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Radiochemistry teaching and research activities in Brazil

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Much concern has been expressed lately about the decline of teaching and research activities in radiochemistry in many countries, as was discussed in an IAEA Technical Meeting in Antalya, Turkey, in 2002, and also at MTAA-11 in Guildford, UK. In the IAEA meeting, a survey was presented about the current situation in different regions of the world (Eastern Europe, East and West Asia, Africa, North America and Latin America) by experts of each region. In the case of Brazil, which has nuclear research reactors and also cyclotrons in operation, the teaching and research activities in radiochemistry are concentrated in the three main institutes of the Brazilian Nuclear Energy Commission, in the University of São Paulo and in other universities, in different regions of the country. In the present paper, a closer look is given to the radiochemistry teaching and research activities that are being conducted nowadays in Brazil, comprising: number of radiochemistry courses and students being formed, main research areas being conducted, as well as research and production of radioisotopes for nuclear medicine, using nuclear reactors and cyclotrons.

Introduction

In many developed countries throughout the world, much concern has been expressed lately about the decline of teaching and research activities in the field of radiochemistry. This fact can be attributed to several factors, such as the closing of nuclear reactors in several countries, retirement of professors and researchers, and also lack of interest from the part of students. In some European countries, a general lack of interest is being observed from students, not only in the nuclear field, but also related to the physical sciences in general.

In June 2002, the International Atomic Energy Agency (IAEA) organized a meeting in order to discuss the situation of the teaching activities and applications of radiochemistry in Africa, Asia, Europe, Latin America and in the United States, since the mandate of the IAEA is to support peaceful uses of nuclear energy, which include training of the human resources needed to maintain and develop the knowledge in this field.[1]

The representatives of each continent presented detailed reports of the situation in their regions and the main conclusions were:

In most countries, students are losing interest in radiochemistry, because it is difficult to find good jobs in the field and also due to concerns about radioactivity risks;

The number of teachers in radiochemistry has been declining, mainly due to the retirement of researchers and professors or their moving to other areas of research;

Many nuclear facilities are closing down, due to the cutting of funds and lack of personnel, aggravated in many countries by public opinion being strongly against nuclear activities;

In many research institutes and universities, the age of the professionals working in radiochemistry is increasing and as a consequence innovative work is going down and the productivity can decrease.

The situation seems to be more drastic in the United States and in Europe, but a similar trend is being observed in Latin America, Africa and Asia. On the other hand, in some countries of these latter regions, there is not such a strong rejection of the public towards nuclear energy. For example, in China several nuclear power reactors are being built. In Brazil, there is also the possibility of building nuclear power reactors in the future, in addition to the already operating, Angra 1 and Angra 2.

VASCONCELLOS[2] presented a survey about the situation of teaching and applications of radiochemistry in Latin American countries and it became clear that the activities are concentrated in: Argentina, Brazil, Chile, Cuba, Jamaica, Mexico and Peru, which have nuclear research reactors operating, except for Cuba. These reactors are mainly dedicated to radioisotope production, industrial applications, neutron activation analyis, and nuclear physics research.

Only Argentina, Brazil and Mexico have nuclear power reactors: Atucha 1 (335 MWe), Atucha 2 (692 MWe) and Embalse (600 MWe); Angra 1 (626 MWe) and Angra 2 (1275 MWe), Laguna Verde 1 (654 MWe) and Laguna Verde 2 (654 MWe), respectively.

Cyclotrons are in operation in Brazil, Argentina, Chile and Mexico, mainly for radioisotope production aiming at nuclear medicine. These countries also possess electron accelerators for research and for medical and industrial applications.

Brazil also dominates the uranium fuel cycle, from enrichment of uranium by ultracentrifugation to the production of U_3O_8–Al or U_3Si_2–Al fuel elements.

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These fuel elements will be produced mainly for future utilization in the existing nuclear power reactors, Angra 1 and Angra 2. These reactors utilize uranium enriched at 4% and it is expected that the country will produce 60% of the uranium needed for Angra 1 and Angra 2 until 2010. The nuclear research reactor of IPEN/CNEN-SP uses uranium at 20% enrichment and this level is still not attained by the enrichment plants operating in the country.

In the present paper, a closer look is given to the radiochemistry teaching and research activities that are being conducted nowadays in Brazil, focusing on: number of radiochemistry courses and students being formed, main research areas being conducted, and also research and production of radioisotopes for nuclear medicine, using nuclear reactors and cyclotrons.

Activities at the Brazilian Nuclear Energy Commission

A great part of the radiochemistry teaching and research activities in Brazil are being conducted in the institutes of the Brazilian Nuclear Energy Commission: Institute for Nuclear and Energy Research, in São Paulo, SP (IPEN/CNEN-SP), Center for the Development of Nuclear Energy, in Belo Horizonte, MG (CDTN) and Institute for Nuclear Engineering, in Rio de Janeiro, RJ (IEN).

Activities at IPEN/CNEN-SP

IPEN/CNEN-SP is the largest nuclear institute in Brazil and it is located in the campus of the University of São Paulo (USP), occupying an area of about 500,000 square meters, with 20% of constructed area.[3]

The Institute plays a very important role in nuclear science and technology in Brazil, being recognized as a national leader in the generation of knowledge in this field. It runs the 5 MW IEA-R1 nuclear research reactor, which has been in operation since 1957, a Van de Graaf accelerator, two electron accelerators of 1.5 MeV and two cyclotrons: CV-28 and Cyclone 30, for radioisotope production.[4]

Several radiochemical laboratories are available, as well as nuclear metrology labs and radiological protection and environmental radiation monitoring labs.

Neutron activation analysis activities: The Neutron Activation Analysis Laboratory of the Research Reactor of IPEN/CNEN-SP has a permanent staff of seven PhD researchers, three with MSc degree, three technicians and one secretary. For many years, the Laboratory has been developing research work on applications of NAA to several fields: geological, environmental, health studies, archaeological, agricultural, nutritional, industrial and others.

Some of the works being conducted using NAA are briefly described below:

Multielemental analysis of biological samples for clinical studies: analysis of human bone tissue (IAEA CRP on osteoporosis), human hair and nails, as well as blood serum of an elderly populational group.

Determination of nutritionally important and/or toxic elements in Brazilian individual foodstuffs and diets, such as: diets of children and elderly, diets of renal patients, fruits and vegetables of the Amazonic region, whose composition is still very unknown, and diets of industry workers.

Environmental applications: analysis of sediments from contaminated sites in different regions of Brazil and Argentina, determination of mercury and other elements in hair of populations living in the Amazonic region, analysis of different kinds of plants that can be used for air pollution biomonitoring (*Canoparmelia texana*, *Tillandsia usneoides*, *Tradescantia pallida*).

Characterization of Brazilian prehistoric ceramics: samples of several archaeological sites in Brazil have been analyzed for the study of questions of exchange and sociopolitical interaction between prehistoric cultures, and a new light to these cultures is being given, with very exciting discoveries.

Study about the emission of platinum group elements (platinum, palladium and rhodium) by automobile catalytic converters in soils adjacent to a road in São Paulo. These elements have been determined by NAA, after fire assay preconcentration.

Study about the use of marine organisms for biomonitoring of coastal pollution in São Paulo: the bivalve *Perna perna* has been transplanted from clean regions to coastal areas in the state of São Paulo, which are impacted by human activities. Toxic elements like mercury, arsenic, lead and cadmium will be determined by NAA and AAS (atomic absorption spectrometry).

The Neutron Activation Analysis Laboratory (LAN) of IPEN is also very much committed to the establishment of a quality system and has been engaged for several years in the ARCAL XXVI Programme of the IAEA for the Latin American region. This Programme had the objective of helping laboratories working with nuclear analytical techniques to establish quality systems, if possible obtaining formal accreditation by their national metrology institutes or a recognition by the IAEA, based on external audit performed by this Agency. LAN has obtained a letter of recognition emitted by the IAEA, after an external audit, for having reached the level established in the framework of the Programme.

Radioisotopes and radiopharmaceuticals for nuclear medicine: Production of primary radioisotopes: Research and development of methods for the production of primary radioisotopes are being carried

out at the Radiopharmacy Center of IPEN, aiming the nationalization of the production of primary radioisotopes, such as: ^{99}Mo by the (n,γ) reaction of ^{98}Mo using a zirconium molybdate gel; ^{131}I by irradiation of TeO_2 in the research reactor and using separation by dry distillation; ^{67}Ga (a hot production cell was assembled in order to produce this radioisotope by irradiation in the Cyclone 30 cyclotron); ^{201}Tl by irradiating an enriched thallium target in the Cyclone 30; ^{123}I by irradiating in the cyclotron a Xe target enriched in ^{124}Xe; ^{18}F by cyclotron irradiation to be used by hospitals with a PET equipment.

Production of labeled compounds: ^{153}Sm-EDTMP – this compound is a therapeutic agent indicated for the relief of pain in patients with confirmed osteoblastic metastatic bone lesions. The ^{153}Sm radioisotope is produced in high yield and purity in the research reactor by irradiating isotopically enriched ^{152}Sm oxide.

^{131}I-MIBG – for many years, MIBGM, meta-iodobenzylguanidine radiolabelled with ^{131}I has been produced at IPEN, in the research reactor, and used as a diagnostic agent to image neural crest-derived tumors.

^{123}I-MIBG – it is being used as non-invasive probe in the diagnosis of cardiomyophathy and cardiac transplant rejection, and also in the localization of pheochromocytoma, neuroblastoma, non-functioning paraganglioma and carcinoid tumor.

Production of lyophilized kits for labeling with ^{99m}Tc: The following compounds labeled with ^{99m}Tc are produced at IPEN: ^{99m}Tc–DTPA, used for brain imaging, renal flow study and glomerular filtration rate measurement; ^{99m}Tc–MDP for skeletal imaging, used to demonstrate areas of altered osteogenesis; ^{99m}Tc–DMSA, used primarily for renal cortical imaging; ^{99m}Tc–DISIDA, used as hepatobiliary agent, to evaluate hepatic function, biliary duct patency and cholescingraphy.

Teaching and advizing activities: Since 1976, IPEN/CNEN-SP has a well-established graduate course on nuclear technology, in a partnership with the University of São Paulo. This course has three main areas: applications of nuclear techniques (TNA), materials (TNM) and nuclear reactors (TNR), awarding MSc and PhD degrees.

In 2004, the course commemorated its 1000th thesis and the number of students is increasing each year. The actual number of ongoing MSc dissertations is 180 and of PhD thesis is 220. Also undergraduate students develop experimental work at IPEN, under the advising of the researchers of IPEN, and the latest number registered is 280 students. The course has attained a high degree (6 in a maximum of 7) in the evaluation of the official organization that controls all the university degrees in Brazil.

Although the course has a concentration area named as nuclear technology, not all applications are nuclear. In the materials area, TNM, there are many applications on lasers, metallurgy, polymers and others. A great part of the applications are in the nuclear area.

Specifically in the Research Reactor Center, the number of students developing their work, in 2004, was: 23 PhD students, 18 MSc students and 23 undergraduate. Of these, 11 PhD students, 9 MSc students and 16 undergraduate were working with neutron activation analysis. The others were working in nuclear physics and condensed matter physics, using the IEA-R1 nuclear research reactor.

The number of graduate courses offered in the nuclear technology course is 45 and of undergraduate courses is 17.

VASCONCELLOS[5] has described in detail the methodology of the radiochemistry and neutron activation analysis course that has been given since 1979 in the graduate course in Nuclear Technology, which about one hundred students have attended. The course is of a theoretical as well as practical nature, and has contributed very much to the development of the experimental work of many MSc and PhD students.

The perspective for the future is of a steady expansion of the number of students enrolled in the nuclear technology course, since it has a very good evaluation by the national organization in charge of evaluating all university level courses in Brazil, opening excellent possibilities of getting scholarships for all the levels of students. Brazil has a very strong need for education at the graduate level and the goal of the Ministry of Science and Technology for 2006 is of 10,000 PhD degrees being awarded. In 2003, the number of PhD titles granted was 8,094, according to official sources.

Activities at CDTN – Center for Development of Nuclear Technology

CDTN – Center for the Development of Nuclear Technology is an institute also belonging to the Brazilian Nuclear Energy Commission. It is situated in the city of Belo Horizonte, state of Minas Gerais, about 600 km from the city of São Paulo.[6]

The Center operates a Triga Mark I reactor, with 250 kW power and has an active neutron activation analysis group, which develops applications in environmental and health studies, such as the study of occupational exposure of workers of galvanizing factories to gold and other elements, by means of analysis of hair, toe-nail and urine samples, as well as analysis of air filters placed at their working environment. Other applications include archaeological studies and applications in mineral technology and materials engineering. Special efforts are being dedicated to applications using k_0-NAA. The group has eight complete gamma-ray spectrometers with HPGe

detectors, five gamma-ray spectrometers with NaI detectors, two alpha-spectrometers, two proportional counters for total alpha and total beta, one system for radon emanation and other facilities.

CDTN also runs radiochemical laboratories for measurement of low and high level radioactivity, as well as very good installations for tritium determination at environmental levels, including two electrolizers, in a laboratory designed for ultra low background. Determinations of ^{14}C are also made.

As to teaching activities, a graduate programme on science and technology of radiations, minerals and materials was started at CDTN in the beginning of 2003, at MSc level. This programme includes a so-called concentration area on applications of nuclear techniques. Among the several lines of research in this area it can be cited: ionizing radiations in health and biology, applications of radioisotopes and radiochemistry, and environmental control and radioisotopes in industry.

Courses on radiochemistry and liquid scintillation detection are offered, being attended by an estimated number of 46 students from 1995 to 2002.

Activities at IEN – Institute of Nuclear Engineering

The Institute of Nuclear Engineering (IEN) of the Brazilian Nuclear Energy Commission, situated at the city of Rio de Janeiro, about 400 km from São Paulo, runs a CV-28 Cyclotron, for production of ^{123}I in the NaI form, to serve the population in this region, due to the short half-life of this radioisotope.[7]

Since 1998, the Institute started conducting a project aimed at making positron emission tomography (PET) available to the population of Rio de Janeiro. Recently, the ^{18}FDG has become a breakthrough in nuclear medicine. The FDG application, associated with new generation equipments for PET and/or single photon emission computed tomography (SPECT), is now widely applied in oncology, since it allows visualizing and differentiation of benign and malign tumors. There are also relevant applications in cardiology and neurology.

In 2002, IEN received and installed a new system for production and synthesis of ^{18}FDG, the RDS-111, by CTI/SIEMENS, and from the year 2003 on, the Institute was able to produce ^{18}FDG in two independent ways, with different installations, being one of them a backup, to guarantee the reliability of the production and delivery to the hospitals.

IEN develops research on production and radiochemical quality control of radiopharmaceuticals, as well as use of radioactive tracers for different applications, such as the study of the behavior of units of sewage plants using ^{140}La.

As to the teaching and advising activities, five courses are of the responsibility of IEN, in collaboration with COPPE, producing both master dissertations and doctorate thesis.

Activities at UFF – Universidade Federal Fluminense

The Institute of Chemistry of the Universidade Federal Fluminense, situated in the state of Rio de Janeiro, has two courses in the nuclear area offered at undergraduate level by its Department of Physical Chemistry: i.e., nuclear chemistry and radiochemistry.

A recent evaluation of the attendance at these courses[8] brought up the following numbers: 131 students were enrolled from 1998 to 2004 in the nuclear chemistry course and 58 students were enrolled from 1996 to 1997 in the radiochemistry course.

Activities at CENA – Center for Nuclear Energy in Agriculture

CENA – Center for Nuclear Energy in Agriculture, which belongs to the University of São Paulo, has also a very active graduate course in the concentration area of Nuclear Energy in Agriculture. The following courses related to the nuclear area are offered at CENA:[9] atomic and nuclear physics I – 263 students from 1995 to 2004; atomic and nuclear physics II – 247 students from 1995 to 2004; radioisotope methodology – 108 students from 1995 to 2004; radioactivity in the environment – 17 students from 1997 to 1999; nuclear analytical techniques – 45 students from 1997 to 2001.

Neutron activation analysis and radiochemistry activities

The Laboratory of Radioisotopes at CENA has developed research work on NAA and radiochemistry for several years, in different types of matrices, using the IEA-R1 nuclear research reactor for the irradiations. Under the supervision of the head of the Laboratory, Dr. Elisabete FERNANDES, 22 students have developed works in these areas, at undergraduate (7), MSc (9) or PhD (6) levels. At present, seven other researches are in development: 2 MSc, 3 PhD and 2 undergraduate works.

Among the many studies that have been developed by the group, the following subjects can be cited: use of native trees of the Atlantic forest for biomonitoring of chemical elements; assessment of elemental composition of conventional and organic potatoes using k_0-INAA; production of certified reference materials for agriculture (*Coffea arabica*); use of chemical elements as a discrimination criterion of conventional and organic citrus; improvement of plant material analysis using INAA with Compton suppression.

Many of these works have support of Brazilian financial agencies for research and development, such as CNPQ and FAPESP and the perspective is also of increasing the number of students and expansion of the research activities.

The Laboratory of Radioisotopes has invested efforts for establishing a quality system and has also participated of the ARCAL XXVI Programme of the IAEA. After an external audit, the Laboratory has reached the level established in the Programme for recognition by the IAEA.

Final remarks

The activities of teaching and research in radiochemistry in Brazil are concentrated mainly in the institutes of the Brazilian Nuclear Energy Commission and in the University of São Paulo.

The course on nuclear technology conducted by IPEN/CNEN-SP in collaboration with the University of São Paulo has a staff of 160 advisers and a survey conducted in 2004 showed that the number of ongoing MSc dissertations is of 180 and of PhD thesis is of 220. Also 280 undergraduate students were developing research work at IPEN in 2004. It is expected that this number will grow in future years.

In 2004, 45 graduate courses were offered in the nuclear technology course and among them are radiochemistry and neutron activation analysis, nuclear measurements, nuclear chemistry and other nuclear-related courses.

CENA – Center for Nuclear Energy in Agriculture, an institute of the University of São Paulo, also offers several courses, i.e., radioisotope methodology, radioactivity in the environment, nuclear analytical techniques and others, which were attended by about 700 students from 1995 to 2004.

Research work on neutron activation analysis and radioisotope and radiopharmaceuticals for nuclear medicine is going strong at several institutes of the Brazilian Nuclear Energy Commission, i.e., IPEN, CDTN, IEN and also at CENA (NAA).

At CDTN, a new graduate course was started in 2003, on science and technology of radiations, minerals and materials and it includes a concentration area on applications of nuclear techniques.

Other universities, like the Universidade Federal Fluminense (UFF) in the state of Rio de Janeiro, offer courses on nuclear chemistry and radiochemistry, attended by about 200 students from 1996 to 2004.

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