Recent IBA setup improvements in Chile

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Abstract

This paper describes the main characteristics of the ion beam facility based on a 3.75 MeV Van de Graaff accelerator model KN3750 of HVE at the University of Chile. Recent setup improvements on three beam lines available, one dedicated for PIXE analyzes, one designed for RBS–PESA analyzes and a multipurpose vacuum chamber, as well as beam energy calibration experiments of the accelerator will be summarized. Current research activities are focused on the application of the different IBA techniques for the material, biological and environmental analysis. In addition, nuclear activation analysis and the study of nuclear reactions of astrophysical interest has begun to be developed as basic research.

Keywords: Ion accelerators; Experimental chambers; RBS; PIXE

1. Introduction

The installation of a Van de Graaff accelerator, KN3750 built by High Voltage Engineering in the Campus of the Faculty of Sciences, University of Chile has promoted the setups of IBA methodologies. This accelerator, initially at Lucent Technologies Laboratory in New Jersey, USA, can produce several single charged ion beams in the energy range from 200 keV to 3700 keV. The Van de Graaff replaces the former 22 in. isochronous cyclotron [1] decomised in 1996 and occupies the same building and major utilities. The experience obtained in PIXE applications with deuteron and proton beams [2,3] provided by the cyclotron triggered the interest in expand the possibilities of non-destructive IBA methodologies. In fact, besides PIXE other techniques like RBS and nuclear activation analysis have been installed and used. The laboratory is intended to be a multidisciplinary research center, its primary aim being the material modification and analysis by making use of the ion beam-based techniques giving the possibility of carrying out experiments in a wide variety of fields: Material Science, Environmental Science, Medicine and Archaeology, even though these low-energy accelerators have been proved to be important for basic research such as nuclear astrophysics. Here a brief description of the facilities is given and examples of the analysis are shown.

2. Experimental

2.1. The accelerator

The facility is based on the Van de Graaff accelerator which occupies an experimental area of around 235 m^2 and its layout is illustrated in Fig. 1. Normally it operates under a SF_6 pressure of 30 psi. An automatic SF_6 recovery system by ENERVAC Co. allows the storage of this gas at

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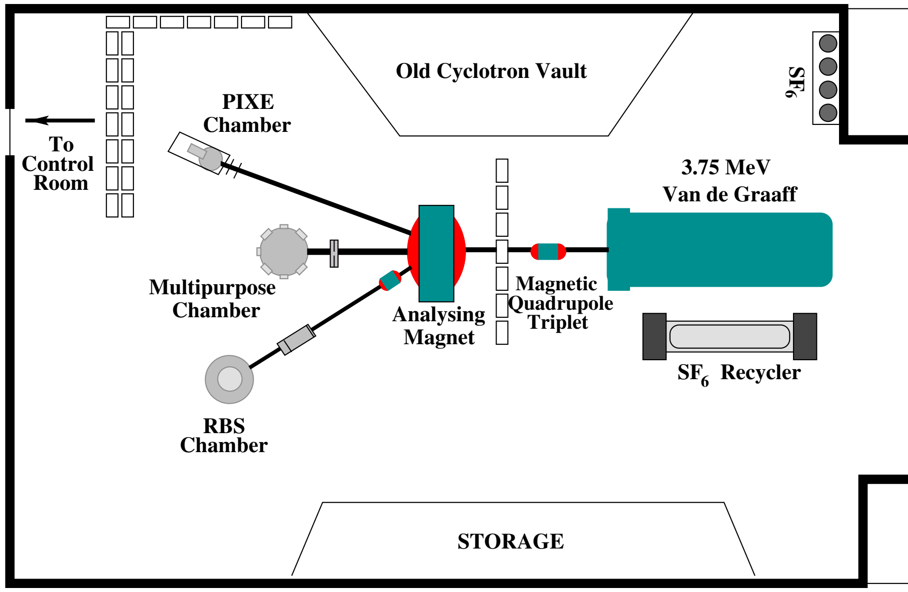

Fig. 1. Schematic layout of the Van de Graaff accelerator and the experimental beam lines.

liquid temperature or transfer it to the VDG pressure tank. Turbomolecular pumps allow a vacuum of 10^{-6} Torr in the beam tube and experimental chambers. A radio-frequency ion source permits to carry out experiments with intensities from a few nA to μA. Currently, the ion source is capable to produce ion beams of $^{1}H^{+}$, $^{2}H^{+}$, $^{4}He^{+}$ and $^{131}Xe^{+}$. The beam pass directly to the 0° line or can be deflected by the HVE Switching Magnet Model DD towards one of the beam lines at ±15°, ±30°, ±45° or ±60° with corresponding mass-energy product of 650, 179, 81 and 48 amu-MeV, respectively. The magnet generates a maximum magnetic field of ±16.5 kG at 350 A. The field of the analyzing magnet is measured using a high accuracy Hall effect probe, which is connected to a Bell Gaussmeter model 620. The gamma radiation field at various locations inside the accelerator hall is continuously monitored by an Eberline radiation monitoring system (RMS II), holding six channels of radiation monitors. A Nemo neutron-detector model 9179 by Texas Nuclear Co. can also be used to measure the neutron radiation dose. The main parameters of the beam handling system are remotely controlled and monitored at a console located in the control room.

Specific tests are routinely performed to check the capabilities of the accelerator. Its absolute energy calibration is determined using the 872 keV and 1370 keV resonances of the $^{19}F(p,\alpha\gamma)^{16}O$ reaction and the 1735 keV resonance of the $^{12}C(p,p)^{12}C$ reaction. The results show a linear relationship between the terminal voltage and the voltage read at the generator voltmeter, having a relative error of about 3%.

2.2. Data acquisition

Data acquisition and analysis systems include four NaI(Tl), one HPGe, two Si(Li) and several surface-barrier detectors, computer data acquisition and analysis software, two ORTEC PC MCS Model Triump-8K system and associated standard NIM electronic components. Recently, a new multiparametric data acquisition system based in the CAMAC standard has been installed allowing spectra acquisition using up to sixteen detectors simultaneously. It uses a software called PelROOT [4] developed at the University of São Paulo, which is based in the ROOT [5] package. Beam current and dose are measured with a ORTEC 439 digital current integrator in combination with a computer-controlled preset counter (ORTEC 871 Counter-Timer).

2.3. Experimental areas

PIXE is a powerful and relatively simple analytical technique that can be used to identify and quantify trace elements typically ranging from Al to U [6]. In the PIXE setup a NEC beam profile monitor Model FP3 and a set of steerers and collimators allow the control and monitoring of the beam along the line. The targets are attached to a computer-controlled sample holder and irradiated with a 2.0 MeV proton beam of 3 mm^2 cross section. The beam, after passing through the target, is stopped by a Faraday cup located at 0.5 m behind the sample position. Typical proton currents range between 5 nA and 20 nA. X-rays emitted from the samples are recorded under vacuum by a CANBERRA Si(Li) cryogenic detector Model 7300 having 220 eV FWHM resolution at 5.9 keV. Pulses are analyzed with proper electronic circuitry and collected by an ORTEC PC MCA Model Trump-8 K. The stored PIXE spectra, containing characteristic X-ray peaks plus a bremsstrahlung background are analyzed by the AXIL code [7] obtaining the net area of all detected elements in the sample. To verify the homogeneity of concentrations in the sample, several spectra are usually taken in different parts of each target. Following standard PIXE methodology the elemental concentrations are calculated from X-ray intensities, accumulated charge and mass density of the samples. The sensitivity of the detection system is determined by the irradiation of a set of certified samples provided by Micromatter. Currently, a new PIXE chamber manufactured by CINEL-Strumenti Scientifici is being installed, which is designed for automatic analysis of a maximum of 30 samples affixed to a wheel driven remotely by an acquisition PC code.

Given the acceptance of the RBS technique as an important ion beam analysis tool [8], a beam line for this purpose was installed in our laboratory [9]. RBS analysis is generally performed with 2.0 MeV beams of alpha particles in a stainless steel 600 series ORTEC scattering chamber which features two vernier reading turntable angles with an accuracy better than 0.1°, an air-lock hub to allow insertion of targets with the chamber under vacuum, a Faraday Cup, two collimators (antiscattering) defining a beam spot about 2 mm^2, fourteen coaxial vacuum feedthrough fittings at different angles to connect the detectors and two accessory ports. The target holder is a rectangle of 243×17 mm^2 and support seven samples of up to 15×12 mm^2. A goniometer is used to position and orient the sample with respect to the beam (±1 mm) and to select the tilt angle (±0.5°). A solid state detector is positioned at 165° in relation to the beam direction. An "oil-diffuse" pump provides a reasonable pumping down while an Edwards LN_2 cold trap is also used to improve the vacuum conditions. Prior to performing RBS analysis, the detection system is calibrated by using ^4He backscattering spectra of a thin Al/Ti/Ta multilayer on a carbon substrate as it is shown in Fig. 3(a).

A third beam line has been designed as a general purpose one, i.e. not only to carry out IBA experiments, but also, to develop basic physics research. The 295 mm diameter experimental scattering chamber set in this line allows simultaneous PIXE, PIGE, RBS and PESA and can be equipped with a HPGe ORTEC detector for γ-ray analysis, two CANBERRA Si(Li) cryogenic detectors used for low and high Z element analysis and two EG&G surface barrier detectors for RBS (150°) and PESA (30°) analysis. Also an Raster Scanner RS1200 by Physicon installed in the beam-guide about 50 cm in front of the multipurpose chamber can be used either for macroscanning or to sweep the beam on the collimator placed in front of the sample for normalization purposes. In some kind of experiments an important requirement imposed on each target is its capacity to withstand high beam intensities while suffering no structural damage during extended irradiation periods, demanding a method to remove the heat deposited in the target during this time. A target cooling system using liquid nitrogen was built [10] allowing targets to operate at temperatures around 300 K and providing acceptable working conditions even for thin targets after 13 h of continuous irradiation. This facility is specially adequate to perform systematic studies of proton capture reactions of nuclear astrophysics interest.

3. Applications

At this laboratory the PIXE technique has been extensively used for trace element analysis of atmospheric pollutants, characterization of obsidian samples from different source sites in Chile [11,12] and in geological, medical and biological samples [13]. As an example, in a recent

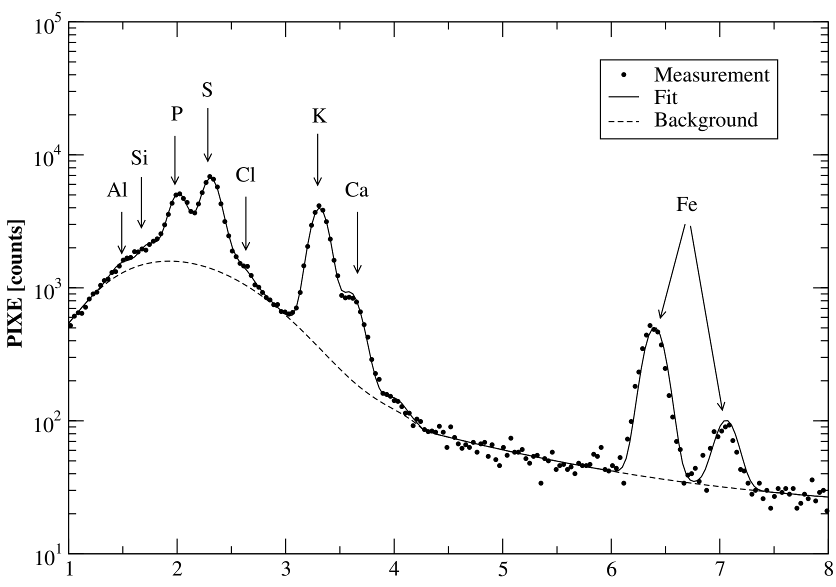

Fig. 2. Characteristic X-ray spectrum of a biological sample (*Cyprinus carpio*) induced by 2.0 MeV protons. Peaks and background fits are calculated using the AXIL code.

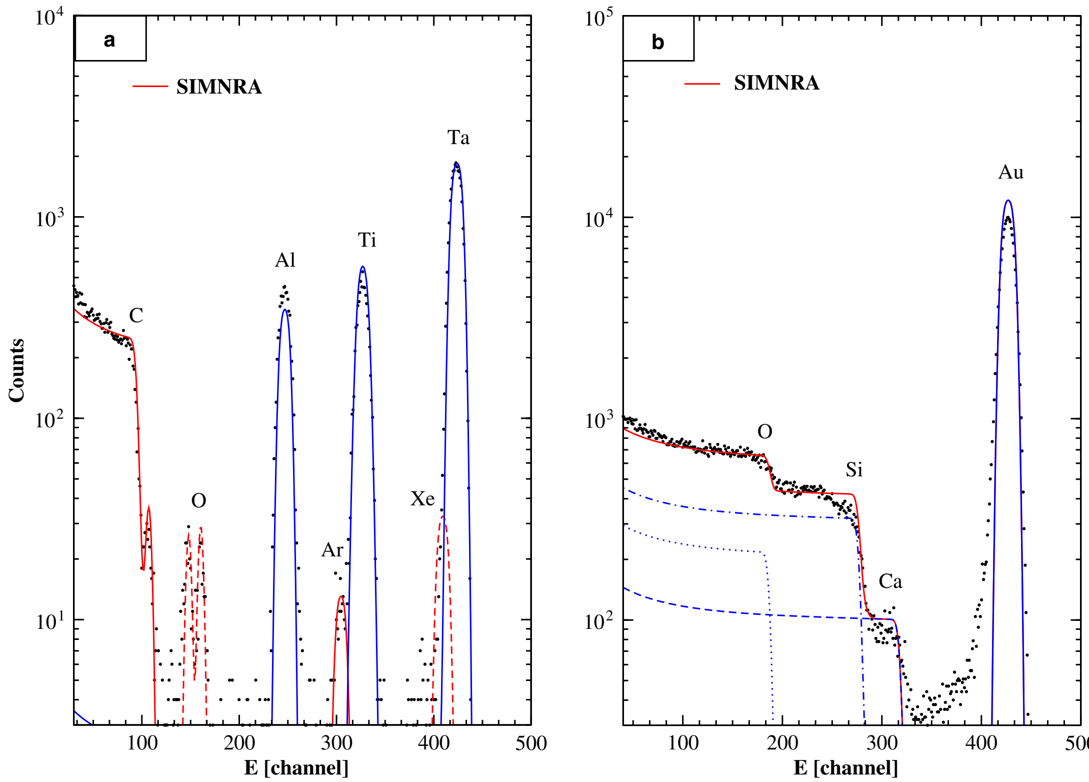

Fig. 3. (a) RBS spectra of a multielemental AlTiTa sample taken with 2.0 MeV alpha particles. (b) RBS spectra of a Au/Mica samples with $E_\alpha = 1.3$ MeV. The theoretical fit was calculated using the SIMNRA code.

study of metal bioaccumulation by fish (*Cyprinus carpio*) samples of muscle, gill and liver have been analyzed [14]. All the samples were identically treated by a digestion process, using HNO_3, to obtain an homogeneous solution. A controlled quantity of each solution was deposited on a 8.4 μm kapton film thickness obtaining thin targets as required by PIXE. A typical spectrum, corresponding to a liver sample is shown in Fig. 2. Also the characterization of inhalable urban aerosols from Santiago by PIXE is undergoing. A similar study on aerosols to be collected in the Antarctica is being prepared. In order to improve the efficiency of PIXE analysis of a large number of similar samples, the application of artificial neural network (ANN) is being implemented [15].

RBS has proved successful in the analysis of thin gold films (50 nm thickness) deposited on preheated mica substrates under high vacuum conditions. This measurement has been applied to determine the resistivity and the Hall effect to test the predicting power of the so-called mSXW model, a quantum transport theory that permits the calculation of the increase in resistivity induced by electron-surface scattering [16]. Fig. 3(b) shows typical experimental data and theoretical fitted spectra from RBS analysis by means of the SIMNRA code [17].

As for basic research, the potentialities of this low energy accelerator in the field of nuclear reactions are significant. In fact, there are some reactions of importance for a better understanding of the nucleosynthesis process whose cross sections have not been yet measured. At energies around 300 keV in the laboratory, the natural conditions in both static and explosive stellar scenarios with temperature in the range 10^8–10^9 K can be reproduced to generate the same final nucleus. Another example deals with some production cross sections of a particular radionuclide required for applications in medicine, or, as a tracer. Due to the lack of experimental values, in many cases the cross sections are estimated through the application of some nuclear codes. Systematic cross sections measurements in reactions whose final nucleus can have an electron capture decay mode, is underway at the laboratory. A method combining the detection of the characteristic X-rays from the daughter nucleus, with a separate PIXE experiment on a foil of the daughter material, increases the sensitivity and reduces the irradiation time [18]. Measurements of cross section values in the range of μb, have been achieved for ^{64}Cu production through the ^{63}Cu(d,p)^{64}Cu reaction. The method have been successfully tested at 2.4 MeV for the same reaction.

Since 1998, the facility has provided specialized training courses to undergraduate and graduate students, offering a combined theoretical and experimental approach. For example, training of medical physics students using the reaction ^{12}C(p,γ)^{13}N for proton emission tomography (PET) fundamentals and experiments of Xe ion implanted on Au foils to study resistivity modifications have been carried out in this laboratory [19].

4. Conclusions

Recent setup improvements at the IBA facility of the University of Chile, can sustain applied and basic research in a variety of fields demanding precise nuclear parameters. The current plan is to add other analytical methods like PIGE, channelling and to further improvement of the setup of the others like ion implantation, which can increase options for applied research. In addition, the training of undergraduate and graduate physics and engineering students, is being stimulated by the access to a modern laboratory.

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