Nuclear Instruments and Methods in Physics Research B 123 (1996) 34–38

ELSEVIER

NIM B
Beam Interactions with Materials & Atoms

Brazilian accelerator mass spectrometry program

G.M. Santos [a,1], J.C. Acquadro [b], R.M. Anjos [a,1], P.R.S. Gomes [a,*,1], C. Tenreiro [c], R. Liguori Neto [b], M.M. Coimbra [d], C.R. Appoloni [d], A.M.M. Maciel [a,1], N.H. Medina [b], M.A. Rizzuto [b], N. Carlin Filho [b]

[a] *Instituto de Física, Universidade Federal Fluminense, Av. Litoranea s / n, Gragoatá, Niterói, R.J., 24210-340, Brazil*
[b] *Instituto de Física, Universidade de São Paulo, C.P. 20516, São Paulo, 01498-970, Brazil*
[c] *Departamento de Física, Faculdad de Ciencias, Universidad de Chile, Santiago, Chile*
[d] *Departamento de Física, Universidade Estadual de Londrina, Paraná, Brazil*

Abstract

The present status of the Brazilian AMS program, based on the University of São Paulo 8UD tandem accelerator, is described. Results of tests and developments on voltage stability, focusing, automatic system for changing beams and detection system are presented. ^{36}Cl and ^{26}Al beams have already been successfully accelerated and detected.

1. Introduction

The Brazilian AMS program has been initiated in 1993 at the University of São Paulo (USP) [1]. After a gap period in 1994, it has been re-started in 1995. At the present there are three Brazilian and one Chilean universities involved with it. The accelerator used is the 8UD tandem at USP. Fig. 1 shows the schematic layout of the facility. The initial major emphases are on projects based on the determination of ^{36}Cl, ^{26}Al concentrations, with main applications on geological quaternary dating archaeology, glaciology, climatology, environmental and biological studies. Several Brazilian institutions are already very interested in the implementation of the AMS technique. There are also plans for the purchase of a 2 MV tandem at Rio de Janeiro. Its main aims are Atomic Physics research projects, but it will also be used for ^{14}C and ^{10}Be dating.

The first research projects to be implemented are concerned with ^{36}Cl samples. Environmental studies on the atmospheric circulation differences between North and South hemispheres and on the ozone layer will be done by comparing the ^{36}Cl concentrations as a function of the latitude.

This paper reports the present status of the program, with emphasis on the developments made since 1995. Section 2 describes the facilities available for the AMS

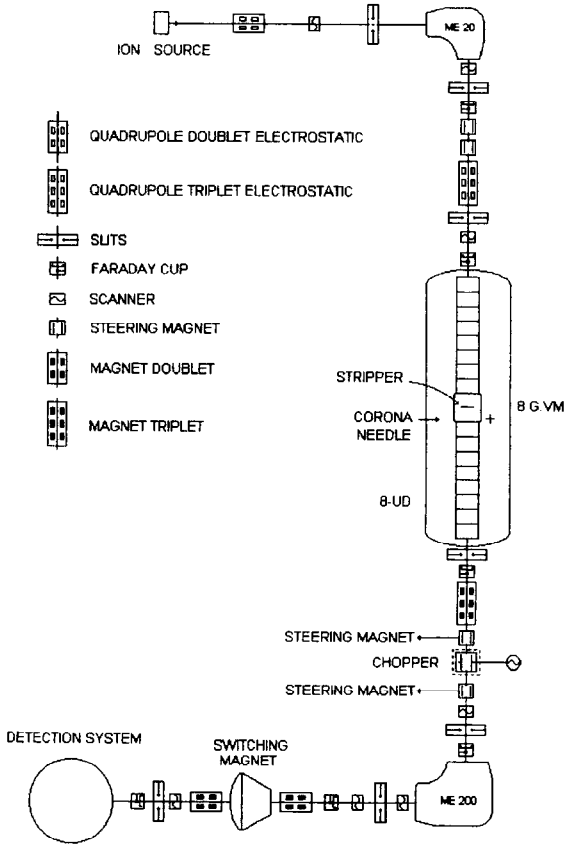

Fig. 1. Schematic diagram of the São Paulo 8UD tandem facility.

* Corresponding author. Tel. and fax +55 21 620 6735, e-mail paulogom@if.uff.br.

[1] Fellow of the Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq.

PII S0168-583X(96)00425-9

program, such as the ion source and accelerator. Section 3 is concerned with the developments, tests and results for the AMS program. Section 4 is a summary of the paper.

2. The AMS system

2.1. Ion source, samples and beam extraction

The ion source that has been used is the usual single cathode SNICS (source of negative ions by cesium sputtering) of the laboratory, built at São Paulo [2], similar to the Middelton source [3,4]. It is made of stainless steel and it has a simple axial geometry, with a copper cathode at -4 kV. Recently the laboratory has purchased from NEC a multi-cathode sputtering source, suitable for a regular AMS program, which is able to contain up to 32 different samples. As this source has not yet been installed, all the tests reported in this paper are related with the single cathode source.

The extracted negative ions leave the source through a 20 kV potential and are pre-accelerated by 70 kV, stabilized within ± 100 V, reaching the analyzing magnet and acceleration region with 90 keV. The optics after the extraction from the ion source is controlled by a doublet electrostatic quadrupole. It follows an analyzing magnet ($ME/Z^2 = 20$) and a triplet of electrostatic quadrupoles, responsible for the beam focusing in the accelerator tube. The magnetic field of the analyzing magnet, within a typical range from 2.43 kG for $A = 7$ and 7.17 kG for $A = 60$, is monitored by a Gaussmeter with sensibility of ± 20 G. The long term variations of the current in the coils of this magnet is better than $1/5000$.

The beams that have been tested so far, for the AMS program, are Cl^- and AlO^-. The typical currents of the stable beams of those elements are of the order of 300–500 nA before the acceleration region. Beams of ^{36}Cl were produced from samples of snow from South Chile (Antarctic and Andes region). They have been prepared following the prescription of Ref. [5]. An ^{26}Al sample, prepared for testing purposes, was produced via the $^{26}Mg(p,n)^{26}Al$ reaction, which has a cross section of the order of 100 mb for 16 MeV protons. The target used was MgO pressed powder. From a sample placed at the ion source cathode, beams of $^{26}AlO^-$ and $^{26}MgO^-$ molecules were extracted (mass 42). Following the prescription of Ref. [6], this sample was mixed with another one containing stable ^{27}Al. The $^{27}Al\ O^-$ (mass 43) beams were produced from a mixture of Al_2O_3 and Cu powders pressed into the cathode. More details of the sample preparation are found in Ref. [1].

2.2. The accelerator and focusing devices

The tandem accelerator at USP (see Fig. 1) is a vertical 8UD pelletron NEC machine [7] modified to reach a terminal potential of 9 MV. The electron stripping and molecule breaking are carried out with 20 $\mu g/cm^2$ carbon foils. The vacuum in the accelerator tube is of the order of 10^{-8} Torr. The usual energy control system for the stabilization of the machine uses the slits-current feedback mode. However, this procedure cannot be applied for the extremely low intensity unstable beams. Therefore, one has to rely on the stabilization via the generating voltmeter. Several stability tests have been performed with the generating voltmeter, as a function of the position and current of the corona probe. They have shown that the generating voltmeter is able to control the terminal voltage within fluctuations of ± 2 kV at 8 MV, which is good enough for AMS purposes.

The overall transmission of the beam electrical current for 8^+ ^{35}Cl beams is of the order of 20% for 8 MV. It is stable during periods much longer than the cyclic period of swapping from unstable to stable beams.

The beam focusing on the acceleration system consists of electrostatic quadrupoles before the injection into the tandem, magnetic quadrupoles after it, analyzing magnet (ME 200) and a switching magnet. Several Faraday cups and beam profile monitors are installed along the beam line.

3. Developments for the AMS program: tests and measurements

3.1. First tests

Several tests have been made concerning the stability of the machine for weak beam currents, and some developments were implemented in this field. Some of those initial tests were already reported in Ref. [1]. An intense ^{35}Cl beam (300 nA) was used for the adjustment of the magnetic and electrostatic elements of the optics in order to maximize the transmission. Then, all the magnetic elements were kept fixed and the ^{37}Cl beam was focused and transmitted with only two parameters' changes: the field of the injection magnet and the terminal voltage. The focusing conditions for the ^{36}Cl beam were, then, interpolated. Measurements were performed in sequences for each of the three Cl isotopes. An Au target was used to scatter the intense stable beams, with the detector placed at 20° to the beam direction. For the ^{36}Cl beam, the target was removed and the detector placed at 0°. A figure with the overlap of the three Cl isotopes spectra can be seen in Ref. [1]. The tests have shown that the stability controlled by the generating voltmeter is suitable for the use of this machine for AMS purposes.

Tests of the detection of unstable beams were performed with an existing position sensitive ionization chamber detector, coupled with a silicon barrier position sensitive detector, described in Ref. [1]. They were placed in a 1 m diameter multipurpose scattering chamber. The atomic

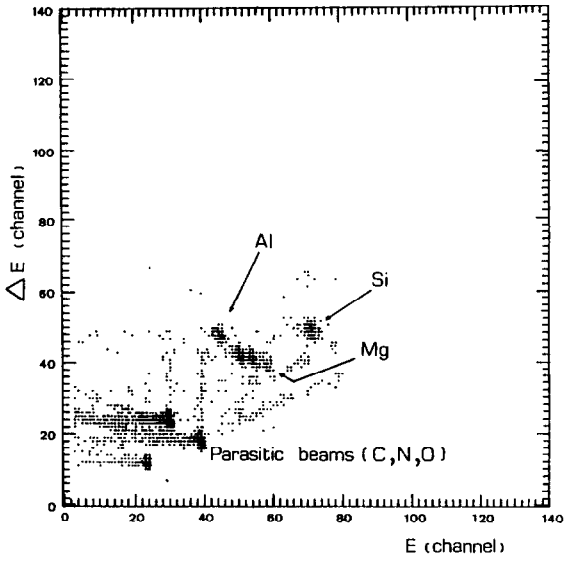

Fig. 2. Two-dimensional $E \times \Delta E$ spectrum of ^{26}Al detection.

number calibration of the spectra was obtained from reactions and scattering of the stable ^{16}O and ^{12}C beams with ^{12}C foils. Fig. 2 shows a bi-parametric $E \times \Delta E$ spectra for the ^{26}Al measurements, where it can be seen that the detection system was able to separate the ^{26}Al and ^{26}Mg isobars. In both cases (^{26}Al and ^{36}Cl), however, due to the lack of a velocity filter, low intensity parasitic beams with $Z < 10$ were observed, mainly the O beam coming from the AlO^- and MgO^- molecules. The results have shown that, although the peak positions of the isobars could be separated, the background tails of ^{36}S and ^{26}Mg on the ^{36}Cl and ^{26}Al spectra are too high to be used for AMS purposes. Therefore, improvements on the detection system had to be developed.

3.2. Recent tests and developments

As result of the previous tests, we have decided to study the improvements of the beam focusing and the periodic change of ionic beams by keeping fixed all the parameters involving magnetic fields, both in analyzing magnets and quadrupoles. Also, it has been shown worthwhile to develop an automatic system, controlled by a microcomputer, for the cyclic and periodic change of beams. This system should be able to reject the transmitted stable beams when the detector is positioned to detect low intensity unstable beams, and to optimize the procedure of the swapping from one ion beam to another. An improvement on the detection system was also desirable, as mentioned earlier. The recent tests and developments will be discussed in the following. Most of our recent developments are based on the reported results and ideas from Chalk River [8].

In order to avoid possible hysteresis problems and for a quick change of the beam, we have opted for keeping fixed the magnetic field of the first analyzing magnet. The only parameters that were allowed to change are the ion source bias pre-acceleration potential, the terminal voltage and the voltages of the electrostatic quadrupoles needed to focus the ^{35,36,37}Cl beams. The starting point is the optimized focusing conditions for the ^{35}Cl beam. Focusing was obtained for a ^{35}Cl beam with a pre-acceleration bias of 90 kV and a terminal voltage of 8 MV. Then, good and reproducible focusing was successfully achieved for the ^{37}Cl beam, with the modification of these values to 85.14 kV and 7.57 MV. We are convinced that any automatic system for changing beams will operate much more efficiently with the procedure of keeping fixed all the parameters related with magnetic fields, than otherwise.

In the search for a device that would be able to deflect, and consequently to reject the focusing of undesirable stable beams, we have firstly tried to introduce a current variation on a magnetic trimmer located at the exit of the ion source. This current produces a magnetic field that should be able to deflect the low energy beam and to decrease the beam current by orders of magnitude. However, the results with a ^{35}Cl beam showed that for $\Delta i = 1$ A the beam intensity decreases only to 5% of the original one.

The next trial was the use of a chopper, already installed before the high energy analyzing magnet (ME 200). The deflection of the beam would occur by the introduction of a transverse electric field. The predictions, from a simulation Monte Carlo computer code, for the response of the beam characteristics due to changes in the optics elements, were very encouraging. However, once more, the results of tests with ^{35}Cl beams were very unsatisfactory. The decrease of the beam current with the increasing of the applied voltage became saturated in 15% of its original value, for voltage values greater than 4 kV.

Then, we designed and built a mechanical system as shown in Fig. 3. An Au target is mounted on a target holder coupled with a Faraday cup. If a stable and high intensity beam is accelerated and focused, the system moves in order to intercept and block the beam. Therefore, it avoids the undesirable beam to reach the detector placed at 0° with the beam direction. When this happens, the beam is scattered by the target. The beam scattered at 150°

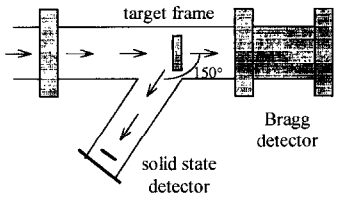

Fig. 3. Schematic layout of the detection system. Low intensity unstable beams are detected in the detector at 0°, when the target is removed. High intensity stable beams are scattered by a Au target and detected by a solid state detector.

is detected by a surface barrier silicon detector. A quantitative measurement of the stable beam intensity is then derived.

A computer controlled system for AMS has been commissioned and it is being developed in São Paulo. Its main aim is to change periodically and simultaneously the terminal voltage, the bias potential of the ion source and the voltages of the electrostatic focusing devices, in such way that one keeps a constant moment per unit of charge for the different beams. This system will also be responsible for blocking or letting through the beam on the 0° detector, as described above. When the system is ready for operation, the swapping of ionic beams will be controlled by a program that changes the accelerator parameters at preset times. An interface between the accelerator control and the data acquisition computers sends the information of the change of parameters to the acquisition side. For example, for the ^{35,36,37}Cl beams, the input parameters are the time interval (T_{Ai}), the terminal voltage (V_{Ai}) and the injecting bias potential (B_{Ai}), for $A = 35, 36, 37$. With those parameters preset, the code generates cycles of stable and unstable beams. The target holder device moves up and down, controlled by a trigger pulse related to the terminal voltage. If the parameters are not the suitable ones for the focusing of the unstable beam, the target moves down and intercepts the beam. Fig. 4 shows a scheme of the cyclic isotope selection procedure.

3.3. New detection system: a Bragg detector

The main technical problem when dealing with ultra high sensitive accelerator mass spectrometry is the presence of isobaric contamination on natural samples, like ^{10}B in ^{10}Be, ^{26}Mg in ^{26}Al and ^{36}S in ^{36}Cl. In all these examples, the chemical separation of the contaminants, in the levels needed for AMS purposes, is very difficult. Therefore, one needs a detection system that is able to separate elements that differ by one unit of charge in the mass energy region of interest. A complete particle identification can be obtained if one combines such detector with a time of flight device.

The most widely used detector for charge identification is the gas filled ionization chamber, combined with a solid state detector. This is the kind of detector that we have being using until recently [1].

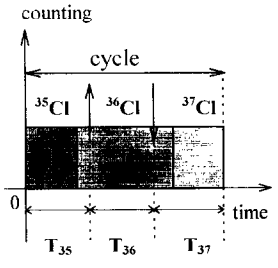

Fig. 4. Scheme of the periodic change of ion beams. The arrows indicate the motion of the target/Faraday cup, in front of the detector.

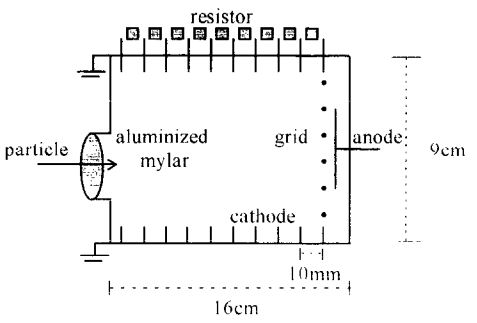

Fig. 5. Schematic view of the Bragg detector.

In order to improve the quality of the identification of the detected particles, and the energy and charge resolution of the detection system, over a wide range of Z and energy, a new detector has been designed and built at UFF and USP: a Bragg detector [9]. This detector has a geometry that will allow its coupling with a time of flight device. This system will be fully dedicated to the AMS program.

Fig. 5 shows a schematic layout of our Bragg detector. It has a cylindrical geometry and contains 10 equipotential guard rings. The entrance window, made of aluminized mylar foils, serves as the cathode, which is on ground potential. The electrons, produced by the particle in the gas, drift to the anode and are sensed by the amplifier when they cross the Frisch grid, which consists of parallel copper–beryllium wires, with 50 μm diameter, separated by 1 mm. A constant drift velocity is obtained by the presence of the guard rings, which produce a homogeneous electric field along the drift direction. The rings are 10 mm apart from each other. The Frisch grid is 10 mm from the anode and 170 mm from the cathode. A resistor chain divides the voltage from the Frisch grid and the cathode. The gas used is the usual P 10 (90% Ar, 10% CH_4).

The discrimination between the ionization near the Bragg maximum (charge identification signal) and the total ionization (total energy signal) is obtained by the use of two main amplifiers, with different shaping times, following the split of the output signal of the pre-amplifier. For the total ionization, the shaping time is longer than the total electron collection time, while the other one operates with a shaping time of the order of the collection time of the electrons from the Bragg maximum.

The first tests of the detector, with beam, are scheduled to be performed in June 1996. From those tests we will be able to decide whether the detector system is satisfactory or if further improvements have to be made.

4. Summary

The Brazilian AMS program is being implemented, after the initial tests that have shown that the 8 UD tandem

of the University of São Paulo stability conditions are suitable to be used for such purposes. ^{36}Cl and ^{26}Al beams have been successfully accelerated and detected. New advances are expected in a near future, with the use of a multi-cathode ion source and a Bragg detector, which are already available at the laboratory, and an automatic system for cyclic and periodic change of beams, which is being developed.

References

[1] C. Tenreiro, R.M. Anjos, J.C. Acquadro, G. Kremer and G. Ramirez, Nucl. Instr. and Meth. B 92 (1994) 89.
[2] L.A.B. Tessarotto, J.C. Acquadro, M. Stier, P.R.S. Gomes and O. Sala, Proc. 7th Int. Symp. on Ion Sources and Ion Assisted Technology, Kyoto (1983) p. 147.
[3] G.T. Caskey, R.A. Douglas, H.T. Richards and H.V. Smith Jr., Nucl. Instr. and Meth. 157 (1978) 1.
[4] R. Middelton, Nucl. Instr. and Meth. 214 (1983) 139.
[5] L.E. Tubbs, Rochester Ann. Rep. (1981) p. 163.
[6] J. Barker, J.P. Day, T.W. Aitken, T.R. Charlesworth, R.C. Cunningham, P.V. Drumm, J.S. Liley, G.W.A. Newton and M.J. Smithson, Nucl. Instr. and Meth. B 52 (1990) 540.
[7] O. Sala and G. Palek, Nucl. Instr. and Meth. 122 (1974) 213.
[8] H.R.Andrews, G.C. Ball, R.M. Brown, R.J.J. Cornett, W.G. Davies, B.F. Greiner, Y. Imahori, V.T. Koslowsky, J. McKay, G.M. Milton, J.C.D. Milton and K.W. Allen, Nucl. Instr. and Meth. B 52 (1990) 243.
[9] C. Schessl, W. Wagner, K. Hartel, P. Kienle, H.J. Koner, W. Mayer and K.E. Rehm, Nucl. Instr. and Meth. 192 (1982) 291.