11m)	+(15-16)	1.0 x 10^{5}	2.7/12.3
^{75}Kr (4m)	+(15-16)	7.0 x 10^{5}	2.7/11.9
^{76}Kr (14.8h)	+(15-16)	3.0 x 10^{6}	2.7/11.6
^{77}Kr (74m)	+(15-16)	2.0 x 10^{7}	2.7/11.3

3 TESTS OF CIME

(More detailed results of the tests of CIME are given in a poster presented at this conference by F. Varenne et al.) [6]

Preliminary results of the tests of CIME where already presented at Caen in the CYCLOTRON's 98 conference. This was really the first attempt to inject and accelerate a beam in this new machine, but we were puzzled by the behavior of the accelerated beam which stopped about 5 cm before reaching the extraction radius. At this time, we had only one radial probe available in the machine and it has taken quite a long time to understand that this was due to a relatively strong first harmonic magnetic field component (~ 10 G) pushing the beam to the opposite direction of the extraction septum.

This was a very surprising situation as all of the magnetic field maps showed harmonics components lower than one gauss. All the elements installed after field mapping were suspected in turn (RF resonators, extraction channels, steerers, …) without success. Finally, the vacuum was guilty : all the field measurements were done at the atmospheric pressure, while under vacuum, the vacuum chamber which is not completely symmetric (in order to accommodate the extraction elements) pushes on the poles and induces a deformation of the order of 0.1 mm, sufficient for the production of this first harmonic component.

This magnetic defect was first corrected by powering the small coils which are wounded around the four return yokes of the magnet, but, by construction, the efficiency of these coils is very low and a high current had to be applied to get a sufficient correction. Once the real cause was better understood, a simple post provided a much efficient correction.

Let us now recall some characteristics of CIME and give the main results obtained :

CIME has an off-centred axial injection. To cover the large energy range required, two different central geometries were computed and are alternatively used :

- For the range 5 to 25 MeV/u we use a Muller type inflector, the injection radius is 34 mm and the tip angle of the dees is 60 degrees. The RF harmonic mode is either 2 or 3.
- For the lower energies, we have to change the central region geometry and use a spiral inflector (Pabot-Belmont type) followed by an electrostatic quadrupole. The RF harmonic is either 4 or 5; the injection radius is 45 mm. and the tip angle of the dees is reduced to 40 degrees. In this latter case there are no posts in the dees.

The stable ion beams which were accelerated along the tests are plotted on the working diagram (figure 4). The two central regions and the four harmonic modes have been successfully tested. The total transmission (ratio of the extracted beam current to the injected one) measured are shown in table 2 for some beams. They are usually rather good or very good, except at the lower energies, in harm. 5 (this effect was predicted as a very good adaptation looks impossible), and at the maximum energy where some efforts are still to be made.

Table 2. Some beam transmissions

Ion	Energy (MeV/u)	Harm.	Trans. %
$^{40}Ar^{6+}$	1.7	5	18
$^{40}Ar^{6+}$	3.8	4	57
$^{40}Ar^{7+}$	6.0	4	44
$^{18}O^{5+}$	7.0	3	39
$^{12}C^{4+}$	9.3	3	47
$^{40}Ar^{9+}$	11.2	3	45
$^{12}C^{5+}$	25.0	2	13

The buncher is a saw tooth signal and we can catch about 65% of the CW beam. The extraction transmission is also about 65%, but sometimes with 2 turns.

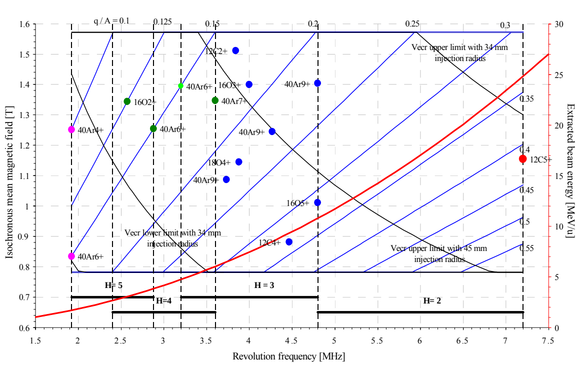

Figure 4. Working diagram of CIME

3.1 Beam diagnostics [7]

One particularity of CIME is its richness of equipment for beam diagnostics. The figure 5 is a simplified view of the median plane of the cyclotron showing some of these diagnostics.

There are the usual beam diagnostics in a cyclotron for intense stable beams : two interceptive, multi fingers radial main probes (one in a valley, the other one below the hills), one semi interceptive radial probes (to eliminate the beam phases which are not wanted), a set of non interceptive phase probes and the usual interceptive probes in front of the extraction elements.

In addition, for the control of the possibly very weak radioactive beams, two radial probes carry an additional low intensity diagnostic device. The radial probe "SDR" in the valley is equipped with a retractable plastic scintillator dedicated to the measurement of the acceleration phase and of the phase width of the beam. The probe "SDRSi" in the hill carries a silicon detector (E, ΔE) for the identification of the accelerated species.

These nuclear-type detectors are able to give very useful figures for very low intensity beams, down to a few pps.

The figure 6 is an illustration of the usefulness of these diagnostics when several beams of very near q/m (some 10^{-4} are simultaneously present in the machine.

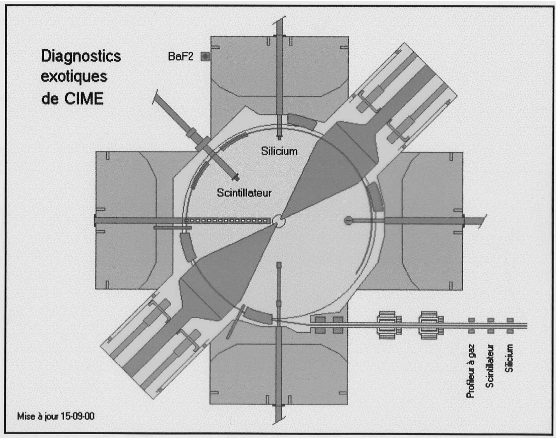

Fig 5. Low intensity diagnostics of CIME

Downstream of the cyclotron the beam line is also equipped with silicon detectors and a plastic scintillator. A special ionisation chamber for beam profile measurements has been developed to control the beam with only 100 pps from an energy as low as 2 MeV/u.

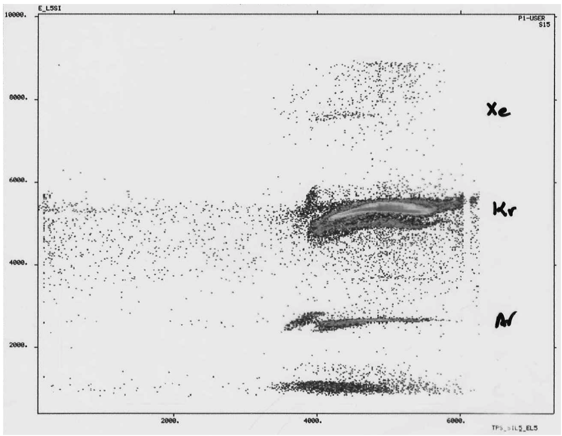

Figure 6. Silicon tests

Tuning of the cyclotron for the radioactive beam required will be obtained in the following way :

Firstly, the machine will be tuned using a stable beam with a very near q/m value. Then, a very small dF or dB shift will be applied (eventually with the necessary injection corrections) to shift to the radioactive specie. As the pollution by the stable beam will obviously remain important, the nuclear diagnostics will play a major role to allow the final tuning of the radioactive beam.

4 ADMINISTRATIVE AUTHORIZATIONS

Getting the necessary authorizations delivered by the French Nuclear Safety Authorities to run SPIRAL was definitely a much longer and tedious process than foreseen when the project was decided.

Due to the fact that the laws for the protection of the environment were strongly and rapidly evolving during the construction of the machine, many steps which were even not imagined at the beginning had to be covered : Public enquiry for the environment, new decree, new safety documents, not only for SPIRAL but for GANIL as a whole (and the rules, since the creation of GANIL, more than 20 years ago, have strongly evolved and are much more constraining now).

Fortunately, most of the official documents are now established and signed by the ministers and we have reasonable hope to get the final green light in the next few months, maybe before summer. This will be a great relief for the SPIRAL and GANIL teams and for the whole community.

5 FUTURE PLANS

Even if we are still expecting the authorization to run SPIRAL, plans to increase the possibilities of the facility are already prepared; these plans are most generally known as “SPIRAL phase 2”.

The present SPIRAL will produce and accelerate nuclei by fragmentation of the projectiles delivered by the GANIL cyclotrons. This produces mainly (but not only) proton rich isotopes. In addition, the GANIL primary beam is less intense and have a lower energy per nucleon when the atomic number increases. For the production of heavy, neutron rich isotopes, it is envisaged to add a complementary equipment based on fission of heavy elements.

A working group extended to the French community was created in October 2000 whose tasks are :

- to investigate the research domains that can be reached with exotic beams issued from fission at a rate of about 10^{13}/s.
- to compare the advantages and drawbacks of two possible primary beam generators : a 80-100 MeV, 500 µA deuteron accelerator and of a 45 MeV, 500 µA electron linac which would use the photofission process.
- to evaluate the issues of the construction of a target-source assembly capable of withstanding 25 to 50 kW and to produce singly-charged ions
- and to study the installation of such a new driver, with the setting up of the beam lines to inject the exotic species into either CIME or the GANIL cyclotrons used as post-accelerators.

The study of the production of neutron-rich isotopes through fast neutron induced fission by deuterons had started already almost three years ago as an European R & D program with several goals :

- measurements of cross-sections, mass distribution, isotopic distributions
- development of a model for calculating these cross-sections
- neutron production induced by deuterons in light and heavy targets (with or without converter).
- measurements of yields and release times of the gaseous products
- singly charged ion sources
- safety aspects.

If deuterons are finally chosen as primary beam, the driver could be a commercial compact, fixed energy cyclotron.

Concerning the photo-fission process, the radioactive beam production was proposed both by W. Diamond and Y. Oganessian. The Dubna physicists measured a variety of parameters (yields, etc.) with a modest 25 MeV, 20 µA microtron. The results raised the interest in the competition with the deuteron accelerator. If this photofission solution is finally retained, then an existing cryogenic electron linac could be moved from Saclay to GANIL and rejuvenated.

A preliminary proposal should be ready to be submitted in summer of this year, so that a go-ahead permission could be given to prepare a detailed proposal. The aim is to have such a complementary machine by the year 2005.

On the other hand, GANIL is also a member of the European program EURISOL which is in charge of producing the European proposal for the third generation of RIB facility with intensities comparable with the stable beam intensities we have now.

6 CONCLUSION

SPIRAL is now ready to produce its first radioactive beams. The administrative authorization is expected to arrive in the few coming months or even weeks. The production of radioactive species measured at the test stand SIRa are really encouraging and the tests of CIME with stable beams have allowed us to solve all the youth problems of this cyclotron.

The first radioactive beam which will be accelerated is already determined : It will be ^{18}Ne, probably rapidly followed by a ^{6}He or a ^{8}He beam which are strongly expected by the nuclear physicists.

in the meantime, the evolution of SPIRAL is already foreseen and a preliminary proposal for SPIRAL phase 2 will be submitted this year.

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