SPIRaL: A Radioactive Ion Beam Facility at GANIL

A. Joubert, R. Anne, P. Bertrand, MP. Bourgarel, C. Bieth, B. Bru, A. Chabert, M. Duval, R. Leroy, Ch. Ricaud, P. Sortais and the project group

GANIL

BP 5027, F-14021 CAEN Cedex

Abstract

The SPIRaL project makes use of the very high intensity ion beams soon available at GANIL (over 10^{13} pps at 95 MeV/u from He to Ar) to produce radioactive nuclei by the ISOL method. The facility will consist of a production target situated close to an ECRIS specially designed for this purpose, a very low energy beam line, a k=265 compact cyclotron as postaccelerator (2 to 20 MeV/u according to the Q/A factor), a medium energy beam line transferring the radioactive beams into the existing experimental rooms through the α spectrometer. The whole facility will be installed at the end of the existing machine.

I. INTRODUCTION

From the first experiments at GANIL, fragmentation reactions have been used to produce and study exotic nuclei. Such a research made use of the large intensities obtained through the whole accelerator system. It was realized that these beams could also be used to produce nuclei at rest in thick targets and to adapt the ISOL method to primary heavy ion beams.

This program is now under consideration with the project of a RIB facility here presented and a strong effort of R&D concerning the production and the ionization of secondary elements has been set up [1].

Such a program can only be conducted if the GANIL accelerator is able to deliver very intense beams. The first part of this operation is almost completed [2] and over 10^{13} pps of light ions (He to Ar) are already available at the exit of the injector cyclotron. The second part, which consists in injecting, accelerating and transferring such beams up to the high energy beam line, has partially been funded this year. So more than 10^{13} pps (~5 kW of beam power) at full energy (95 MeV/u) will routinely be obtained by the end of 1995.

After various versions [4] our final project for a RIB facility called SPIRaL (Séparateur et Postaccélérateur d'Ions Radioactifs produits en Ligne) is described below.

II. TARGET AND ECRIS SYSTEM

Having decided to look at a RIB facility based on a heavy ion primary beam and a high charge state ion source, we soon began an important R & D program to investigate the possibilities of this solution and to get some experience on the target and associated ECR devices.

A first rather crude test bench [1] was built and gave the first results in 92. Using a 95 MeV/u, ²⁰Ne beam and a MgO target, radioactive isotopes in charge states 1 to 4 have been produced (18 , 19 , 23 , 24 Ne, 13 N...). The yields for the

various isotopes were, at the target level, in the range of 10^9 to 10^7 pps per puAp of primary Ne beam.

These encouraging results leed us to conceive a new efficient test bench now under construction [1] with the goal to run it by the end of this year.

It will really be the prototype of the target-ECRIS system of our project allowing us to study all the technical problems involved : target behaviour under high power, permanent magnet ECR in a high radiation field, coupling of the target to the ECR, remote handling problems and so on.

III. THE POST-ACCELERATOR

Our choice of a compact cyclotron is based on the following main reasons :

- First of all, using a high charge state ion source allows us to consider a cyclotron,

- Second, the energy range to be covered ($\equiv 2$ to 20 MeV/u) and the charge over mass ratio as given by the ECRIS ($\equiv 0.1$ to 0.35) are typical of a compact cyclotron whose beam characteristics satisfy rather well the requirements of the physicists. Moreover, a cyclotron is by itself a powerful mass analyser and will deliver rather pure beams, a prime quality in RIB physics.

- Third, GANIL has a good knowledge about cyclotrons and a large experience in their design and operation so that no more than 4 years after funding will be needed to deliver a first beam. Moreover, this new facility will fit in the loose end of the existing building still lowering the cost of an already rather cheap solution.

A. The working chart

The goal being to provide the A $\cong 100$ ions produced by the ECRIS with Q/A $\cong 0.15$ at an energy $\cong 6$ MeV/u, we thus obtain :

$$(B.\bar{r})ejec = 2.344 \text{ T.m}$$
 (K = 265)

The magnetic rigidity of the present high energy beam lines being 2.88 T.m, the cyclotron beams will be accepted without any problem in our experimental areas.

Choosing a mean ejection radius of 1.5 m results in a conservative Bmax \cong 1.56 T and in the working charts displayed on the figures 1 and 2. The limits seen on these figures are related to the values chosen for the max and min mean field (0.75 - 1.56 T), the max voltage on the 2 dees (\cong 100 kV), the lowest ion source extraction potential (\cong 10 kV) and the revolution frequency range (\cong 1.92 to 7.25 MHz).



B. Description of the cyclotron

. The RF system covers the $f_{re\,v}$ range using the harmonics 2-3-4 and 5 with $9.6 \le f_{rf}$ (MHz) ≤ 14.5 . Such an RF frequency range leads to a rather compact resonator : external diameter $\equiv 1.2m$, length $\equiv 1.3m$, internal coaxial line diameter $\equiv 0.25m$ and displacement of the short circuit $\equiv 0.70m$. The power dissipated at 100 kV turns out to be as low as $\equiv 40$ kW. Using two 40° dees and choosing to accelerate all the ions whatever their output energy with a constant turn pattern, the number of turns will be $\equiv 250$ and the turn separation at ejection $\cong 3mm$.

. The magnet will be built using 4 independant yokes and common circular poles (3.5 in diameter) equiped with 4 straight 45° sectors. Hill and valley gaps are respectively 12 and 30 cm allowing an easy fitting of the 2 dees and giving a good flutter.

Using TOSCA code, we have refined the magnet geometry so that the maximum correction required is as low as $\approx \pm 200$ gauss, the gradients being ≤ 5 G/cm. Circular trim

coils (≈ 10) located on the poles and giving 7.5.10⁻² G/AT and 2.5.10⁻³ G/cm/AT, will be used to shape the field within the required tolerances. The inner region ($r \le 20$ cm) where the sectors join the central plug is still to be refined.

. The central geometry (axial injection and Mueller type inflector) is under study with the goal to work out a fixed injection pattern suited for the 4 harmonics we will use. Our first studies concerning the beam centering and its 6D matching lead to fine results for h = 2 - 3 (above the heavy ion Coulomb barrier) and h = 4. In the case of $h = 5 (\le 3 \text{ MeV/u})$ the same geometry can still be used but the acceptance and so for, the intensities will be reduced.

. The extraction system is quite conventional including one electrostatic deflector located in a valley ($\leq 60 \text{ kV/cm}$) followed by two magnetic channels (gradient compensation). A field bump will be used to increase the turn separation.

C. The beam characteristics

Using either the multiparticule code NAJO or the newly written one LIONS [3] we have simulated the beam behaviour in this cyclotron.

. Beam transmission : using similar central region and injection line (6D matching) as for our present GANIL injector [2], we can expect similar transmissions $e.g \ge 40\%$ from the ion source analyzed beam to the cycloton extracted one (we have obtained a 75% record transmission in our injector).

. Beam emittance : injecting a matched beam, 80π mm.mrad in each transverse plane and $\pm 6^{\circ}$ in phase width, leads in front of the extraction system to a monochromatic transverse emittance $\equiv 8.5 \pi$.mm.mrad and to an energy dispersion of $\pm 3.5\%$. In these conditions, the extracted beam will contain parts of the 3 last accelerated turns and so the characteristics of the extracted beam will be lowered. However, it seems possible, at least for h = 2 - 3 to bunch the injected beam in a $\pm 3 - 4^{\circ}$ phase width, in this case due to the low energy spread ($\leq \pm 1\%$) a single turn extraction is possible and the extracted beam qualities are much improved ($\Delta W/W \leq 1\%$, emittances $\leq 10 \pi$.mm.mrad).

. Mass analysis : besides the usual analyser following the ECRIS which eliminates most of the contaminents, (see IV), the cyclotron will select Q/A within 3.5 to 1.5 10^{-4} depending upon the harmonic. These values should be sufficient for most of the experiments ; if not, we will put a thin target at the object point of the α spectrometer, which will select the right component within some 10^{-5} taking advantage of the difference in the energy losses of the various ions (isobars) through the foil. The resulting beam will of course suffer of the target crossing (mean energy, emittances and energy dispersion), nevertheless good characteristics could be restored, the price being to be paid on the intensity. This method will be limited to ions of A \leq 80 at W \geq 6 MeV/u.



Figure 3. Layout of the SPIRal facility

IV. THE BEAM LINES

The layout of the RIB SPIRaL facility is shown on the figure 3. As we see, we need to study and to build three beam lines.

. The primary beam line from the SSC2 output to the target will be the prolongation of L3. From the object point of the α spectrometer, the primary beam (Bp ≤ 2.88 T.m) goes straight through the first α dipole and is bent down to the heavily shielded production target cave (-3m) using an antisymetrical achromatic deviation and a two quadrupole doublet system devoted to the transverse matching of the beam on the target. The beam spot is adjustable from ± 2.5 to ± 13 mm for transverse emittances ranging from 2.5 to 6π .mm.mrad. This primary beam line ≈ 13 m in length could be extended to a second target cave using the same optics.

. The low energy beam line (Bp ≤ 0.05 T.m) from the ECRIS extraction to the cyclotron inflector is ≈ 19 m in length. It can be divided into two main parts :

- The first part includes an achromatic magnetic mass spectrometer system followed by a matching section to the second part. The optics [1] will insure a m/ δ m resolution of 250 for a 80 π .mm.mrad radial emittance. Such a resolution is quite enough as far as the cyclotron injection is concerned, anyway it would be almost impossible to exceed the cyclotron resolution at this level in order to fulfil the physics requirements. The second dipole will accommodate the beam from the second ECRIS if any, it can also be crossed without any deviation to feed a very low energy beam area under discussion (atomic and astro physics).

- The second part similar to the one used on our present injector is devoted to the 6D matching on the first accelerated orbit of a 80 π .mm.mrad, \pm 6° in phase beam as accepted by the cyclotron.

. The high energy beam line (Bp ≤ 2.344 T.m) extends from the cyclotron exit to experimental caves through the analyzing section of the α -spectrometer (to do so the first 2 dipoles of the α -spectrometer can be rotated by 45°). The acceptance of this line will amount at least to 10 π .mm.mrad and $\pm 3\%_{e}$ in energy dispersion. We will have to build $\cong 21$ m of new line divided into a first part allowing a betatronic isochronisation of the cyclotron beam and a second one to be used for the transversal matching of the beam at the α spectrometer object point.

V. CONCLUSION

The proposal will greatly enlarge the possibilities opened at GANIL in the field of radioactive ion beam physics at low and medium energy. Moreover, this new facility can be built without disturbing the classical use of GANIL.

Due to its rather low cost (\leq 100 MF), to the short delay involved (\leq 4 years) and to the available experimental facilities we can really expect that this project will be funded and so be confident in the future of our laboratory.

VI. REFERENCES

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