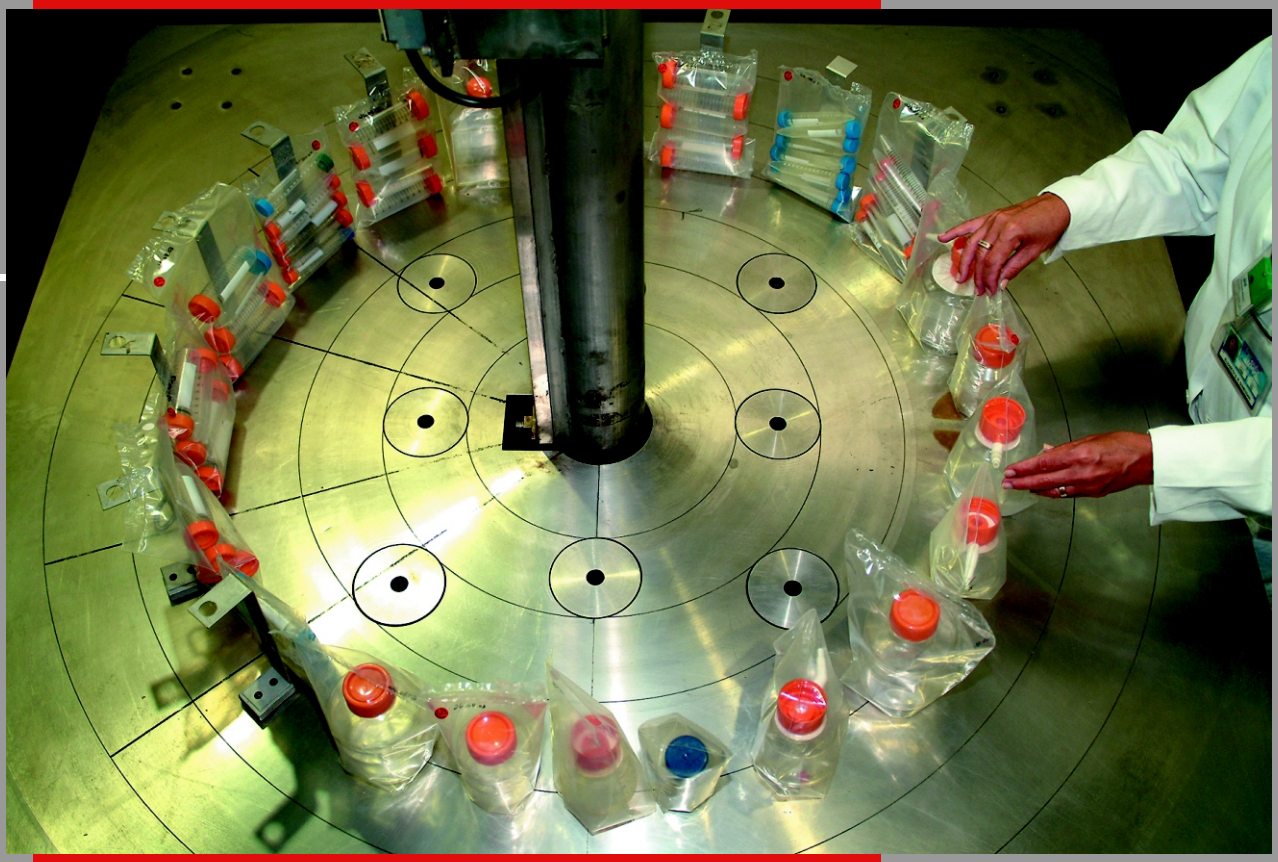
Applications of Ionizing Radiations



Packaging with different materials are sterilized in the cobalt-60 panoramic irradiator

Applications of Ionizing Radiations

Introduction

Ionizing radiation can modify physical, chemical, and biological properties of materials. Today's market dynamics using industrial electron beam, X-ray and gamma ray technologies are changing approaches to radiation sterilization, including an increasing trend towards processing small batches of high value-added, dose sensitive, complex multi-component healthcare products that require rapid turnaround. Significant progress is being made in the development of X-ray systems for large scale, high volume sterilization of medical products.

Many gamma ray (^{60}Co) irradiators have been built and it is estimated that about 300 are currently in operation in Member States of the IAEA. In recent times, the use of electron accelerators as a radiation source (and sometimes equipped with X-ray converter) is increasing. However, gamma irradiators are difficult to replace, especially for non-uniform and high-density products.

Electron beam radiation treatment of polymers continues to be the largest field in the application of radiation. Market surveys indicate there are more than 1,400 high-current electron beam accelerators (EBA) in commercial operation today, providing an estimated added value to numerous products of $85 billion USD or even more. Primarily, EBA are used to treat wire and electric cable, heat-shrinkable tubing and film, and tires, as well as for surfacing curing. Research laboratories and scientists are working together with companies in the development of advanced materials.

For spreading and consolidating techniques that lead to the use of the radiation technology and radioisotopes applications in Industry, Human Health, Agriculture and Environmental Preservation, the Radiation Technology Center was founded in 1972.

The main R&D activities of the Applications of Ionizing Radiations program are in consonance with the IPEN Director Plan (2008-2010) with four subprograms:
- Food and Agricultural Products Irradiation;
- Radiation and Radioisotopes Applications in Industry and Environment;
- Radioactive Sources and Radiation Applications in Human Health; and
- Radioactive Facilities and Equipment for Nuclear Techniques Applications.

During its trajectory of success and achievement it can be highlighted the projects for implantation of the ^{60}Co Multipurpose Irradiator and the EBA, supporting the local scientific and industrial communities on development of process and products; for technological domain production and distribution of ^{125}I seeds for prostate cancer treatment; and also, the assembling of an third-generation industrial computed tomography scanner for multiphase flow system analyses. The improvement of the activities of radioisotope technology application in the petrochemical and chemical industries for processing control and sanitation, and activities in the RadTech South America and ICTR, and organization of the IX ENAN together with the International Nuclear Atlantic Conference (INAC 2009) can also be highlighted.

All realizations and achievements were only possible with the governmental financial support, standing out projects by FAPESP, CNPq, CAPES and FINEP, and international projects, such as, ARCAL, Technical Cooperation (TC) and Research Contract (RC) supported by the IAEA, as well as, the national and international partnership and cooperation with industries, universities and institutions.

Facilities and Devices for Application of Nuclear Techniques

At the IPEN/CNEN/SP there are two Industrial Electron Beam Accelerators of 97.5 kW (1.5 MeV - 65 mA) and 37.5 kW (1.5 MeV - 25 mA), supplied by IBA Industrial Inc. and two Cobalt-60 Irradiators - Gammacell (2,142 Ci Dec - 2010), Panoramic (394 Ci Dec-2010) designs, and Gamma Multipurpose Irradiator covering 76 m^2 of floor area, the irradiator design is product overlap sources and the maximum capacity of cobalt-60 wet sources is 37 PBq (1 MCi). The performed qualification program of this multipurpose irradiator was based on AAMI/ISO 11137 standard, which recommends the inclusion of the following elements: installation and process qualification. The initial load of the multipurpose irradiator was 3.4 PBq (92.1 kCi) with 13 cobalt-60 sources model C-188, supplied by MDS Nordion Ion Technologies - Canada. For irradiator dose optimization, the source distribution was done using the software Cadgamma developed by IPEN-CNEN/SP. The poly-methylmetacrylate (PMMA) dosimeters system, certified by the International Dose Assurance Service (IDAS) of the International Atomic Energy Agency (IAEA) was used for irradiator dose mapping. The economic analysis, performance concerning to dose uniformity and cobalt-60 utilization efficiency were calculated and compared with other commercial gamma irradiators available in the market.

The Electron Beam Accelerator and Cobalt-60 Irradiators are mainly applied for research, development and services of preservation and disinfestations of food and agricultural products; treatment of industrial and domestic effluents, sludge and hospital waste; paints, varnishes, adhesives and coating cure; preservation of art works and books; radiosterilization of bones and human tissues; Brazilian gemstones enhancement; polymer grafting and modification; radiation processing of composite materials and natural polymers. The gamma rays (electromagnetic energy) and electron beam (EB) are very efficient agents for radiosterilization of medical, pharmaceutical, and biological products due to high sensitivity of pathogenic bacteria to radiation. In 2010, 26,340 medical, pharmaceutical, and biological products were radiosterilized and 372,500 semiconductors (diodes) were processed by ionizing radiation in these radioactive facilities. Annually, 3,530 km of wire and electric cables for chemical, automobile, aircraft and electro-electronic companies have been irradiated in the Industrial Electron Beam Accelerator. The radiation processing promotes crosslinking among the polymeric chains, increasing electrical, thermal, mechanical, and chemical properties. The modernization of the installation promotes the elevation of wire and electric cables processing velocity to 300 m/min and polyethylene foams to 15 m/min, becoming the product prices more competitive in the Brazilian market.

Industrial dosimetry in radiation processing

In radiation processing, a well characterized reliable dosimetry system that is traceable for recognized national and international dosimetry standards is the key element of such activities. The Industrial Dosimetry Laboratory has the responsibility to measure the radiation dose absorbed in the processes induced by ionizing radiation at Co-60 gamma ray irradiation (Gammacell, Panoramic and Multipurpose Irradiator) and electron beam (two Industrial Electron Beam Accelerators of 97.5 kW and 37.5 kW) facilities in ordinary services and to develop new products and services by radiation processing. The dosimetry procedures for radiation processing are carried out in agreement with the ISO (International Organization for Standardization) - ASTM (American Society Testing and Materials) standard guides and practices. To establish a reliable dosimetry system, the laboratory has participated of the intercomparisons of gamma dose measures, organized by International Dose Assurance Service (IDAS) offered by the International Agency Energy Atomic (IAEA) and of the national intercomparisons to check on the entire radiation dose measurement system: dosimeters, measurements equipment, and irradiation and data procedures. The dosimetry systems used for the quality control of the radiation process are: Fricke solution as reference standard dosimetry system, Alanina as transfer standard dosimetry system and as routine dosimetry.

Radiation detectors and industrial computed tomography

In the last years, industrial computed tomography (iCT) in Brazil has had its application in non-destructive testing. Nowadays, a wide range of chemical and petrochemical industries have great interest in using iCT for improving design, operation, optimization and troubleshooting of industrial processes. The industrial distillation systems involve fast dynamic processes and, in addition, contain solids, liquids and gas mixtures. The industrial distillation columns are usually built with steel and have large diameters and thicknesses that become unfeasible their analysis with conventional X-ray beam. For these reason gamma radioactive sources in the energies range of 317 keV from ^{192}Ir, 662 keV (^{137}Cs) to ~1250 keV (^{60}Co) are preferable instead of X-ray sources. Gamma ray iCT for multiphase processes is now a promising technique and has been studied for advanced research centres. To follow t his trend and to remain updated, the CTR/IPEN laboratory studies the development of the CT methodology for industrial multiphase systems. Three types of gamma ray iCTs have been developed for different applications:
A first generation iCT, a one detector-one source was developed. The data acquisition board, the mechanical control interface and the software were

developed to be used in this iCT system. The developed tomography system was validated using an IAEA phantom placed between a 2"x2" NaI(Tl) detector and a collimated ^{60}Co source. A good resolution was observed for all images reconstructed from the developed CT systems. A third-generation type CT, where the collimated detectors are arranged in an arc at the center of the radiation source, was developed in our laboratory. The whole assembly of the detectors and the radiation source are mounted on a gantry suitable to be rotated around the axis of the test section through a stepper motor interfaced with a host computer. The electronic system with twelve multichannel boards with their HV supplies, a circuit to control three step motors and data acquisition system were specially developed for the third-generation system.

Figure 1. Electronic system for data acquisition and step motor control

A fourth generation iCT (4D ICT) was proposed and its development is ongoing. It will be mounted on a wooden platform (a lightweight platform easily adaptable for working conditions in industrial plants), using multi small detectors surrounding the distillation column (the object). Among the advantages of this system, it should be emphasized that: (a) this system is fixed around the column, not requiring movements, (b) it is weightless and (c) it is portable, which makes it suitable for its use in industrial plants. While the fourth generation iCT will be more suitable for use in industrial plants, the third generation iCTs are often used in laboratories for demonstration of this technology and/or to establish parameters in the development of a new design for chemical reactors/ columns; the third-generation iCT is, also, useful to promote improvements aiming to increase the production efficiency. As to the first generation iCT, it is being used to establish a methodology to analyse the concentration gradient of uranium in the nuclear fuel plate produced at Ipen-Cnen/SP. This R&D has been supported by the IAEA (RC 12459 and TC BRA8031 Projects) and MCT/CNPq/CT-Petro (505161/04-4 and 620201/2008-8 Projects).

Semiconductor radiation detectors to be operated at room temperature

The lead iodide (HgI_2) and thallium bromide (TlBr) are very promising materials with large technological applicability as a room temperature semiconductor radiation detector for X and gamma rays spectrometry. Several studies have been carried out about the preparation of both crystals and progress has been achieved by the advance of purification techniques, growth and characterization of HgI_2 and TlBr crystals. Material processing, especially purification, was found to have influence on the detector response, suggesting that improvement in the performance of detectors could be possible with more purification. Higher purity crystals exhibit significant enhancement in the detector performance. TlBr crystals were grown by Bridgman technique, while different methods have been studied for establishing the growth of HgI2 crystals, such as, (a) physical vapor transport (PVT) and vapor growth of HgI_2 precipitated from KI and acetone solution and (b) using dimethylsulfoxide solution as a complexion agent. The results suggest PVT to be the technique more suitable for HgI_2 crystals. However, further studies should be carried out to certify this statement. The Bridgman technique was effective to grow TlBr crystals. However, problems still exist in both crystals, used as room temperature semiconductor detectors, due to the low charge carrier collection efficiency, what is being investigated. The energy resolution of these detectors has been, currently, limited by incomplete charge collection. Further improvements of the detector performance will be achieved investigating the structural and surface properties, optimizing the measurement conditions and reducing the electronic noise.

Development of an automation system for ^{125}I brachytherapy seed encapsulated by (ND:YAG) laser welding

The aim of this work is to develop an automation system for Iodine-125 radioactive seed production by (Nd:YAG) laser welding, which has been used successfully in low dose rate (LDR) brachytherapy treatment. This small seed consists of a welded titanium capsule, with 0.8 mm in diameter and 4.5 mm in length, containing Iodine-125 adsorbed onto a silver rod. The Iodine-125 seeds are implanted into the human prostate to irradiate the tumor for cancer treatment. Nowadays, the IPEN-CNEN/SP imports and distributes 36,000 Iodine-125 seeds per year, for the clinics and hospitals in the country. However, the Brazilian market potential is now over 8,000 Iodine-125 seeds per month. The local production of these Iodine-125 radioactive sources became a priority for the Institute, in order to reduce the price and the problems of prostate cancer management. It will permit to spread their use to a larger number of patients in Brazil. On the other hand, the industrial automation plays an important role for Iodine-125 seeds in order to increase the productivity, with high quality and assurance, avoiding human factors, implementing and operating with good manufacturing practices (GMP). The technology consists of appliance electronic and electro-mechanical parts and components to control machines and processes. The automation system technology for Iodine-125

seed production developed in this work was mainly assembled employing a Programmable Logic Controller (PLC), a stepper motor, an (Nd:YAG) laser welding machine and a supervisory. The statistical repeatability of correctly encapsulated sealed sources with this automation system is greater than 95%.

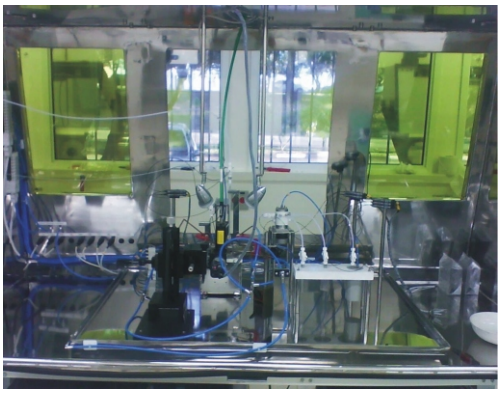


Figure 2. Automation system with electro-mechanical and pneumatic components for Iodine-125 seed production

Radiation-Hard Si Diodes response in radiation processing and clinical beams dosimetry

Epitaxial and FZ silicon diodes processed at the University of Hamburg and Helsinki Institute of Physics has been successfully used as dosimeters in radiation processing, with total doses up to 5 MGy and clinical electron and gamma beams at a total dose of 16 Gy. In this range, the dosimetric response of the diodes is linear.

Measurements of electron transport parameters in avalanche regime

The goal of this work is to measure the first Townsend coefficient and the electron drift Velocity in gases at high uniform electric fields. The heart of the chamber is an RPC like cell with a bulk aluminum anode and a glass cathode. The signal is readout with a fast digitizing oscilloscope to record the fast signal induced by the electron movement in the thin gas gap. A first set of data with nitrogen and isobutane was collected as part of project FAPESP 02/04697-1 and CNPq 78859/2009-0.

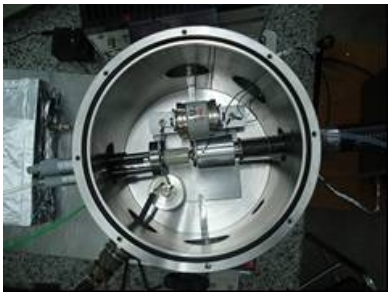


Figure 3. RPC like cell with a bulk aluminum anode and a glass cathode

Use of a low cost pin photodiode for dosimetric purposes in radiation processing

The silicon PIN photodiode (SFH 00206) has been used as a routine dosimeter for irradiation processes performed with a Gamma Cell facility in the. Until now, the diode's response as a function of the gamma-ray doses is linear in the range of 5 Gy to 100 Gy.

Ionizing Radiation Application in Food and Agricultural Products

Irradiated food detection laboratory has been developing different studies in the food irradiation area. These studies embrace many subjects, not only food irradiation detection but also the effects of ionizing radiation on a variety of food stuffs. Works focused on food irradiation detection are based on the application of the microbiological method DEFT/APC and other assays as DNA Comet Assay and germination test. DEFT/APC method and DNA Comet Assay were applied to different minimally processed vegetables. DNA Comet Assay was also used to detect irradiation treatment of soybeans and poultry liver as well as cold chain rupture in food industry control. Moreover, the research also included the detection of genetically modified irradiated and unirradiated food. Several works have been performed to evaluate the effects of ionizing radiation on different kinds of food, such as: meat, through lipid peroxidation analysis in salmon and beef burgers; grains, physical, microbiological and sensorial tests in soybean, peanuts, pistachio; herbs, microbiological and sensorial analysis of medicinal herbs; vegetables, effects of gamma radiation on ready-to-eat vegetables. Besides food analysis, other studies evaluated the decontamination of biological ferment by gamma radiation and the radiation degradation of biological residues (aflatoxins) produced in food laboratories.

During this period, the project (IAEA TC BRA/5/058) related to irradiated mangoes were concluded where a total of 1300 fruits were treated, analyzed and compared. The main activities envolved an international consignment of 600 irradiated mangoes from Brazil to Canada; a regional workshop at Petrolina region where the main mangoes producers of the country are located. The results strongly indicated ionizing radiation as a good alternative for disinfestations purposes.

Studies related to irradiated honey were performed with nutritional, physical-chemical and sensorial evaluations, as well as rheological behavior. Results favorable were obtained with sensory untrained panel and HMF and others relevant contents remained within official limits.

Figure 4. Different honeys irradiated at 5kGy

Considering other applications of irradiation technology, studies on physical-chemical of irradiated tomatoes were realized. Licopene, the most important component of tomatoes, were nutritionally assessed in irradiated tomatoes and also in their sauces. Results showed that irradiation contributed positively.

Figure 5. Study of physical-chemical properties on irradiated tomatoes and its sauces

Industrial and Environmental Application of Ionizing Radiations

Cure of inks, paints, and varnishes by UV/EB technology and evaluation of its degradability

The search for environmentally friendly materials is becoming one of the major focuses of research in the twenty-first century, considering the high level of pollution generated by the inadequate disposal of materials, especially polymers or plastics, in the environment. In addition, environmental legislation already in course in many countries limits the emission of volatile organic compounds (VOC) in the atmosphere. Thus, the technology of curing polymer coatings by radiation is based on the interaction of chemical system with the ultraviolet (UV) or electron beam (EB) incident radiation, forming reactive species capable of inducing polymerization reactions and cross-linking. In this technology, the organic solvents used to reduce the viscosity of the formulations are replaced by reactive monomers that remain in the cured product, providing no VOC emission. The dry/cured film is obtained at room temperature. However, the cured products are insoluble and infusible, increasing the degree of complexity for reprocessing, recycling, and required degradation.

Reduction of environmental impact generated by radiation-cured print inks on post-consuming biodegradable plastic packaging

Research is being done in order to improve the degradability of cured films disposed in the environment. This project aims to evaluate the influence of pro-degrading agents on printing ink formulations, applied on different polymeric substrates or plastic packaging and cured by UV or EB radiation. The degradability of these cured films is being evaluated by the changes in their thermal, mechanical, rheological, and morphological properties during natural weathering and accelerated ageing, as well as biodegradation in simulated soil.

Preservation of cultural heritage by ionizing radiation

Cultural heritage on paper and works of art in general made of organic materials in nature are submitted to a constant process of degradation by ageing through physical, chemical, microbiological, or insect attacks. The use of ionizing radiation aims the disinfestations of works of art and the preservation of artifacts in their original form or in the state in which they are found. The effects of gamma radiation on Brazilian paper and wood based cultural heritage have been investigated concerning some specific characteristics.

The wood is considered a natural composite of extreme complexity, basically composed of cellulose, lignin, hemicelluloses (polyosis) and extractives. Its composition promotes biological attacks from different species. In this context, several techniques have been studies and applied for disinfecting and decontaminating works of art and cultural heritage made of wood, which have been damaged by biodeteriorating organisms (fungi, bacteria, and insects). Gamma radiation is been studied as an alternative to chemical methodologies for wood-made artifacts restoration. By this way, the objective of this project is to evaluate the effect of gamma radiation on some physical-chemical properties of Cedro-rosa and Imbuia wood species. The irradiation has shown itself to be an efficient process to eliminate infestations by both insects and microorganisms, to be fast and not to require quarantine because of the no-generation of toxic residues. Additionally, this process does not protect the irradiated material from re-infestations or re-contamination. In this study, relatively high gamma radiation doses were applied up to 100 kGy so that radiation effects, which are cumulative, could be retrieved. The results showed that gamma radiation, in the studied dose range, does not promote meaningful alterations on the evaluated properties, which allows that artifacts be irradiated multiple times, even if a re-infestation occurs.

Fungi can cause spots or stains on paper and degrade its cellulose fibers affecting paper's integrity. These stains may be due to chemicals produced by fungi in metabolic processes, using cellulose as a nutrient source, and also to the pigmented mycelium and/or spores. Books and documents attacked by fungi and insects have already been treated by radiation for disinfestations purposes. However, there is still need to investigate the influence of radiation on the cellulose paper structure. The aim of this research was to study the effects of radiation on paper properties, especially those related to strength and appearance. Paper sheets for this study were prepared in the laboratory, using bleached eucalyptus pulp as raw material. No additives were used to concentrate the attention only on the effects of irradiation on the pure cellulose matrix. The samples were irradiated at IPEN's ^{60}Co Gammacell irradiator with six radiation doses from 3 to 15kGy, at the dose rate 0.817Gy/s. The properties of paper sheets were tested after irradiation and compared with unirradiated samples according to ISO methods. No significant changes were detected in paper samples irradiated up to 15kGy.

The Institute of Brazilian Studies (IEB) from the University of São Paulo received the charge from São Paulo's Federal Justice to take care of part of the collection from Santos Bank that was severely attacked by insects and micro-organisms (moulds) when stored in a warehouse that was flooded by intense rainfall. A chemical treatment to eliminate the bio-deteriorating agents was tried but it was not effective. As the heap has a large amount of Xylograph wood dye, printings and manuscripts from cordel literature an urgent way to treat was

searched and after the study and previous experience on wood irradiation process it was decided to submit promptly the heap to gamma irradiation. After the treatment the pieces were restored by IEB staff and now are being part of IEB collection and available for the scientific research community.

Modification and preparation of polymeric materials and composites by ionizing radiation

Application on composites based on biodegradable polymers and coconut fiber

The development of polymeric materials that are susceptible to microbiological degradation and have properties similar to the conventional polymers would reduce waste deposit. And, the addition of natural fibers can lead to physical properties improvement and also can reduce cost. Additionally, it will reduce the amount of agribusiness waste disposal in the environment. In Brazil, coconut production is around 1.5 billion fruits by year in a cultivated area of 2.7 million hectares, but the coconut husk fiber has not been used much for industrial applications. Moreover, biodegradable polymers have attracted the attention of the most part of population, due to the environmental issues arising from the increasing use of polymeric materials of low degradability discharged as waste residue. Besides, when considering an application in the medical field, it is necessary that the products are sterilized and, ionizing radiation is widely used to sterilize medical and surgical devices. In this work, it was studied blends and composites based on two commercial polymers: poly (caprolactone), PCL, and poly (lactic acid), PLLA, and coconut fiber. Those polymers are biodegradable as well as biocompatible, so it is important to know the effect of ionizing radiation in these materials. Samples were irradiated with gamma rays from ^{60}Co source and electron beam with radiation doses ranging from 10 kGy up to 1 MGy. The non-irradiated and irradiated samples were studied using several analytical techniques and characterization assays that allowed understanding their properties in order to enable their application as precursors for medical and surgical devices. Thermal processing used to obtain composites and previous acetylation by chemical treatment contributed to the bioburden reduces. Furthermore, reducing initial bioburden it was possible to diminish radiation doses needed to perform sterilization. Enzymatic and soil degradation were not negatively affected by radiation processing. Even though fiber incorporation to the polymer blend slightly reduced degradation process, composites continued degrading through time. Artifacts produced by means of the materials studied here can be radiation processed with doses up to 100 kGy without prejudice of their biodegradability.

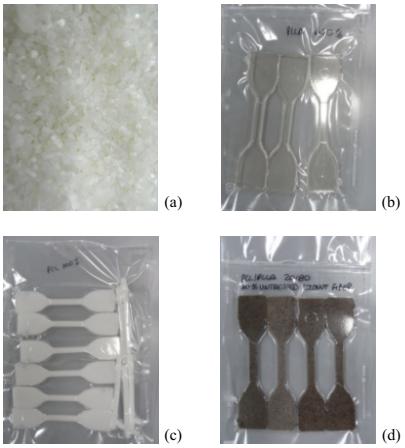


Figure 6. (a) Pellets of PCL:PLLA 20:80 w:w; (b) PLLA; (c) PCL; (d) Composite PCL:PLLA blend and 5% coconut fiber

Utilization of rice husk ash as reinforcement filler for polyamide 6 EB irradiated

New reinforcement fillers like mineral or fiber are developed to improve the dimensional stability, electrical, thermal and chemical resistance, and strength of many kinds of polymers. The aim of this work was to present, dimensional stability, thermal and strength results of the study of amorphous rice husk ash (RHA) like reinforcement filler in a polyamide 6 matrix irradiated by electron beam at different doses and compare it with talc, the most utilized mineral filler by the composes producers. The results showed that the use of the rice husk ash as filler for polyamide 6 composite is technically and economically viable. The irradiation of the studied composite (PA 6 with 30% of rice husk ash) did not provide any improvement for the mechanical and thermal properties previously appraised.

Characterization of crosslinked polyethylene foam by EB irradiation

The foam of polyethylene obtained by crosslinking process by irradiation performs excellent appearance in the surface, which is formed basically by closed cells. The aim of this work was to study the effect of different radiation doses on the low density polyethylene that after irradiation it is thermally expanded for foam obtaining. To certify about the effect of the radiation it was studied the mechanical and thermal properties of the foams. The foams obtained from the crosslinked LDPE by irradiation process (30kGy) presented a smooth and the homogeneous surface and they are formed basically by closed cells.

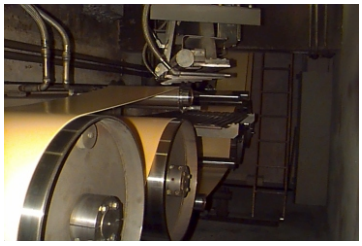


Figure 7. Low density polyethylene foam processed by ionizing radiation

Industrial and Environmental Application of Ionizing Radiations

Polyethylene (terephthalate) - PET recycled post-consumption and of its properties when it is undergone ionizing radiation

The plastic materials have an important role in the life style changing, in the lives of the people and it is more and more utilized in the production and consumption by the world population. By the plastic utilization, it became possible the growth phenomenon of disposable products. As a consequence of this conjecture, the recycling of these materials becomes an obliging option of the modern society. The economy provided by the reutilization of the recycling materials is advantageous not only in consideration to the reutilization of the natural resources involved in these products, but specially for its benefit provided in which concern to the preservation of the environmental matters. The aim of this work was to recycle the PET post-consumption and to evaluate the effects caused by the action of different radiation doses, on the properties of this recycled polymer. The recycling process with super-washing allowed the production of PET post-consumption recycled with lower losses of intrinsic viscosity. It was concluded that the effects caused by the action of the ionizing radiation by mean of the electron beam from electron accelerator and gamma rays emitted by ^{60}Co source in the virgin and recycled PET polymer promoted the predominance of random scission reactions of the main chain, with a consequent decrease in the polymer molecular weight.

The viability of PVC/Al blister reuse and PVC property studies after ionizing radiation processing

The objective of this research was to separate, by means of a process of dissolution, the PVC and the aluminum that compose blister packs, generally used for pharmaceutical pills. It also studied the effect of the ionizing radiation on the PVC, and, finally, the mechanical recycling of the separated PVC, by a process of extrusion. The material it used in this work is the surplus of the pharmaceutical industry, i.e., packs with defects or burrs. It ground the material to facilitate the handling and the homogenization of the system. The system with potassium hydroxide base, concentration of 2M and agitation presented the best relation between time of dissolution and characteristics of the resulting material, without degradation of the PVC. After the dissolution, the samples of the material were submitted to ionizing radiation with doses of 50 kGy, 100 kGy,150 kGy and 200 kGy. In the following, these samples were submitted to traction resistance tests to analyze which modifications the irradiation caused. The last step of the research was the recycling of the PVC separated from the Aluminum. It was made the recycling in industrial equipment, a PVC tube extruder. The material was combined with lubricants, heat stabilizers and pigment in an intensive mixer and processed into the form of rigid PVC electrical conduits. In the irradiated samples, the color of the material changed as well as its extension that was as larger as the radiation dose that they received, indicating the dissociation of the PVC molecules. The extrusion of the PVC was successfully realized: about 200 kg of properly combined were processed. These results presented viability of the whole research.

Electron beam irradiation effect on some properties of aromatic aliphatic copolyester films

Biodegradable plastics and green plastics are the new tendency in the world. The effect of the electron beam irradiation in aromatic aliphatic copolyester and the blend with corn starch films (Ecoflex® and Ecobras®) were studied by tensile strength at break, elongation at break, Scanning Electronic Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FT-IR), Differential Scanning Calorimetry (DSC), crosslinking degree and biodegradability. The Ecobras® material presented crosslinking, when submitted to doses of 10 kGy and 40 kGy. The Ecoflex® material did not present crosslinking when submitted to these doses. The biodegradability of the materials was evaluated by two methods of test: soil simulated and enzymatic. In both methods of assays, the irradiated samples presented faster biodegradation than the references non irradiated.

Rice husk ash utilization as filler in polypropylene matrix and ionization radiation effect on this composite

In the first step of this work, it was evaluated the possibility of using rice husk ash as a filler in polypropylene (PP) making a comparison with talc which is the most used mineral filler in polymers. This comparison was made by using polypropylene with 20% rice husk ash as well as polypropylene with 20% talc measuring their properties. Despite the properties of the PP with 20% rice husk ash decreased compared with the composite of polypropylene with 20% talc. It can be said that the rice husk ash can be used as filler for other utilization less noble of PP. This way it is being given a destination for this residue that it is disposable in the environment contributing to its preservation, moreover reducing the product cost. This work had also as aim to study the ionizing radiation effect in the properties of these composites. It was used the coupling agent, maleic anhydride, to verify a best sample homogenization. According to the results it can be said that PP is a semi crystalline polymer, and so it has its morphology modified when exposed to the irradiation process. This fact is due to the scission mechanisms of the polymeric chains which it is in compliance to the literature.

Comparison of the properties polyamide 6.6 surfaces untreated, treated by plasma and ionizing radiation

The aim of this study was to compare the properties of the polyamide 6.6 surfaces untreated, treated by plasma and ionizing radiation in order to verify if it adheres to the polyacrylic rubber used in seals in

automotive manufacturing. Plasma treatment of polyamide 6.6 was performed using nitrogen gas at a pressure of 1.40 kg/cm^2. The samples irradiation was carried out by electron beam at different doses. After the samples treatment by plasma and by irradiation, they were added to polyacrylic rubber using a hydraulic press. The polyamide 6.6 surfaces were characterized using different techniques. The untreated samples and the irradiated did not adhere to the polyacrylic rubber. The treated samples by plasma adhered to polyacrylic rubber efficiently and presented differences in surface roughness. Also, these samples presented an increase in contact angle when compared with untreated samples.

Development and applications of polymer, matrix composites, and nanocomposites by ionizing radiation

The studies are focused on the development of polymer, matrix composites, and nanocomposites based on natural and synthetic polymers and nanoclays, fibers from the Brazilian biodiversity and wastes arising from Brazil/Uruguay agro-industry, treated by ionizing radiation. The utilization of fiber residues avoids waste through the reuse of materials that would otherwise have been discarded and can bring social and economic benefits for several regions in South America by generating jobs and preventing rural people from having to migrate to the city in search of better conditions of life. CONAP is formed by researchers and students from Radiation Technology Center of IPEN-CNEN/SP, Department of Metallurgy and Materials Engineering of São Paulo University, A. Schulman Brasil-Mash Industry: Technology in Compounds and Masters, the Norte Fluminense State University “Darcy Ribeiro”, and the Technology Laboratory of Uruguay, other universities in South America and recently the starting projects in cooperation with the Center for Advanced Materials (T-CAM) at Tuskegee University, Tuskegee, Alabama, USA. The academic research comprises:

Development of composites and nanocomposites based on thermoplastic polymers, natural biodegradable polymers, Brazilian nanoclays, vegetal fibers from biodiversity and wastes arising from agro-industry

Gelatin/Brazil nut Shell composites processed by casting process and treated by electron-beam irradiation, and Gelatin/Brazil nut Shell/Brazilian clay nanocomposites processed by casting process and treated by electron-beam irradiation.

Figure 8. Gelatin/Brazil nut Shell/Nanoclay

The results showed that the incorporation of those fibers and Brazilian nanoclays to those thermoplastic matrixes represented a gain by up to 200% in tensile strength at break, flexural strength, and flexural module. After electron-beam irradiation treatment, there was an additional gain of around 10 to 30% in those properties, as well as a better interfacial adhesion between the fiber and the polymer matrix.

Ionizing radiation application on renewable energy production

The purpose is the application of ionizing radiation as pretreatment to lignocelluloses conversion in fermentable sugars for ethanol biofuel production. Sugarcane bagasse used has about 42% of cellulose, 31% of hemicelluloses, 20% of lignin, 6% of soluble, and 1% of ash. The moisture maintenance (50%) after irradiation is a positive point for combination with enzymatic or chemical hydrolysis. The main challenge is to obtain the desirable effects applying doses as low as necessary to get some break in the polysaccharides, and at the same time to avoid the glucose loosing due to uncontrolled degradation of polysaccharides.

The obtained results have demonstrated that absorbed doses from 5 to 150 kGy showed to modify the structure and the composition of sugarcane bagasse. The lignin is not degraded completely, but the cellulose and hemicelluloses are cleaved forming cello-oligosaccharides from glucanases and xylanases. About 99% of cellulose and hemicelluloses are converted to oligosaccharides with 70kGy.

The obtained results demonstrate that electron beam treatment enhances the enzymatic hydrolysis of cellulose in SCB. Nowadays the studies are focused on combination of pretreatment technologies, as irradiation with steam explosion or hydrothermal. Combinations of pretreatment technologies are important for economic and feasibility studies, and the purpose is the reduction of processes severity, e.g., decreasing the absorbed dose, the hydrolysis time, as well as, the acidity and enzymes charge. In addition this work will be followed by the use of different complexes of enzymes.

Figure 9. EB-processing of bagasse

Industrial and Environmental Application of Ionizing Radiations

Advanced oxidation processes by ionizing radiation on the treatment of industrial effluent and environmental recovery

The Advanced Oxidation Process by ionizing radiation on removing toxic and refractory pollutants, e.g.,. organic compounds, reactive dyes and pharmaceutical products, in industrial effluent, drinking water, solid wastes, and on destroying pathogenic microorganisms in wastewater and sludge have been studied. These studies are focused on becoming this technology feasible economically for real industrial effluent, which is recalcitrant when treated by conventional methods. Advanced alternative technologies are being developed for effective treatment of herbicide-polluted waters, through the degradation studies of important target molecules such as ametryne methomyl, dimethoate, carbofuran, and methydathion, triazine, thiophos, atrazyne, endosulfan, chlorpyrifos, thriazophos, and trifluralin.

Two reactive dyes as remazol black and remazol orange were also studied. These dyes were selected once cotton is the principal type of fiber to be colored in Brazil and the reactive dyes are suitable for it. More than 10.000 different compounds were commercialized as dyes and pigments. Nearly 12% of processed dyes are lost to aquatic environment, forming mainly three different chemical, such as, sulphatoethylsulphone, vinylsulphone, and hidroxiethyl-sulphone.

The presence of drug residues into waters as environmental contaminants is a new issue and it was selected fluoxetine hydrochloride, and 17α etinilstradiol as pharmaceutical product for radiation degradation and toxicity evaluations.

Besides irradiation application for environmental benefits, two projects were carried out only for water quality and toxicity assessment. They were developed at Jundiai River, Sao Paulo, Br, with the collaboration of Jundiai Water and Wastewater Department. The second study concerned to the effluents and their discharge into Tietê River and with SABESP collaboration. Sediments from Tietê River were submitted to Neutron Activation Analysis in a joint activity with INAA Laboratory of IPEN.

Remediation of soil contaminated with pesticides by treatment with gamma radiation

An understanding of the processes that affect the transport and fate of pesticides is crucial to access their potential for soil and groundwater contamination, and to develop efficient and cost-effective site management and soil remediation strategies. The main objective of this study is the evaluation of the pesticides transferring from contaminated mixture of commercial polymeric packing of high-density polyethylene, HDPE, used in agriculture to soil and their removal by gamma irradiation. Two soil samples of argyles compositions and media composition were exposed to a mixture of commercial polymeric packing contaminated with the pesticides methomyl, dimethoate, carbofuran, methydathion, triazine, thiophos, atrazyne, ametryne, endosulfan, chlorpyrifos, thriazophos and trifluralin. The pesticides leaching from packaging to soil was homogeneous considering a experimental research. The radiation treatment presented high efficiency on removal pesticides from both soil. However it depends on the physical-chemical characteristics of the contaminated soil. The higher efficiency was obtained in soils with higher organic material and humidity. In addition the pesticides removal yield was higher for medium texture soil, than argyles texture soil.

Biological assays for effluent control

In order to measure the efficacy of radiation treatment, luminescent *Vibrio fischeri* bacteria have been used, called as biological assays. Each toxicity assay applies one given specie of living organisms and its sensitivity for contaminants is of concern when applying this type of assessment for effluents treatment. During our researches the priority is given to Cladocera, Luminescent Bacteria and Amphipods when sediments are included for toxicity evaluation.

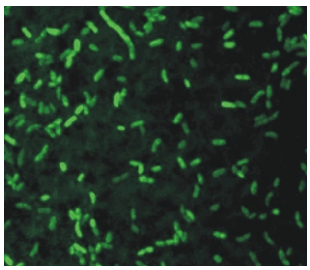


Figure 10. *V. fischeri* bacterial cells as luminescent response to toxins in effluents (toxicity assays)

Gemstones enhancement using gamma radiation

Enhancement services through gamma radiation of colorless quartz and other types of gemstones samples for the companies Murta Gems Trade Gemstones (BH), Stoll Precious Stones of Brazil (RS) and Geoscience Institute of USP. Research of process to induce or enhance the color in several gemstones, and their dosimetry using gamma radiation.

Figure 11. Colored varieties of quartz

Industrial and Environmental Application of Ionizing Radiations

Sealed source production for gammagraphy and industrial process control

Radioactive sealed sources production for radiography and industrial process control. The gamma writing is an important non-destructive technique to analyze metallic components from small to large ones that need high performance and security in operation. Then on-existence of internal failures is checked by gamma rays radiography, because of its great penetration characteristics that allows obtaining the photographic record of failures. This non-destructive analysis is used for quality control of welded components in chemical, nuclear, and mechanical industries, such as pipelines, turbines, reservoirs, and pressure vessels. According to the International Atomic Energy Agency (IAEA) information, the petrochemical and chemical process industries are the mains users and beneficiaries of the radioisotope technology. Radioisotope techniques are very competitive and are largely applied for troubleshooting and process analysis of technically complex, continuously operating industrial plants. Due to this fact, the application of sealed sources becomes more diversified, including for gamma scanning of columns, vessels and pipes, level and interface detection. Since 1983, IPEN-CNEN/SP has supplied industrial gamma sealed sources to more than 25 customers in Brazil and other countries in Latin America and Caribbean. Annually, the laboratory produces 280 sealed sources, with activities ranging from 740 GBq (20 Ci) to 4,444 GBq (120 Ci) of Iridium-192 and from 0.37 GBq (10 mCi) to 18.49 Gbq (500 mCi) of Cobalt-60. The CTR has made 290 inspections in irradiators, command cables and guide pipes annually and also Selenium-75 sources loading services. These supplies allow taking more than 100,000 radiographies per year. The principal CTR's customers are Arctest, ASNDT, Brasitest,CBC, JLM, Confab, Nuclep, TopCheck, Gamatron, Qualitec, Engisa, Capaz, Endlabor, NDT, Sperj, Polyteste, Usiminas, Real WDR, Nuclep, Radiolab,Voigth Hydro, Metaltec, Startec, Accend and Sertech.

Use of radioisotopes as tracers in the environmental and industrial process control

Radioactive tracers, as bromine-82, and dye tracer, as rhodamine WT, are applied to grounded pipe flow rate measurements. Flow rate order of magnitude: 0.1 m^3/s up to 3.5 m^3/s. Radioactive tracer, iodine-131, applications for mean residence time determinations in tanks and digesters of domestic and industrial wastewater treatment plants. Volume order of magnitude: 7,000 m^3 up to 12,000 m^3.

Health Application of Ionizing Radiation and Radioactive Sources

Radiosterilization for tissue banks

In Latin America, the industrial level ionizing radiation sterilization has been used for more than three decades for foods and medical, pharmaceutical and cosmetics products are treated. Later, this activity was extended to the sterilization of human tissues for graft and reinforced in some countries by the technical cooperation and International Agency of Atomic Energy - IAEA financial support.

Brazil was incorporated to this project in 1998 through the Clinical Hospital of Sao Paulo, where the Tissue Bank was installed and the Energetic and Nuclear Research Institute, where the tissues are being irradiated. Since 2009, Brazil has the coordination of IAEA-ARCAL CVIII "Consolidation of Tissue Banks In Latin America And Radiation Sterilization of Tissue Allograft" project with 12 Latin-Americans countries participation. In the last few years, preserved tissue allograft, such as bone, cartilage, skin, amnion and other not viable tissues, have been used in reconstructive surgery by many clinical specialties, like orthopedic and plastic surgery.

The transmission risk of infectious diseases by allograft, however, is a constant concern. To this end, many steps should be taken, including tissue sterilization. This technique is used to minimize the immunogenicity, to kill bacteria and to reduce the contagious diseases transferring risk. As an example, the skin glycerol preservation has a bacteriostatic effect after certain time, on the other hand, skin sterilization by ionizing radiation may reduce the quarantine period for transplantation in patients, and their safety is considered excellent.

The ionizing radiation is a very efficient sterilization technique; nevertheless, its deployment is still contested since there is few data on its effects upon the tissue allograft. At IPEN-CNEN/SP, procedures using two sources of ionizing radiation for sterilization of human skin allograft, and to evaluate the skin after gamma and electron beam irradiation, were established. Besides implanting the irradiation services routine to the tissue banks of the country, the researchers developed irradiation devices for human tissues; implanted dosimetry procedures for irradiation processes control; implanted the quality warranty program for tissue irradiation; optimizing type and dose to be supplied according to the preservation process which the tissue was submitted.

The research group has been collaborating with the implementation of quality systems of the Tissue Banks, as well as with experimental and clinical applications of irradiated tissues. Tissue samples were submitted to 15, 25 and 50 kGy doses and the impact of the irradiation on the mechanical properties was evaluated through the analysis of stress-strain and the morphology was accomplished by and ultra-structure studies, immune histology and others histological tests. Also in the current work, the studies using non destructives tests, like optical coherence tomography, OCT, with the Laser Program collaboration, has been carried out.

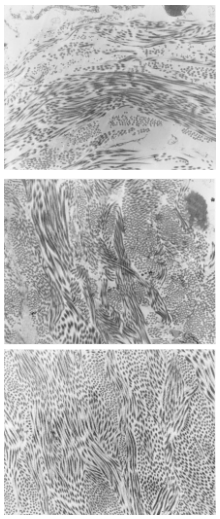


Figure 12. Transmission Electronic Microscopy. Human skin processed in glycerol not irradiated (a); Human skin processed in glycerol gamma irradiated (b) and human skin processed in glycerol submitted to electron beam (c)

Development and production of radioactive sources for brachytherapy application

The number of prostate cancer cases in Brazil is increasing and only a small part of the patients are submitted to brachytherapy treatment using Iodine-125 radioactive seeds. Nowadays, these seeds are imported at a high cost, restricting this application. The local production of these radioactive sources became a priority in order to reduce the problems of prostate cancer management for end users. Such action will permit to spread the use to a larger number of patients. Due to such reasons, the Nuclear Energy Research Institute established a program, in order to produce Iodine-125 radioactive seeds. In brachytherapy, small seeds with Iodine-125 are implanted into the prostate to irradiate the tumor. The Iodine-125 seeds consist of a welded titanium capsule (0.8 mm diameter and 4.5 mm length) containing Iodine-125 adsorbed onto a silver rod. During the project execution, the following methods were developed: the seed core (silver) cutting, the titanium tube cutting, the iodine immobilization through its deposition in silver substrate and the sealing of the seeds through welding process, so that the classification of the seeds, as sealed sources, and the leakage tests can be done according to the international norms. In the moment, the routine production line is settling up. The production line consists in three gloves-boxes. In the first one the Iodine-125 will be adsorbed in the silver core. In the second one, the titanium tube will be sealed. And finally, in the third one, all the assurance tests will be carried out. All the

automation process of the welding glove and the quality control glove are finished.

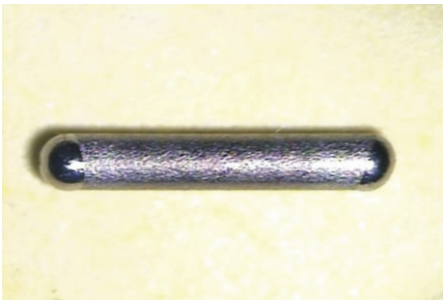


Figure 13. Radioactive seed of Iodine -125

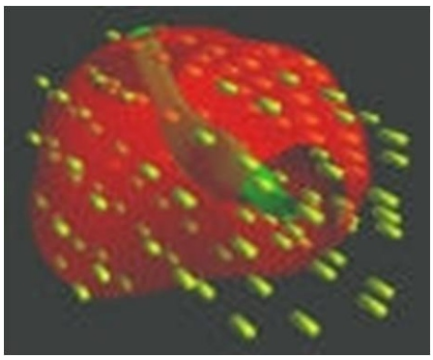


Figure 14. Implanted seeds for prostate cancer treatment

Program Team

Research Staff

Dr. Anna Lúcia C. H. Villavicencio; Dr. Carmen Cecília Bueno Tobias; Dr. Celina Lopes Duarte; Dr. Esperidiana Augusta B. Moura; Dr. José Eduardo Manzoli; Dr. Josemary Angélica Corrêa Gonçalves; Dr. Leonardo Gondim de Andrade e Silva; Dr. Luci Diva Brocardo Machado; Dr. Margarida Mizue Hamada; Dr. Maria da Conceição Costa Pereira; Dr. Maria Elisa C. Martins Rostelato; Dr. Monica Beatriz Mathor; Dr. Nelson Minoru Omi; Dr. Paulo Roberto Rela; Dr. Sueli Ivone Borrely; Dr. Susy Frey Sabato; Dr. Wagner dos Santos Oliveira; Dr. Wilson Aparecido Parejo Calvo; MSc. Carlos Alberto Zeituni; MSc. Célia Marina Napolitano; MSc. Cyro Teiti Enokihara; MSc. Gilberto Carvalho; MSc. Hélio Rissey Nagatomy; MSc. Hiroshi Oikawa; MSc. Yasko Kodama; MSc. Anselmo Feher; Carlos Gaia da Silveira; Claudia Regina Nolla; Cláudio Botelho; Djalma Batista Dias; Edinir Antonio Pereira; Edmilsom Carneiro de Amorim; Eduardo Pavão Araújo; Elizabeth S. Ribeiro Somessari; Fábio Eduardo da Costa; Francisco Edmundo Sprenger; Gilberto da Cunha Albano; Hélio Antonio Paes; João Carlos Gimenez; João Silva; José Aparecido Nunes; José Fernando Condeles; Jose Jorge Ambiel; José Mauro Vieira; Júlio Raposo da Câmara; Manoel Enésio da Silva; Manoel Nunes Mori; Marcos Cardoso da Silva; Paulo de Souza Santos; Pedro Eiti Aoki; Reginaldo Inácio Granieri; Samir Luiz Somessari; Vagner Fernandes; Valdemir Silvério da Conceição; Valdir Cosmos da Silva; Valdir Fanhani da Costa; Vladimir Lepki.

Graduate Students

Adriana Diaz Toni Fabbri; Alessandro de Sá Pinheiro; Alex Terela P. de Castro; Alexandre Bera; Ana Cláudia M. Silva; Antonio Carlos Martinho Junior; Carlos Nabil Ghobril; Cynara Viterbo Montoya; Danilo Cardenuto Ferreira; Eliana Borba Cattaruzzi; Fabiana de Andrade Bringel; Fábio de Camargo; Flávio Thihara Rodrigues; Gilberto Carvalho; Gustavo Bernardes Fanaro; Iara Batista de Lima; José Roberto Soares; Kelly Cristina da Silva Pascoalino; Leila Módanez; Marcelo Augusto A. Bardi; Marcia Almeida Ribeiro; Michel Mozeika Araújo; Rebeca da Silva Cantinha; Renato César Duarte; Rodrigo Crespo Mosca; Sonia Heilman; Thaís Cavalhieri dos Santos; Thaise Cristine Nunes; Túlio Ceramicoli Vivaldini; Vladimir Rogovschi; Amanda Galassi Santillo; Antonio Carlos Nogueira Neto; Bianca da Silva Sufi; Camilo Furgeri; Christian Alexandre Heinz M. Teixeira; Daniele Yoshito; Débora Cristina Salum; Deborah Cristina de Andrade; Drielle Calixto de Ramos; Dymes Rafael Alves dos Santos; Eduardo de Faria Alfaro; Érica Gauglitz; Fernando Augusto Neves Soares; Gabriel Fonseca Alegre; Guaraciaba de Campos Tetzner; Helbert Sanches Franco Costa; Janilson Silva Santos; João Augusto Moura; Jefferson Mendes do Nascimento; Jorge Luiz Pirolla; Juliana Nunes da Cruz; Larissa Andreto Marcato; Letícia Cristina Alves Mesquita; Lúcio César Severiano; Marcel Wilke Caruso; Marcela Cantelli Higa; Marcio Issamu Haraguchi; Maira Milanelo; Mara de Melo Leite Munhoz; Mariana Corrêa de Almeida; Natália Hamada; Paula Bergamin Arthur; Paulo Elígio Pirolla; Renata de Souza Leão Martins; Silvana Cereijido Altran; Tiago Luiz de Almeida; Pablo Soares Damaceno; Priscila Vieira da Silva; Vanessa Bernardo Uehara; Vanessa Miguel Cardoso; Vanessa Silva Granadeiro Garcia; Wanderlei Andrade.

Undergraduate Students

Anna Carolina Ferasin Villarubia; Anna Raquel Petri; Camila Aparecida Pedrozo; Daniela Souza Futro; Diego Vergaças de Sousa Carvalho; Eduardo Santana de Moura; Felipe Theodoro Gonçalves; Felipe Theodoro Kraide; Jéssica Raquel Cardoso; Maria de Fátima Resende Nascimento; Rafael Augusto Modenez Mota; Rebeca dos Santos Cardoso; Rita de Cássia Matos Leme da Silva; Robinson Alves dos Santos; Stéfany Plumeri Santin; Thiago Luiz da Silva Souza.

Honor Mentions and Awards

The paper "Study of physical, chemical, and structural effects caused by ionizing radiation and preservation on human costal cartilage" was the best poster winner on the 5th World Congress on Tissue Banking and 12th International Conference of Asia Pacific Association of Surgical Tissue Banks (APASTB), in Kuala Lumpur, Malasia, 2008. The authors are A. C. Martinho Junior, L. D. B. Machado, M. R. Herson e Monica Beatriz Mathor, the research coordinator.

The researcher Luci Diva Brocardo Machado, has received the Honor Member title of the Thermoanalytical Branch of Hungarian Chemical Society, 2008.

The paper "Development and production of radioactive sources used for cancer treatment in Brazil" (NUKLEONICA 2008, 53, Supplement 2), received the Premium Publication of the Year (2009) award of the Latin American Session of American Nuclear Society. The authors are Maria Elisa C. M. Rostelato, Paulo R. Rela, Carlos A. Zeituni, Anselmo Feher, José E. Manzoli, João A. Moura, Eduardo S. Moura and Constância P. G. Silva.

The paper "Effect of gamma irradiation on the vitamin E content and sensory qualities of pecan nuts (*Carya illinoensis*)" won the Panamerican Bimbo 2010, in Nutrition, Science and Technology of Food. The author is Magda Sinigallia Taipina.