

# Design of the Radioactive Ion Beam Facility at the LNS

E. Migneco, R. Alba, L. Calabretta, G. Ciavola, G. Cuttone

M. Di Giacomo, S. Gammino, P. Gmaj, M.H. Moscatello

G. Raia, D. Rifuggiato, A. Rovelli, J. Sura, Q. Zhou

I.N.F.N.-Laboratorio Nazionale del Sud - V.le A. Doria ang. via S.Sofia  
I-95125 Catania

## Abstract

At the "Laboratorio Nazionale del Sud" the existing 15 MV Tandem will be coupled to the Superconducting Cyclotron booster, which will provide light and heavy ion beams in the energy range 100-20 MeV/n. Using these beams, secondary radioactive beams can be produced by projectile fragmentation. A fragment separator will collect the secondary beam produced at energies near that of the projectile and deliver it into the experimental areas. It is also discussed the possibility of using an ECRIS source for the axial injection into the Cyclotron and producing radioactive ions on a thick source placed inside the Tandem preinjector.

## 1 INTRODUCTION

At the "Laboratorio Nazionale del Sud" (L.N.S.) a 15 MV MP-Tandem has been delivering ion beams since 1983 [1]. In 1993 The Tandem will be coupled to the K-800 Superconducting Cyclotron (C.S.) [2], which will permit to reach energies up to 100 MeV/n for fully stripped light ions and up to 20 MeV/n for the heaviest ions, like Bi or U. The project to build a superconducting ECRIS source [3] for axial injection in the C.S. has started and will be completed by 1995. The Cyclotron will work in "stand alone" mode; the beam intensities are expected to be 2-5 times higher for light ions with respect to the Tandem injection. In addition to the superconducting source, a room temperature one will also be installed. Two different facilities for the production of secondary beams can be available at L.N.S. in the coming years: a fragment separator, which has already been designed, and a low energy radioactive beam facility, which is now proposed. In the first case, radioactive ion beams at intermediate energies (up to 90 MeV/n) can be obtained by projectile fragmentation on a thin target, then they will be analysed and collected by the extraction beam line, which is designed as a Fragment Recoil Separator (F.R.S.), and sent directly to the experimental rooms. In the second case, operating the Superconducting Cyclotron in "stand alone" mode by using the external ECR source, the light ions beams will be accelerated at an energy between 50÷80 MeV/n and will be transported to the Tandem injector's area.

In the following the main features of the low energy facility and of the F.R.S. will be presented.

## 2 THE EXCYT (EXOTICS AT THE CYCLOTRON-TANDEM) FACILITY

The energetic light ions (50-100 MeV/n) are an alternative to high energy protons (1 GeV) for the production of radioactive nuclei by interaction in a thick target. This solution allows to optimize the choice of the projectile-target in order to enhance the production of a given isotope and makes the extraction of secondary beams easier, the target being thinner than in the case of a proton beam.

In fig. 1 the layout of the proposed facility is shown. A major feature of this project is that a large part of components already exist. The new hardware and the modifications of the existing components are shortly described.

### 2.1 The ECR source

A 14.5 GHz superconducting magnets ECR source [3] will be coupled with the C.S. by Autumn of 1995. Moreover a room temperature ECR source will soon be purchased to be dedicated to the production of high intensity light ions beam. In both cases currents up to 1-2  $\mu\text{A}$  of fully stripped light ions and currents up to 10  $\mu\text{A}$  of (Z-1)-charged ions will be delivered. Special care has to be put on the extraction design, because the high magnetic field on the extraction side is detrimental to the emittance, and the performances of the cyclotron inflector are strictly related to the emittance of the beam coming from the source.

### 2.2 The axial beam line and the inflector

The axial injection will be achieved by a couple of solenoids, whose function is to reduce the effects of the magnetic field on emittance increase, and by a spiral inflector. The spiral inflector is the best suited for a Superconducting Cyclotron, considering the small clearance of the central region (height of the inflector  $\sim 2$  cm., width  $\sim 1.4$  cm.) and the fact that the beam can be injected along the axis of the machine (this feature being primordial to the quality of the beam). The emittance of the beam and the conditions at the entrance of the inflector determine the inflector's transmission. As far as the central region is concerned, a harmonic 2 operation is currently planned and the design has been made for a constant orbit mode.

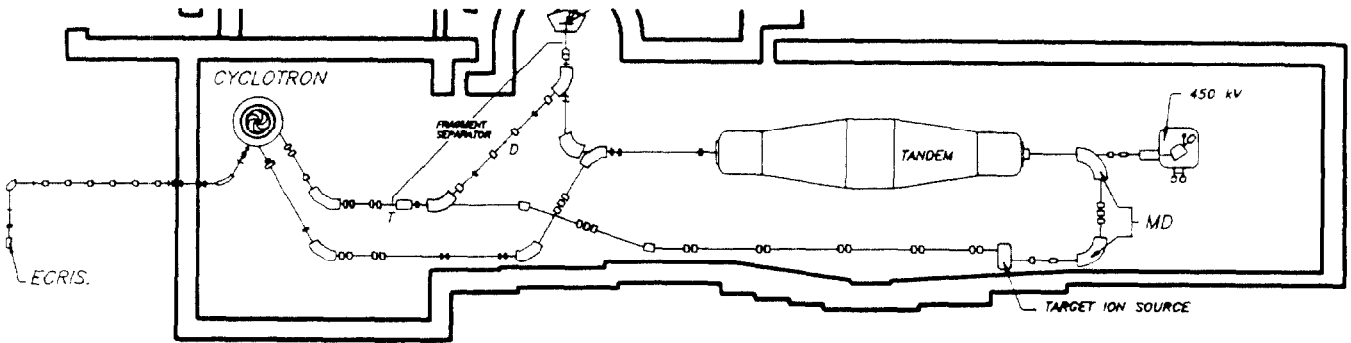


Figure 1: Layout of the EXCYT Facility

### 2.3 The Superconducting Cyclotron

The Superconducting Cyclotron is now near completion. Here we want to point out that up to now there is no experience on the acceleration of intense ion beams with superconducting cyclotrons and special attention must be paid to finding the solution of the intensity limitation problem. Particular care will be devoted to the following aspects: extraction, axial injection, acceleration, loading of cavities. We present some evaluations about the first subject, which we believe to be the most critical. The beam can be extracted in two different ways: by means of an electrostatic deflector, or by means of a sudden change of the beam magnetic rigidity, obtained by stripping an accelerated ion on a carbon foil.

One of the major problems arising with the electrostatic deflector is the maximum beam power allowed. Extraction by stripping is conceived as the solution to this problem.

We have performed a study on the feasibility of extraction by stripping in the case of our Cyclotron, keeping the general lay-out of the accelerator fixed and allowing only for minimum changes. As a consequence of this choice, the magnetic channels will be entirely redesigned. In fact, the beam can be transported along the extraction channel if local fields of about  $6 \div 7$  kG (opposite to the main field) and gradients of  $1 \div$  kG/cm are provided along the extraction trajectory. This result has emerged when studying the case  $^{16}\text{O}$ ,  $q_i=7$ ,  $q_f=8$ ,  $q_i$  and  $q_f$  being the charge values before and after the stripping. The holes already drilled in the cryostat and in the yoke can be used, and a further fixed channel should be installed. In this case the stripping process allows the beam to achieve an inter-turn separation of  $4 \div 5$  cm.

### 2.4 Recoil production and ionization

The target has to be thick ( $1 \div 5 \frac{\mu\text{g}}{\text{cm}^2}$ ), in order to give a number of recoils as high as possible, but has to release promptly the short-lived recoils. This can be obtained maintaining the source near the fusion temperature, but it requires a complicated system of temperature control, which will be working in a very hostile environment. The target has to stand the high operating temperature and must have a low vapour pressure. The thickness has to be optimized depending on the range of primary beams. The

efficiencies of release are element-dependent, and a strong effort will be necessary to find the best suited materials.

A He-jet flow will thermalize the recoils released by the target which will be attached to aerosols, in order to increase the efficiency of the system, as reported in [4].

Two kinds of ion sources have been considered for negative ion production: direct surface ionization and charge exchange. For both of them the total average conversion efficiency from radioactive atoms to negative ions varies widely, depending on the element (2-20 %). Therefore we plan to use two sources on the same high voltage platform, one (FEBIAD) for direct surface ionization and the other for positive ion production (microwave discharge), followed by a charge exchange canal.

### 2.5 The mass separator

The ions are negatively single charged and then no separation in charge is necessary, however they must be separated in mass. To analyze exotic short-lived nuclei a mass resolving power  $\sim 10.000$  is required. This value is feasible with an accurately constructed mass separator which corrects the image aberrations [5]. The High Resolution Separator planned for ISOLDE PSB project [6] represents a possible scheme for our mass separator. The ion source will be coupled to the mass separator by a transfer line consisting of some magnetic or electrostatic lenses which can quickly vary their focal lengths so as to compensate the varying focusing properties of the ion source without changing its plasma parameters.

### 2.6 The Tandem

The performances of the Tandem are not influenced when short-lived radioactive ions are accelerated, and then there is only one pre-caution to take into account: the current to be injected has to be lower than  $1 \mu\text{A}$ , in order to avoid the overcharge and to obtain an optimal transmission. This limitation can be real only for a few species of ions which have an intense contaminant which cannot be discriminated by the mass separator. The transmission through the Tandem depends on the mass: for masses up to 80 and for the most probable charge state we have measured a transmission up to 40%.

## 2.7 The secondary beam intensities

The production rate may be calculated with the formula  $I = \sigma I_o T$ , where  $\sigma$  is the cross section in  $\text{cm}^{-2}$ ,  $I_o$  is the beam intensity in pps and  $T$  is the thickness of the target in  $\text{atoms}/\text{cm}^2$ . In our case, considering a  $\sigma$  value of  $10 \div 100$  mbarn, an extracted Cyclotron beam of  $1 \text{ p}\mu\text{A}$  and  $T=1 \div 5 \text{ g}/\text{cm}^2$ , we expect to have a recoils yield of  $I = 10^9 \div 10^{11} \text{ pps}/\text{p}\mu\text{A}$ . Assuming a total efficiency in the negative source and in the Tandem of  $1 \div 10\%$ , we can obtain a final intensity in the experimental rooms of  $I = 10^7 \div 10^9 \text{ pps}/\text{p}\mu\text{A}$ .

## 3 THE FRAGMENT SEPARATOR

The F.R.S. of the LNS can be operated in two modes. In the dispersive mode it is a useful tool to tune the energy spread of the Cyclotron beam and to determine the time-energy correlation and the dependence on the accelerator parameters. In the achromatic mode the F.R.S. is useful to select enough pure secondary beams. In the latter case a water cooled target will be located at the position T in fig. 1. The first separator stage selects the fragments, produced at T, according to their magnetic rigidity. At the intermediate position D the ions go through a degrader that provide an energy loss roughly  $\Delta E \propto \frac{4^{2.5}}{Z^{1.8}}$ . The second stage is tuned to be achromatic; therefore it can select one isotope with small contaminants from neighbours.

The design rigidity of our F.R.S. is  $4.5 \text{ T}\cdot\text{m}$ , about 10% higher than the maximum magnetic rigidity of the beam accelerated by the Cyclotron, to allow us to separate neutron rich fragments.

The F.R.S. was designed to be mirror symmetric with an intermediate horizontal focus and a zero angular dispersion at the symmetry point, to obtain the achromatism of the device. At this position a degrader is placed. Four sextupoles were also included to correct aberrations.

In Table 1 the parameters of the F.R.S. are presented. They have been determined by the requirement of collecting as many fragments as possible and by constraints imposed by our accelerator rooms. In order to collect the ions emitted in a solid angle of about  $2.2 \text{ msr}$ , a superconducting solenoid 1 m long will be placed 30 cm far from the target.

Table 1: Characteristics of the LNS Fragment Separator

Magnetic elements	SQDQQQF <sub>d</sub> QQDQQF <sub>a</sub>
Magnetic rigidity [T·m]	4.5
$\Delta P/P$	3.6
$\Delta\Omega$ [msr]	2.2
Mom. dispersion at F <sub>d</sub>	1.9 cm/%
Mom. dispersion at F <sub>a</sub>	1.37 cm/%
Resolving power	750
Length [m]	22

S=solenoid lens, Q=quadrupole lens, D=magnetic dipole, F<sub>d</sub>=dispersive focus, F<sub>a</sub>=achromatic focus.

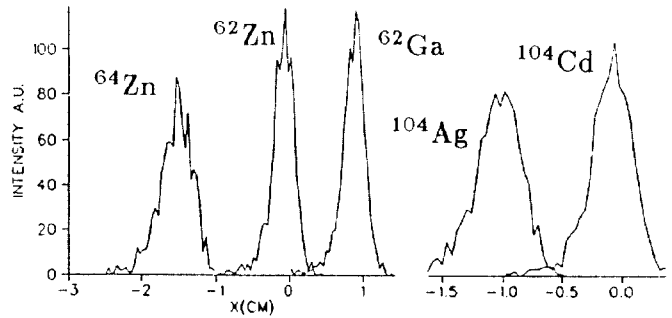


Figure 2: Calculated separation for different elements at the focal plane

Moreover the emittance of the transmitted fragments beam along the FRS and to the experimental beam lines depends on the solid angle collected and on the initial beam spot. To match the emittance of the fragments beam to the acceptance of our beam lines, a  $0.6 \text{ mm}$  wide beam spot was used in the simulation. Such a small spot is difficult to be delivered by our matching line, then it could be necessary to put a superconductive solenoids just before the target to reach the goal [7]. These two superconductive solenoids are the main elements to be designed and realized in the near future.

We evaluate the performances of the F.R.S. using the code "RAYTRACE" with a subroutine simulating the energy loss and the angular straggling introduced by the degrader. Employing an achromatic degrader one third of the range thick, our device has a charge resolving power  $Z/\Delta Z \sim 100$  as shown in fig. 2.

The performances of our device are comparable to other devices, with the remarkable advantage that secondary beams can be delivered to all the experimental areas.

## 4 CONCLUSIONS

The realization of a radioactive ion beam facility has been studied and it is feasible in the framework of the Laboratorio Nazionale del Sud. The study is under development, with the goal of the optimization of injection and extraction in the Cyclotron and of target and ion source efficiencies, in such a way as to permit a deliverance of high intensity secondary beams.

## 5 REFERENCES

- [1] E. Migneco, Nucl. Instr. and Meth., vol. A220, p. 14, 1984
- [2] E. Acerbi et al., EPAC, Nice, France, June 90, p. 425
- [3] G. Ciavola, S. Gammino, Proc. Int. Conf. on Ion Sources, Bensheim, to be published in Rev. Sci. Instr., Apr. 1992
- [4] H. Schmeing et al., Nucl. Instr. and Meth., vol. B26, p. 321, 1987
- [5] H. Wollnik, Nucl. Instr. and Meth., A258(1987)289
- [6] B. Jonson, Proc. Second Int. Conf. on Radioactive Nucl. Beams, Louvain-La-Neuve, Belgium, 1991, p.127
- [7] A. Joubert et Al., The SISSI Project, PAC-1991