Nuclear Safety

introduction

The Program on **Nuclear Safety** comprehends Radioprotection, Radioactive Waste Management and Nuclear Material Control. These activities are developed at the Nuclear Safety Directory.

The Radioactive Waste Management Department (GRR) was formally created in 1983, to promote research and development, teaching and service activities in the field of radioactive waste. Its mission is to develop and employ technologies to manage safely the radioactive wastes generated at IPEN and at its customer's facilities all over the country, in order to protect the health and the environment of today's and future generations.

The Radioprotection Service (GRP) aims primarily to establish requirements for the protection of people, as workers, contractors, students, members of the general public and the environment from harmful effects of ionizing radiation. Furthermore, it also aims to establish the primary criteria for the safety of radiation sources at IPEN and planning and preparing for response to nuclear and radiological emergencies. The procedures about the management and the control of exposures to ionizing radiation are in compliance with national standards and international recommendations. Research related to the main activities is also performed.

The Nuclear Material Control has been performed by the Safeguard Service team, which manages the accountability and the control of nuclear material at IPEN facilities and provides information related to these activities to ABACC and IAEA.

Research and development

Radioactive waste characterization, treatment and disposal

Characterization of ion exchange resins and activated charcoal
The radioactive waste characterization program of GRR follows the guidelines of "IAEA-TEC-1537 - Strategy and methodology for radioactive waste characterization" in order to complete the forms required by CNEN-NN 6.09 - Acceptance criteria for disposal of low- and intermediate-level radioactive wastes, for each waste stream and each waste package, the waste form required by CNEN-NN 6.09 - Acceptance criteria for disposal of low- and intermediate-level radioactive wastes. The main development goals are to set up routine radioanalytical methods and the determination of scaling factors and correlation functions that allow calculate the radioactive inventory of difficult to measure radionuclides (DMR) from the activity of key radionuclides (KR), present in the wastes. DMR include alpha and pure beta emitters, and low energy, low yield gamma emitters that require radiochemical treatment of waste samples to be quantified. KR include gamma emitters that can be detected and quantified by simple gamma spectrometry or calibrated gamma scanning of waste packages, like ^{60}Cobalt and ^{137}Caesium. Radioanalytical methods for determination of twenty one fission and activation products as well actinides were developed and/or implemented to measure the radioactivity concentration of forty nine samples taken from twenty one waste drums containing ion-exchange resins and activated charcoal. Methodologies for sequential analysis of isotopes of U, Np, Pu, Am and Cm present in these wastes were evaluated, considering chemical yield, time spent in analysis, amount of secondary waste generated and cost. Methods based on ion exchange, extraction chromatography and extraction with polymers were compared and validated. Scaling factor methodology was also applied in order to obtain Scaling Factors or Correlation Functions for these types of wastes from the IEA-R1 nuclear research reactor.

Degradation of ion exchange resin using Fenton's reagent
The ion-exchange resins used as filter in the reactor water-cooling system become radioactive. After the useful life is over, these resins are considered radioactive waste. To ensure environment safety, the direct solidification of spent ion exchange resin by cementation is currently the main immobilization process, decreasing its release to the environment. This immobilization consists in a mixture of water, cement and radioactive waste. Because of its characteristic of contraction and expansion, the incorporation of resin is limited in 10%, causing high costs in its direct immobilization. Therefore, it is recommended the utilization of a pre-treatment, capable of reducing the resins volume, degrading them, and increasing the load capacity in the immobilization. GRR studied a method of degradation of ion spent resins from the nuclear research reactor of Nuclear and Energy Research Institute (IPEN), Brazil, using the Fenton's reagent (hydrogen peroxide and a catalyst). Three forms of the resin were used: cationic (IR 120P), anionic (IRA 410) and a mixture of both resins. This low cost technique was capable to degrade more than 95% of the resins and seemed to be effective in volume reduction (Fig. 1).
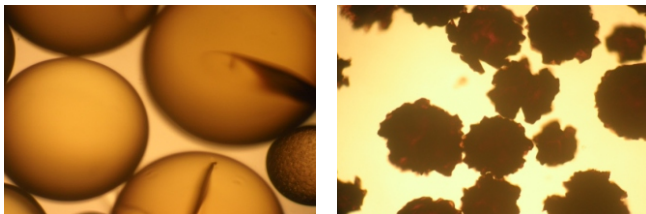

Figure 1. Resins before and after degradation with Fenton's reagent.

Optimization of the radioactive waste storage
GRR is optimizing the radioactive waste storage capacity, taking into account that a fraction of the stored treated wastes has decayed to a very low level and considering that "retrieval for disposal as very low level radioactive waste" is one of the actions suggested to radioactive waste managers. In 2010, a new storage facility was constructed and all

treated waste packages were transferred to it. All the packages that may be subject to clearance levels were stored separately for further segregation. In 2013, a Gamma Object/Tool Monitor (Cronos-1, Canberra) was acquired for monitoring waste bags and other miscellaneous objects. This equipment is being tested and it will be used in combination with a drum monitor to classify and segregate the waste packages.

Isotopic characterization of radioactive waste drums
An automated system for isotopic characterization of radioactive waste drums by segmented gamma scanning (SGS) was developed (Fig. 2). The detection system is composed of an HPGe detector and associated electronics. The drive system of drum is automated and controlled by a PLC (Programmable Logic Controller). This system allows controlling the elevation and rotation of a base where the radioactive waste drum is positioned. The system operates in continuous and programmable mode, in which the number of measurements, operation time and the axial positioning of the detector in the drum can be preset. For the efficiency calibration of the system four standard drums were produced with different densities composed by compressed paper, water, sand and concrete. Five water-equivalent solid standards containing ^{152}Eu were prepared in rod geometry with density of 1.15 g/cc. This system associated with the mathematical techniques such the Monte Carlo Method and Artificial Neural Networks is efficient in isotopic characterization of radioactive waste drums.

Figure 2. Automated system for isotopic characterization of radioactive waste drums.

Treatment and disposal of disused sealed sources
The management of disused sealed radioactive sources (DSRS) is a challenge for most countries and is no different for Brazil, where thousands sources exist, some of them classified in IAEA Category 4 & 5, the most dangerous of incurring serious radiological consequences if not properly managed.

The GRR staff is the leading group in Brazil in the development of the methods and the technologies for the management of DSRS, which include sources from replaced lightning rods and smoke detectors and from other applications of sealed sources in medicine, industry and research. The work undertaken is focused in two steps of the management program: building the hot cell to condition the sources and developing the concept of a deep borehole repository to dispose of the DSRS.

During the reported period, the construction of the hot cell was completed and the facility was started up for testing, with the sources of Categories 1, 2 & 3. So far, 95 sources were removed from the original shielding and conditioned in the disposal packages, after being identified and classified and have their present activities measured or confirmed.

The contribution of the GRR for the establishment of a feasible alternative for final disposal of DSRS continued in the period to further develop the concept of a deep borehole repository, with R&D in the

following topics:

Durability of engineering barriers: the first phase of the assessment of the durability of cementitious material under repository conditions, by accelerated tests in laboratory, was completed. The second phase is being designed in collaboration with researchers from other Brazilian institutions like the Brazilian Synchrotron Light Laboratory (LNLS).

Safety: the development of methods for assessing safety and performance of the disposal concept continued from the previous period in various lines of inquiry: the identification of qualitative and quantitative safety indicators in support to safety assessment; integrating different lines of evidence to build confidence in the acceptability of the disposal concept; assessment of the time of transport of radionuclides by groundwater from the bottom of the repository to the accessible environment through a fracture between the borehole casing and the cement backfill.

Concept and design: in the reported period, a technical cooperation project was designed and agreed with the IAEA for execution in 2014-2015, to bring experts on borehole disposal technologies to advise the Brazilian staff and to allow members of the staff to visit and learn on particular aspects of the enterprise, from similar projects in other countries.

Treatment of radioactive liquid wastes using different biomasses
The radioactive liquid organic wastes need special attention, because the available treatment processes are often expensive and difficult to be managed. Biosorption is a potential technique to replace traditional methods since it allies low cost with relatively high efficiency. Biosorption has been defined as the property of certain biomolecules to bind and remove selected ions or other molecules from aqueous solutions. The biosorption using vegetable biomass from agricultural waste has become a very attractive technique because it involves the removal of heavy metals ions by low cost biosorbents. This technique could be employed in the treatment of radioactive liquid wastes. Among the biosorbents reported in the literature, the coconut fiber (Cocos nucifera L.) (Fig. 3) is highlighted due to the large number of functional groups in its constitution. During the reported period, it was assessed the potential of the coconut fiber to remove uranium from radioactive liquid organic waste. Preliminary results suggest that biosorption with coconut fiber in activated form can be applied in the treatment of radioactive liquid organic waste containing uranium.
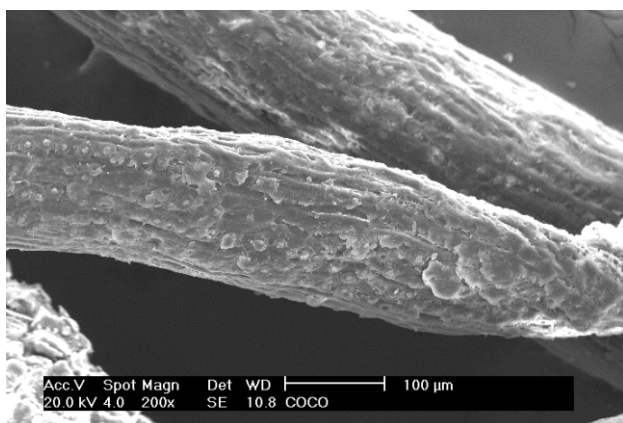

Figure 3. Scanning electron microscopy of coconut fiber.

Products and services

GRR is responsible for reception, treatment and interim storage of the radioactive waste generated at IPEN, as well as those generated at many other radioactive facilities all over the country. GRR has units for: waste reception and segregation; decontamination of small pieces; liquid waste immobilization and conditioning; in-drum compaction; disassembly of radioactive lightning rods; storage and disassembly of

disused sealed source shielding; storage of untreated and treated wastes; characterization of primary wastes and waste forms. The storage facility was restructured and it was divided into two adjacent areas (Fig. 4). The first area was concluded in 2010 and treated waste was transferred from the old building to the new one. The second area was concluded in 2011 and received untreated wastes, including disused sealed radioactive sources.

Figure 4. New radioactive waste storage building (outside and inside view).

Research and development

Occupational epidemiology

The main evidence for the presence or absence of various health outcomes is provided by epidemiological investigations and the main objectives of the research group are:

- To get a solid introduction and a detailed study of the basic epidemiologic methods including the special features of occupational epidemiology;

- To assess the different types of epidemiological study, the applications, advantages, and limitations of the major types of observational and experimental studies, emphasizing the many possibilities for errors in epidemiological for a clear understanding;

- To use epidemiological principles and methods to the practice application of data derived from epidemiologic research, in particular for the radiation epidemiology;

- To determine the possible health consequences of the workplace exposures (exposure standard setting) and to recommend remedial efforts, when applicable.

Follow up of the natural radiation exposure from gamma rays in the city of São Paulo, Brazil
The effective doses received by the general population from the natural radioactivity in the city of São Paulo, Brazil, were assessed since 2007 to 2013 as apart from the variation from place to place due to the background gamma levels in air, which are not constant in time. The outdoor gamma radiation levels were carried out with thermoluminescent dosimeters, TL, quarterly exposed, using twelve monitoring stations, covering both places frequented daily by people with emphasis in the most populated districts and safely recessed places, with no influences from man-made ionizing radiation sources (Fig. 5). The average annual effective dose in the city of São Paulo, found as 1.3 ± 0.1 mSv, is below the annual global *per caput* effective dose due to natural radiation sources of 2.4 mSv and within the annual effective doses range of 1 to 3 mSv, expected to be received by 65% of major population.
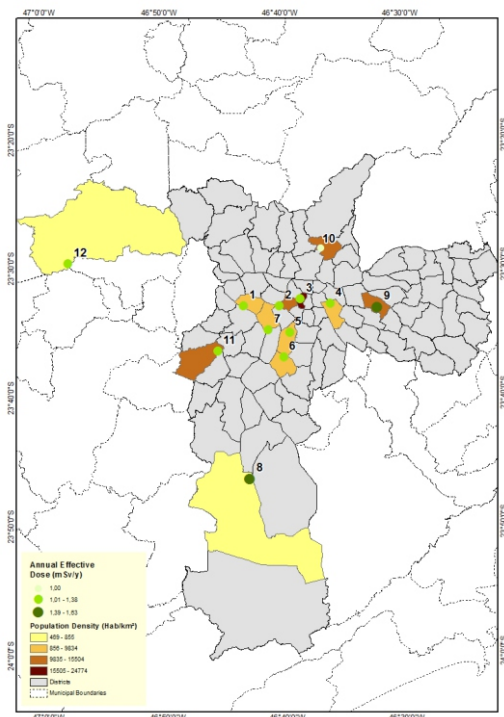

Figure 5. Map of São Paulo city, with the annual effective doses and the population density for the twelve assessed regions.

Occupational exposure assessment in a radioactive facility
The risk that a worker has found on the job is a function of the hazards present and his exposure level to those hazards. Exposure and risk assessment is therefore the heart of all occupational health and industrial hygiene programs involving a continuous process of information gathering. The use of a systematic method to characterize workplace exposures to chemical, physical and biological risks is a fundamental part of this process. The study aimed to carry out an evaluation in a radioactive facility, identifying potential exposures and consequently the existing occupational hazards (risk/agent) in the workplace, which the worker may be subject. The study was based on proposal to carry out a basic characterization of the facility, which could be the first step in the investigation of occupational exposure. For this study was essential to know the workplace, potential risks and agents; workforce profile including assignment of tasks, sources of exposure processes, and control measures. Since the basic characterization of the facility has been carried out, consequently the potential exposure to the agents of risks to workers has been identified. The study provided an overview of the perception of risk founded at facility studied and has contributed with the occupational health program resources for welfare of the worker.

MicroPET Scanner - Characterization and radioprotection procedures
In the past, models of the carcinogenic risks of ionizing radiation have primarily relied on long term surveillance of the Japanese atomic bomb survivors, which showed significant increases in the incidence of cancer after effective doses greater than about 50 mSv. The relative paucity of direct data in the lower dose range delivered by diagnostic imaging has led to conflicting opinions about the shape and slope of the radiation dose-response curve. The assessment of occupational risk associated with the low radiation doses due to microPET scan is the study object.

The microPET scanners present design challenges relative to human PET scanner, especially concerning spatial resolution and sensitivity; the smaller dimensions of mice internal organs demand for better spatial resolution and higher detection efficiency; this demands for new research and development on detection methods for microPET systems.

The project includes the realization of simulations using phantoms to compare experimental data with Albira microPET standard protocols (equipment performance and quality control). In additional, Radioprotection procedures are evaluated involving workplace monitoring and individual monitoring.

Products and services

The main task of the Radioprotection Service of IPEN is to provide for IPEN workers and for general public an adequate protection against ionizing radiation. The Radioprotection Service implements appropriate procedures and monitoring techniques according to the national and international standards. The Radioprotection Service is available to the customers 24 hours per day.

The team helps the employer to comply with the requirements specified by the National Regulatory Authority. The Radioprotection Service provides support to general obligations for any practices which involve or could involve exposure to radiation or radioactive substances in compliance with the standards that include:

- Preparation of local rules and procedures;
- Designation of radiological areas;
- Control and accounting of radioactive material;
- Restriction of exposure;
- Optimization of radioprotection for practices;
- Individual dosimetry (internal and external) and dose assessment;
- Occupational and environmental control and contamination monitoring;
- Contingency planning and radiological risk assessment;
- Training in radiological protection.

In addition, when required, the Radioprotection Service can provide the following services: preparation and review of radiological protection aspects of safety documents; advice and assistance on radiological aspects of categorization of plant and modifications; participation in safety audits; support to engineering projects; analysis of transport packages and waste contents, including assistance with waste characterization; investigation of abnormal dosimetry results; routine reports on personal dose statistics; provision of appropriate radiological information for reports; personal protective equipment including respiratory protection; preparedness and emergency response involving radioactive material.

Concerning the program for the improvement of infrastructures for protection and safety at IPEN, the Radioprotection is the authority responsible for managing the radiological activities survey of access areas under the direction and instructions of Radioprotection staff. The Radioprotection Service is updating in a continuous way its procedures in order to fulfill the new legal requirements derived from the standards.

Preparedness and response for a nuclear and radiological emergencies
IPEN is an operational unit of the Protection System for the Brazilian Nuclear Program (SIPRON) that is a group of organizations with the objectives of the integrated planning, the combined action and the continuous execution of measures in order to assure the nuclear safety in the country and to respond to radiological and nuclear accidents in Brazil. IPEN also takes part in the implementation of the Emergency Situation plan that was developed by the National Commission of Nuclear Energy (CNEN) to respond to nuclear and radiological emergencies, as loss of radioactive sources and accidents during the transport of radioactive material.

The Nuclear and Radiological Emergency Response Team (NRERT) of the Radioprotection Service is responsible for the evaluation and first response to situations of nuclear or radiological emergencies in São Paulo state. NRERT works with other federal and local agencies to monitor, contain, and clean up the release of radioactive material for protecting people and the environment from harmful exposure to radiation. The Fig. 6 shows the actions for response to radiological emergencies.

Figure 6. Response to a radiological emergency.

Training in radiation protection at IPEN
The Radioprotection Service is responsible for the development and implementation of training in radiation protection for a range of users and applications of ionizing radiation. This activity has been established to attend: the training requirements for IPEN workers for any levels; to emergency response personnel, such us fire fighters, civil defense personnel; and to provide and disseminate information in radiation protection education for students and community.

Workers who are occupationally exposed to ionizing radiation need more extensive and deeper training to ensure that radiation is used

safely. The training of the principles of radiation protection is based on the Standards of the CNEN and IAEA (International Atomic Energy Agency). The competences are acquired, developed and maintained through a programme of regular training. The courses are offered, such as basic training, refresher training and on the job training. The content and level of the courses offered are established for each category of persons to be trained.

For the 2011-2013 period, the courses were offered periodically. Upon completion of the course, an examination is given to authenticate the program requirements. A Certificate of Achievement is provided to those who have successfully completed the course, and a permanent record of training is kept in the Radioprotection office. The basic course covers the general principles of occupational radiation protection in the following subject areas: basic radiation physics, definitions and units of radioactivity, principles of radiation protection against external and internal exposures, biological effects of radiation, the risk and assessment of such exposures, instrumentation, inventory and contamination control, emergency response, requirements of the National and International Standards and IPEN procedures. After this basic course all workers must be trained in this specific practice in each work area. The Radioprotection Service provided training to workers as shown in Fig.7.
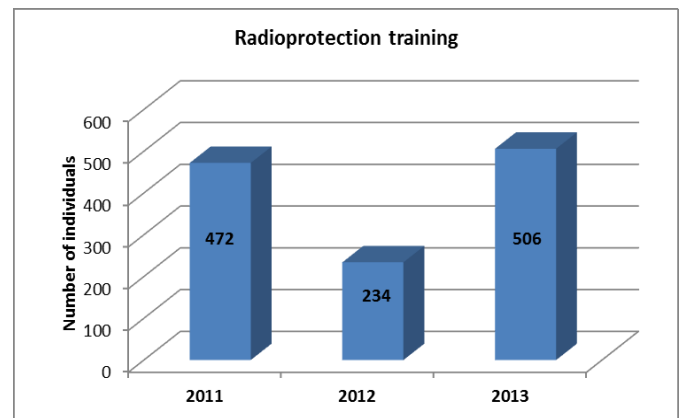

Figure 7. Number of workers trained on radioprotection and safety over the years.

Research Staff

Dr. Ademar José Potiens Jr; Dr. Demerval Leônidas Rodrigues; Dr. Goro Hiromoto; Dr. Janete Cristina G. G. Carneiro; Dr. José Cláudio Dellamano; Dr. Júlio Takehiro Marumo; Dr. Kátia Aparecida Fonseca Normanton; Dr. Linda Viola Ehlin Caldas; Dr. Luis Antonio T. Mattos; Dr. Malvina Boni Mitake; Dr. Nelson Leon Meldonian; Dr. Roberto Vicente; Dr. Solange Kazumi Sakata; Dr. Teresinha de Moraes da Silva; Dr. Valdir Maciel Lopes; MSc. Fábio Fumio Suzuki; MSc. Matias Puga Sanches; MSc. Reynaldo Serra Cavalcanti; MSc. Sandra Aparecida Bellintani; Bel. Christovam Romero Romero Filho; Bel. Eduardo Yoshio Toyoda; Bel. Francisco Mário Feijó Vasques; Bel. Hissae Miyamoto; Bel. Jurandyr S. de Carvalho; Bel. Ricardo Nunes de Carvalho; Antonio Alves de Andrade; Celso Augusto Jacomini; Cláudio Calixto de Almeida; Cláudio Manoel Constancio; Donata Celicea de Oliveira Zanin; Eduardo Cardoso Monteiro; Eduardo Gerulis; Eduardo Wilson M. dos Santos; Estanislau Borges Vianna; Ethel Martins Pedroso; Evandro Alves Almeida; Filomena De Fina Beraldo; Flávio Luiz Rossatto; Haroldo Ramos da Silva; Hélcio Luiz Apostólico Jr; Hélio Francisco Leôncio; Ieda Ribeiro Tavares Venâncio; Ivanatã Martins da Silva; José Carlos Barbosa da Silva; José Laércio de Carvalho; José Roberto Araújo Nicolau; Julio Evangelista de Paiva; Juscelino Martins de Oliveira; Manoel D. F. Brandão; Marcos Maciel de Goes; Maria Aparecida Gonçalves; Maria Cristina Santos Ferreira; Massao Kamonseki; Olavo Pedro da Silva; Paulo Antonio Mestre; Paulo Brasil Sanches Cambises; Ricardo Borbon Lemes; Robson de Jesus Ferreira; Sidnei de Lima; Vera Lúcia Keiko Isiki; Vicente Rodrigues Júnior.

Graduate Students

Alice dos Santos Alves; Amanda Juliene da Silva; Ana Paula Gimenes Tessaro; Bianca Geraldo; Daiane Crisitini Barbosa de Souza; Daniele Martins Sarmento; Eduardo Gurzoni Alvares Ferreira; Eliana Rodrigues Leite; Fabio Henrique Manocchi; Felipe Ramos Correa; Heverton Cardan Oda Fonseca; Isis Elaine Mejias Carpio; Ivani M. Fernandes; Josenilson Barbosa de Lima; Karina Mitie Yoshimoto; Kátia Suemi Tanimoto; Leandro Goulart de Araujo; Ludmila Cabreira Vieira; Maria Eugênia de Melo Rêgo; Maurício Guimaraes Sabbag; Nella Nelci Mussugati de Jesus; Paula Perrucho Nou Silva; Priscila Costa; Rafael Azevedo Nascimento; Rafael Vicente de Pádua Ferreira; Rosana L'agua de Oliveira.

Undergraduate Students

Ana Carolina Oliveira de Souza; Beatriz de Castro; Caroline Andeassa Caracho; Debora Palazon Sesmilo; Eliakim George Alves; Fernando Cozim Melges; Maurício Tiokazu Oshiro; Patricia Martinez Maffei; Rafael Augusto Silva; Renato da Silva Guimarães; Stella Melenis Conti; Vanessa Nobre Bueno.

Co-Workers

Dr. Gian-Maria A. A. Sordi; Dr. Maria Helena Tirollo Taddei; MSc. Adelia Sahyun.