SIX DECADES OF RESEARCH AND DEVELOPMENT WITH ACCELERATORS IN THE DEPARTMENT OF INTERACTION OF RADIATION WITH MATTER OF THE BARILOCHE ATOMIC CENTRE

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Abstract

In 1960, Prof. Wolfgang Meckbach (1919 – 1998), together with an enthusiastic group of young researchers, technicians, and advanced students, created the first "Ion Beam Laboratory" of Argentina at the Bariloche Atomic Center, dependent on the National Atomic Energy Commission. The rich history of scientific research, applications and education and training of human resources, that occurred during the last sixty years of existence of the "Department of Interaction of Radiation with Matter" (such is its current name) is described. New facilities both for basic research in Atomic, Molecular, and Surface Physics, and for the compositional and structural characterization of samples, were continuously incorporated, with applications in branches such as archaeology, biology, environment, forensic science, analysis of materials for nuclear and non-nuclear use, medicine, nanotechnology, and others. Currently, the laboratory counts with two electrostatic accelerators of 100 and 300 keV, and a 1.7 MeV tandem accelerator with PIXE, RBS, ERDA, NRA and channeling capabilities, and a chamber for COLTRIMS reaction microscopy. One of its beam lines is dedicated to the analysis of materials and the implantation of ions, with micro beam capacity, with prospects of incorporating a WDS installation. There is also a time-of-flight system for ISS spectroscopy, surface analysis facilities with AES, UPS, XPS, EELS, ISS, DRS, LEED and GIFAD capabilities, and STM and AFM microscopes.

1. PROF. WOLFGANG MECHBACH

The Department of Interaction of Radiation with Matter (DIRM) of the National Atomic Energy Commission (CNEA) of Argentina is in an area of lakes and mountain forests in the Patagonian Andes. In fact, it is at just 10 kilometres from the tourist city of Bariloche, and at the same distance from Cerro Catedral, one of the most recognized ski resorts in South America.

This first laboratory in Argentina dedicated to Atomic, Molecular and Optical Physics was created in 1960 by Prof. Wolfgang Meckbach [1].

FIG. 1: Prof. Wolfgang Meckbach (1919 – 1998)

He was born in Frankfurt, Germany in 1919. During the war he enlisted in the Navy, where he received the title of naval engineer and was later part of a submarine corps based in La Spezia, Italy. As luck would have it, in the submarine's first incursion it was hit by a depth bomb from an English destroyer. Thus, the war for engineer Meckbach and his submarine companions ended when it had barely begun. As a prisoner of war in the United States, he was authorized to study at the University of Chicago. In May 1946, he returned to his hometown, where he married Gabriela Mack, his first and only girlfriend, and concluded his studies at Goethe University where he received his doctorate in 1951. Since his mother-in-law was Argentinean, the young couple decided to settle in Argentina. He first worked at the Universities of Bahía Blanca and La Plata. Then, in 1955 he accepted an offer from CNEA to create an Institute of Physics in Bariloche.

In 1960 an old acquaintance of Meckbach’s from Chicago, Professor Samuel King Allison, director of the Enrico Fermi Institute, visited Bariloche.

FIG. 2: Prof. Samuel King Allison (1900 – 1965)

At that time, Meckbach and a young group of colleagues were building an accelerator of up to 300 kV. Being aware of the spectacular resurrection of Atomic Physics happening in those years. Meckbach asked Allison if it would not be better to dedicate the accelerator to the study of atomic collisions instead of neutron physics. Allison’s answer was enthusiastic, he said:

"You are right, why don't you come to Chicago
to introduce yourself in that field working in my lab?".

After two years at the Enrico Fermi institute, Meckbach returned to Bariloche with a great knowledge of accelerators and a grant of $ 66,000 from the National Science Foundation, destined for the new Laboratory. During a second visit of Prof. Allison to the Ion beam laboratory, as it was called at that time, the first experiments were initiated.

Unfortunately, in 1965, Allison died. His 400 kV Cockcroft-Walton accelerator, nicknamed by him “Kevatron”, meaning "a big machine for a low voltage", was closed in 1967, but not forgotten. In fact, the modest home-made accelerator, located 10,000 km away, inherited the name “Kevatron”. Up to the present the Kevatron has served to conduct more than one hundred research projects, and master's and doctoral theses. But now, after 60 years of service, it is about to be retired.

FIG. 3: KEVATRON

It is perhaps not useless to say, that this short history shows that the value of an activity in research should not be judged by how much money it costs, but by the enthusiasm, stubbornness, and resilience of people like Meckbach and his young colleagues who built the accelerator in the 1960s.

2. TANDEM

The successor of the Kevatron, is the “Tandem”, which was installed in 2010. This is a 5 SDH Tandem accelerator from the National Electrostatics Corporation with maximum terminal voltage of 1.7 MV, reaching a maximum energy of 3.4 MeV for protons and 5.1 for alpha particles.

FIG. 4: TANDEM

The Tandem has two sources. One is a Source of Negative Ions by Cesium Sputtering, which can deliver negative ions of a wide variety of elements from solid cathodes. The other one is an Alphatross, which provides ions extracted from a gas plasma, excited with radiofrequency, which pass through a Rubidium environment. This source is used solely to produce Helium ions.

During the last ten years this equipment has been growing and incorporating different facilities and end stations. The analysis chamber used for material characterization is a RC43, made also by NEC. It works in high vacuum (10^{-8} mbar) and has surface barrier detectors to perform RBS and ERDA, one fixed and the other one mounted on a rotatable holder, a Sirius silicon drift X-ray detector for PIXE, and flanges to mount a Sodium Iodide Scintillation Detector for gamma ray spectroscopies. The chamber has a lock stage which allows to introduce samples up to 30 mm wide easily and quickly. The sample holder has a micro-positioning ability in all directions and with angular orientation.

A second line was completely designed and made in DIRM 30 years ago. The chamber is intended to analyze energy, charge state and angular distribution of charged particles (electrons and ions) after collision events between an ion beam and a gas jet, using a Channeltron detector with 180º of positioning freedom.

There is also a reaction microscope to perform Cold Target Recoil-Ion Momentum Spectroscopy (COLTRIMS), which is still installed in the Kevatron. But soon it will be moved to the Tandem.

Finally, soon, a new chamber for Surface Science will be added to the Tandem. It will allow to perform Auger Electron Spectroscopy (AES) and Wavelength Dispersive X-Ray Spectroscopy (WDS).

3. KEVATRITO

Going back in time, in the early 1970s, as the Kevatron was bearing its first fruits, a new accelerator of up to 100 kV started to be build. It was called "Kevatrito", which in Spanish is a diminutive that means "little kevatrón". The ion accelerator is an electrostatic one with voltages in the range of 2 to 100 kV. It has two types of ion sources: a radiofrequency one for ionization of gases and a solid-state alumina-silicate one for production of alkali ions. There are three collision chambers mounted in tandem (see Fig. 5). The first one is a high-vacuum chamber for material irradiation. The second one is an ultra-high-vacuum (UHV) chamber with a Time-of-flight scattering and recoiling spectrometer. The third chamber is like the second one but with a more complete surface analysis system including Ultra-violet Photoelectron Spectroscopy, Auger Electron Spectroscopy, Low Energy Electron Diffraction, and Electron Energy Loss Spectroscopy.

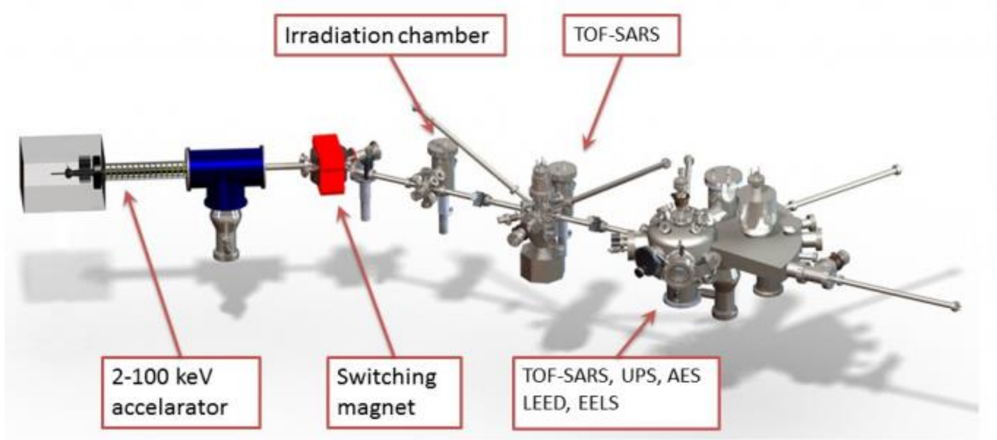

FIG. 5: Collision chambers mounted in tandem at the Kevatrito accelerator

The irradiation chamber has a linear driver for carrying multiple samples with a Faraday cup with an aperture of 1 mm for fluence determination (see Fig. 6). In front of the sample holder there are deflection plates for beam sweeping, and a carrousel with slits of different forms and sizes to control the beam shape.

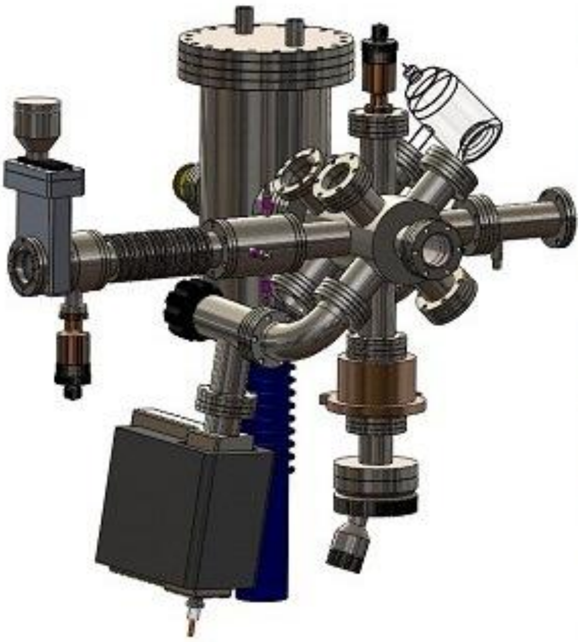

FIG. 6: Irradiation chamber of the Kevatrito.

4. STM / AFM MICROSCOPES

For the analysis of these radiation damages, the laboratory counts with two microscopes, one operating in air and the other in ultra-high vacuum (UHV). The Atomic Force microscope operates in ultra-high vacuum. Images with atomic resolution can be taken at different temperatures of the sample, in a range between 20 and 1500 Kelvin. The chamber is equipped with standard surface analysis techniques (as LEED and AES), with facilities for in-situ sample preparation by means of annealing and a sputtering for surface cleaning; and it has a sample and tip introduction tramp.

On the other hand, the Autoprobe CP microscope from Park Scientific Instruments, operates in air and allows to take images with nanometric resolution. The AFM operates in contact mode with 0.6 micrometer ultra-lever tips. It is mainly used in the topographic mode to provide services to third parties.

5. LOW-ENERGY-ACCELERATOR (LEA)

After the “Kevatron”, and the “Kevatrito”, a Low-Energy-Accelerator facility was built, to perform stopping power measurements with light ionic projectiles (H+, He+), with energies in the range of 1 to 10 keV. It has an electrostatic energy analyser that can measure scattering angles up to 45º (with respect to the forward direction). By using self-supported ultra-thin film samples (thickness < 20 nm) and the geometry of beam foil transmission (~ 0º scattering angle), the electronic stopping power can be measured with a minimum effect of the nuclear contribution.

6. XPS

The more recent acquisition of DIRM is a SPECS system for surface analysis by means of photoelectron spectroscopies. The ultra-high vacuum chamber is equipped with two photon sources, namely, a monochromatic X-ray gun (1486.6eV, Al K alpha line) and a He lamp (21.2 eV and 40.8 eV lines), a high-resolution hemispherical electron energy analyser, a sputtering gun for surface cleaning, and a rotatable sample manipulator with the possibility of cooling with liquid nitrogen. The system has a pre-chamber for fast introduction and remotion of samples.

FIG. 7: Surface Analysis Equipment (SPECS)

7. TUCUTRÓN

Another very nice and dear facility is a Low Energy 30-keV Ion Accelerator, with a Penning ion source. It was manufactured locally, as a personal project of a young researcher from our laboratory. As he was born in a city called Tucumán, he decided to call it "Tucutrón".

8. APPLICATIONS

And this has been a summary of the six-decade history of the DIRM laboratory, of its people and of its facilities. Let us now show some few examples of how this equipment is employed.

8.1. Basic Research

In its early years, the laboratory was mainly dedicated to basic research, and even today this is very important endeavor. Possibly the most surprising and unexpected result was the first measurement done in the 1980s of the double differential cross section for the so-called capture to the continuum cusp in the single ionization of atoms by fast ions, by means of a cylindrical electron detector, as shown in Fig. 8 [2].

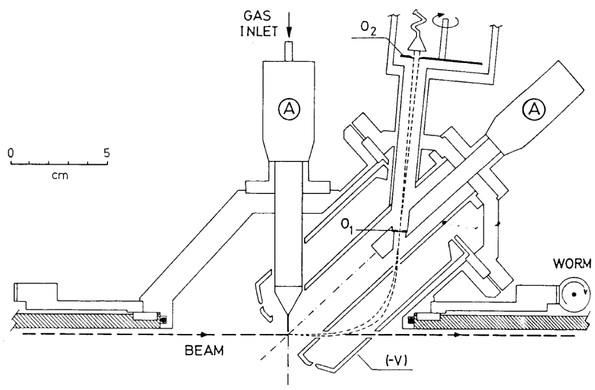

FIG. 8: Cylindrical electron spectroscopic analyzer (1980s)

8.2. CNEA

The DIRM laboratory belongs to CNEA, so it is no wonder that it is its main customer. For instance, in Fig. 9, a RBS measurement of a multilayer ZrO2/SiO2 sample is shown.

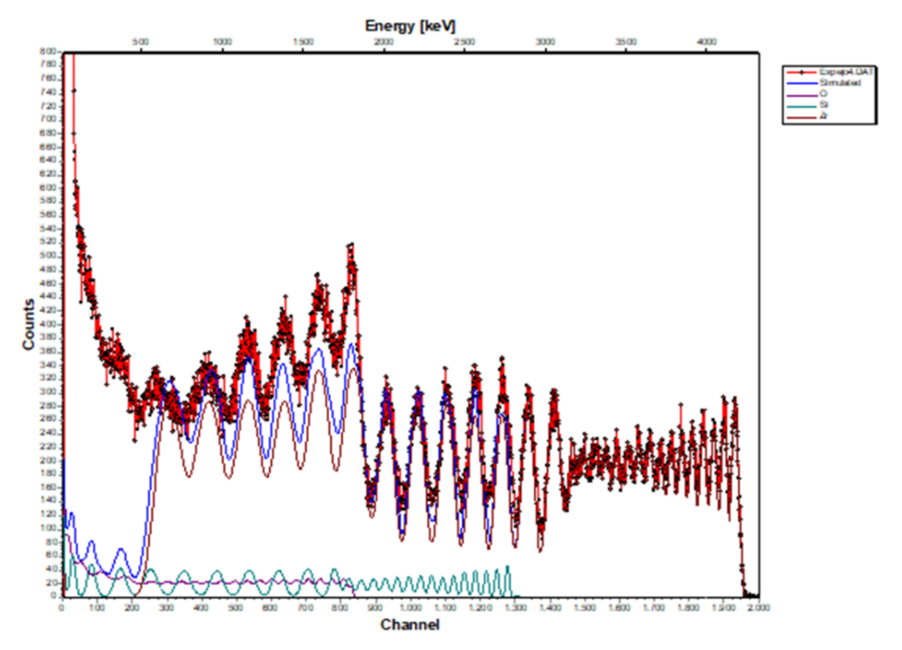

FIG. 9: RBS spectrum for a multilayer ZrO2/SiO2 sample and the fit obtained with the SIMNRA software.

At the RA-6 Nuclear Research Reactor, located in the close vicinity of DIRM, research and development are carried out on Boron Neutron Capture Therapy (BNCT). Fig. 10 shows a study done at the TANDEM accelerator in relation with the Stopping power of alpha particles in compact bone.

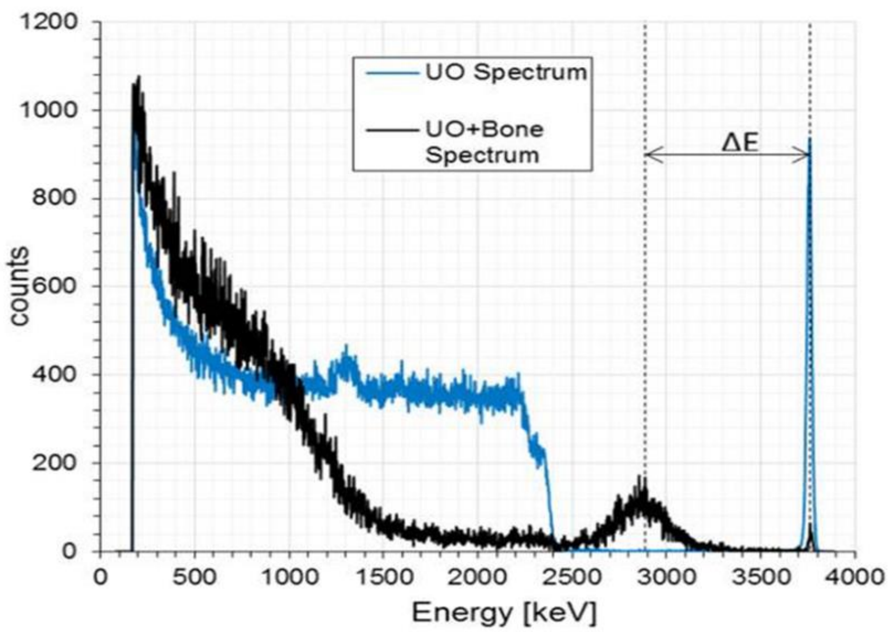

FIG. 10: Stopping power of α particles in compact bone for research in BNCT [3]

8.3. Archeology and Paleontology

Patagonia is a region known for its research in paleontology, especially in relation to dinosaur fossils, but also about prehistoric human settlements Fig. 11 shows a measurement made in DIRM of such an archeological sample.

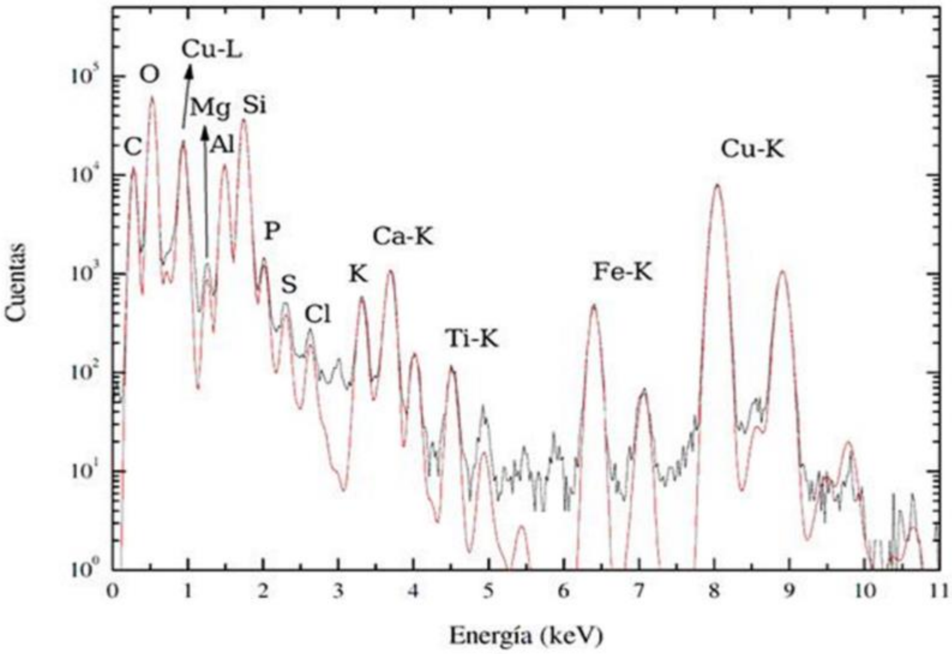

FIG. 11: X-ray spectrum of a Patagonian archeological sample and fit obtained with the GUPIX software.

8.4. Earth Sciences

Our region is surrounded by volcanoes, especially in Chile. In general, they do not represent a great danger, but every so often they become active. This happened, for instance in 2011, with the eruption of Puyehue, located 80 kilometers from Bariloche, and which literally covered the city with ash. One important environmental concern associated with volcanic eruptions is linked to the huge volumes of ashfall that may deliver hazardous elements over large distances from the source. Thus, the group of the XPS SPECS collaborated with colleagues of the Earth Sciences Center of Córdoba in the analysis of the ashes of the most recent volcanic eruptions in our region [4].

9. COORDINATED RESEARCH PROJECT

Finally, it should be mentioned that DIRM [5] is a member of the Global Network for the Atomic and Molecular Physics of Plasmas (GNAMPP) [6] and the Coordinated Research Project G42008 for "Facilitating Experiments with Ion Beam Accelerators" of the International Atomic Energy Agency. During the present year, the first visits will be received within the framework of this CRP.

ACKNOWLEDGEMENTS

Everything described here is the tangible result of 60 years of continuous and passionate work by all the scientists, technicians, and students who are and were the heart and soul of the DIRM laboratory of Bariloche. We should also thank the CNEA and other national (e.g., CONICET) and international (e.g., IAEA) organizations that provided and continue to provide the means to carry out these developments.

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