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Progress in RIBRAS radioactive ion beams in Brasil project ☆

R. Lichtenthäler*[,1], A. Lépine-Szily, V. Guimarães, G.F. Lima, M.S. Hussein

Instituto de Física, Universidade de São Paulo, CP 66318, 05315-970 São Paulo SP, Brazil

Abstract

Nuclear physics has been going through a major evolution over the last decade. The realization that one can investigate nuclei at extreme conditions such as high density, temperature, and angular momentum using several sophisticated experimental innovations opened up the possibility of extending this activity to the study of these systems when more neutrons or more protons are added. The so called exotic nuclei constitute a major research activity in Japan, France, USA, Canada, Germany and other countries. More laboratories are going through the process of re-direction of their experimental effort towards this activity. The nuclear physics community in Brasil has enthusiastically decided to join this endeavor to provide the Pelletron/LINAC complex with two superconducting solenoids which will permit the production of secondary beams of radioactive nuclei. A description of this facility and project RIBRAS follows.

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1. The RIBRAS project

The importance of the radioactive ion beam studies motivated the Institute of Physics of the University of São Paulo, Brasil [1,2], to found a new facility at the Pelletron-Linac Laboratory in São Paulo, Brasil that extended the capabilities of the original accelerator in order to produce secondary beams of unstable nuclei. A drawing of this instrument is shown in Fig. 1. The most important components in this figure are the two new super-conducting solenoids having 6.5 T maximum central field (5 T m axial field integral) and a 30 cm clear warm bore which corresponds to an angular acceptance in the range ($2^\circ \leqslant \theta \leqslant 15^\circ$). The system was conceived to operate following the Linac post-accelerator of maximum energy of 10 MeV. A that is presently under installation at São Paulo Pelletron Laboratory. This energy will be about 3 times larger than the maximum energy of the present Pelletron Tandem of 8 MV terminal voltage. The magnets were designed to be completely compatible with the University of São Paulo (USP) LINAC post-accelerator. The liquid He consumption of these solenoids is 0.14 l/h in persistent mode, and 0.7 l/h with an external current of 90 A at maximum magnetic field. Both of these are compatible with the capability of the He liquifier installed at Pelletron-LINAC Laboratory at USP. The presence of the two magnets in the design is very important. As the first magnet transmits all ions with the same magnetic rigidity, ions of different m/Q values with different energies

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*Corresponding author.
E-mail address: rubens@if.usp.br (R. Lichtenthäler).
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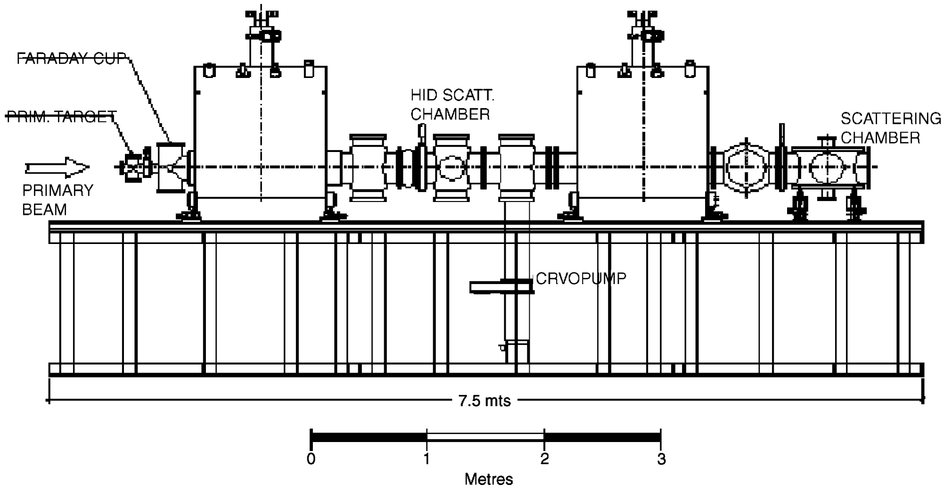

Fig. 1. Scale illustration of the University of São Paulo—double solenoid ion-optical RNB system, RIBRAS.

can be transmitted, and the purity of the radioactive secondary beam can be rather poor, except in very special cases such as the ^{8}Li beam from the Notre Dame-Michigan facility where a fortunate set of circumstances allowed for an 80% pure beam through the use of a suitable blocking aperture for the inelastically-scattered primary beam. With two solenoids, it is possible to use differential energy loss in an energy degrader foil, located at the crossover point between the magnets, to select the ion of interest and move the contaminant ions out of the bandpass of the second solenoid. This method will not separate isotopes of the same element, however, since the energy loss is very nearly the same for all such isotopes having the same magnetic rigidity. Time of flight technique using pulsed primary beam is also very useful in order to identify events with the nuclei of interest in the secondary beam. The buncher system for the Pelletron pulsed beam is presently being installed. An additional advantage of the two solenoid system is the possibility of producing tertiary beams using a secondary target in the middle scattering chamber where a secondary reaction takes place. The second solenoid can be tuned to select a different magnetic rigidity producing a tertiary beam [3]. The solenoids can also be used as a Recoil Mass Separator for reaction products produced in the primary or even secondary targets.

The proposed RIBRAS facility, though it will use essentially the same components as the Notre Dame-Michigan "Twinsol" facility, will have several important advantages provided by the linear post-accelerator. In particular, higher-energy (up to 10 MeV/nucleon), higher mass (perhaps up to $A = 100$) radioactive ion beams can be produced with beam purities approaching 80% in many cases. In addition, the pulsed time structure of the beam will provide a powerful time-of-flight parameter that can be used to reduce backgrounds in many experiments. The capabilities of the Notre Dame Tandem Van de Graaff accelerator (similar in many respects to the USP Pelletron accelerator) limit the reaction mechanism used to produce radioactive ions beams to a one- or two-nucleon transfer process with primary beams of mass less than 40. On the other hand, the higher energies available with the Pelletron-LINAC accelerators will allow fusion-evaporation, deep-inelastic, incomplete fusion and possibly even fragmentation to be used. On a more speculative note, if uranium beams could be accelerated to energies of a few MeV per nucleon, transfer induced fission reactions could be used to produce a wide variety of very neutron rich fission fragments. The beams

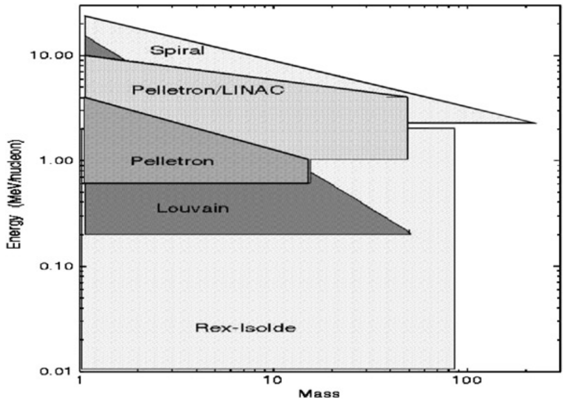

Fig. 2. The regions in terms of mass and energy of operations of several RIB facilities.

formed in this way are not likely to be very pure, but they could be useful in a number of experiments. However, this extended project would require the installation of a low-β initial acceleration stage and an ECR source at the LINAC, and possibly even the addition of more resonators to increase the energy of the primary beam.

Finally, it should be noted that setting up the solenoid system prior to the completion of the LINAC post-accelerator is an important consideration, since this makes possible to begin experiments with a facility similar to the TWINSOL at Notre Dame University, with the aim of learning how to use the solenoid system to produce usable radioactive ion beams. A comparison between RIBRAS and other upgrade projects is shown in Fig. 2.

2. Recent developments

The two 6.5 T solenoids were manufactured by Cryomagnetics Inc, USA and are already mounted on the aluminium support in the 45 B beam line of the Pelletron Laboratory. Both solenoids were bench tested successfully on April, 2002. The magnets were cooled down to liquid helium temperature 4 K and charged up to currents of 80 A (magnet 2) and 50 A (magnet 1). The system will initially operate using the primary beam of the Pelletron 8 MV Tandem and will be moved to the LINAC beam line as soon as it becomes operational. The components of the beam line for the two solenoids, primary target, Faraday cup and mid scattering ISO chambers are in the stage of installation. The secondary scattering chamber is being projected and will probably be manufactured at the Laboratório Nacional de Luz Syncrotron (LNLS), Campinas, São Paulo, Brasil.

We expect that the system will be ready to produce the first secondary beam by the end of the second semester of 2003. Initially the primary beam of the Pelletron Tandem will allow to produce basically the same secondary beams as at the Notre Dame Twinsol facility. The primary beams at the Pelletron Tandem are produced by a NEC-multi-cathode sputtering ion source, delivering typical intensities of 1 to 2μA of ^{6,7}Li; ^{10,11}B; ^{12,13}C; ^{16,17,18}O on the primary target. With such primary beams intensities it is possible to produce for instance, secondary beams of ^{6}He, ^{8}Li, ^{8}B, with intensities of about 10^5 to 10^6 particles per second using the production transfer reactions ^{9}Be(^{7}Li, ^{6}He)^{10}B or ^{9}Be(^{7}Li, ^{8}Li)$\alpha\alpha$ [4]. We are also investigating other production reactions. Two new candidates are the reactions ^{14}N(^{7}Li, ^{6}He)^{15}O [5] for ^{6}He beam and ^{11}B(^{25}Mg, ^{24m}Na)^{12}C [6] for a beam of the excited ^{24m}Na in its isomeric state $E^* = 472$ keV $T_{1/2} = 20$ ms. We performed measurements of angular distributions of these reactions at the São Paulo Pelletron and the data are under analysis. The preliminary results indicate cross sections of the order of 1 millibarn in the forward angle region $(2^\circ \leqslant \theta \leqslant 6^\circ)$ which is in principle sufficient to produce secondary beams of reasonable intensities. A Monte Carlo simulation code was developed [7] in order to simulate the secondary beam transmission through the two solenoids taking into account the experimental features such as angular distribution of the primary reaction, primary beam spot size in the primary target, energy loss, energy and angular straggling in the primary target and Faraday cup and colimators blocking through the secondary beam line. The simulation was applied to the primary reaction ^{9}Be(^{7}Li, ^{6}He)^{10}B and a transmission efficiency $N^{^6\mathrm{He}}(\mathrm{trans})/N^{^6\mathrm{He}}(\mathrm{prod}) \approx 0.15$ up to the secondary scattering chamber was found, in good agreement with experimental data taken at Notre Dame

Twinsol facility. This simulation code shall be a powerful tool in the planning of future experiments using the two solenoid separator.

3. Conclusions

A double superconducting 6.5 T solenoid system is being installed at the Pelletron-LINAC Laboratory of the University of São Paulo in order to produce secondary beams of radioactive nuclei. The two solenoids have been manufactured by Cryomagnetics Inc and are already mounted on their supports and tested. The beam line is being installed. The system shall begin its operation in 2002 using the primary beams of the 8 MV Pelletron Tandem and will be moved to the 10 MeV/nucleon LINAC post-Accelerator as soon as it starts operating.

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