3rd International Conference on

Applications of Radiation Science and Technology

#ICARST2025

Book of Abstracts

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Organized by the
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In Cooperation with the

ISTRA

International Society for Tracer and Radiation Applications

IAEA Headquarters, Vienna, Austria

BOOK OF ABSTRACTS

IAEA-CN-332

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PLENARY SESSIONS

PLENARY SESSION 1

PS01 - Trends in Radiation Science and Technology

IAEA-CN-332/829

Ionizing Radiation in Action: From Crosslinking of Polyethylene to Smart, Green and High-Tech Solutions

ULANSKI, Piotr (Institute of Applied Radiation Chemistry, Faculty of Chemistry, Lodz University of Technology)

Radiation chemistry is a mature field of science. Our understanding of the processes initiated by ionizing radiation – on Earth, in space, in biological systems including our bodies and cells, and in various materials – is much better than was decades ago. Since the 1950's radiation technique has been used on industrial scale, including for crosslinking of polymers, producing heat-shrinkable plastics, sterilization and food processing. While these technologies, due to their distinct advantages, are here to stay, new trends and directions in the application of radiation to the synthesis and processing of materials are emerging. The focus is shifting from the irradiation of commodity plastics to more sophisticated, smart and high-tech materials. Synthetic polymers are being gradually replaced by bio-based materials from sustainable sources; materials combining these two groups of substrates are also of great interest. Radiation techniques are also proving to be useful tools for the synthesis of nanomaterials. Emerging products of radiation processing find applications in various fields, from electronics to agriculture and medicine. Important advances are also being made in radiation-assisted recycling and polymer upcycling. Further progress in radiation synthesis and processing of materials depends on many factors, including our ability to collaborate with other fields of science and technology and draw inspiration from their achievements and new tools and techniques, to cooperate with industry and end-users, but also to promote these solutions and educate new generations of researchers, engineers, entrepreneurs, managers and decision-makers, and also general public, since ultimately these solutions serve to improve the quality of people's lives. The leading and coordinating role of the IAEA is crucial to achieving these goals.

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Track Classification: Track 1: Advanced radiation chemistry and trends in radiation science and technology

IAEA-CN-332/813

Radiation Science and Technology for the Future

PILLAI, Suresh (National Center for Electron Beam Research)

It has been nearly 130 years since X-rays were first discovered in 1895 and almost 120 years since the British patent for its use in food preservation was issued. Today, nuclear technologies touch nearly every aspect of daily life, from our homes to industries worldwide. Despite this, it remains one of the least understood technologies by the public. This gap in understanding has hindered our ability to effectively communicate its immense potential. The future of radiation science and technology is undeniably bright. Encouragingly, public perception is beginning to shift. Retail sales of foods treated with ionizing radiation are at an all-time high globally, and electron beam and X-ray technologies are increasingly replacing radioactive isotopes like cobalt-60 and cesium-137 as safer, more cost-effective alternatives. There is also growing momentum in adopting small modular reactors, using ionizing technologies for vaccine development, to address critical challenges such as electricity, environmental remediation, water scarcity, and food security. Notably, the private sector is now leading the charge in adopting these technologies to meet market demands, while governments create supportive environments for innovation. This shift signals an exciting future where breakthroughs in environmental protection, vaccine development, and industrial applications will continue to unfold. Looking ahead, the role of technology developers will be pivotal. We need more accelerator manufacturers, more compact and user-friendly designs, and innovative approaches that make accelerator technology as accessible as household utilities. A new generation of students and graduates must be inspired to enter this field, equipped with the knowledge and vision to drive progress. Radiation science and technology should not just be confined to scientific conferences and textbooks. Much like information technology today, it should be seamlessly integrated into everyday life, fostering trust in its ability to heal, clean, feed, and shape our world and beyond. The public doesn't need to grasp the intricacies of electron energy or photon penetration—they just need to trust in the transformative power of these technologies to improve lives and sustain our future.

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Track Classification: Track 16: Radiation sciences & technology success stories in support of attaining UN-SDGs

IAEA-CN-332/810

Applications of Radioisotope and NDT Techniques in Industry

PANT, Harish Jagat (International Society for Tracer and Radiation Applications (ISTRA), Vienna, Austria)

Radioisotope techniques have been widely used for troubleshooting and process visualization in industrial systems for more than past six decades. The techniques are broadly classified into two categories i.e. radiotracer and sealed source techniques. In radiotracer applications, a radioactive material in a suitable physicochemical form, similar to that of the process material, is injected into the system at the inlet, and its passage is monitored as a function of time along the system at strategically selected locations using radiation detectors. The monitored radiotracer concentration curves are plotted and information about the hydrodynamic behaviour of the process equipment is deciphered. The commonly carried out applications of radiotracers in industry in include: leak detection in buried pipeline and industrial systems, flow rate measurements, mixing/blending time measurements, residence time distribution in process vessels, wear and corrosion rate measurements and secondary recovery in oil fields.

In sealed source applications, a radiation source encapsulated in a metal capsule is used. The encapsulated radiation source or material never comes directly in contact with either process material or equipment. The penetrating radiation from the encapsulated radiation source are directed at the desired location in the equipment under investigation or material of interest, and the intensity of transmitted or scattered radiation is measured and analysed to obtain information about content of the system or physical properties of the material. The commonly carried out applications of sealed source techniques include radiography, radiometry, tomography and nucleonic gauges. The radiography services to the industry, all over the world, are provided by commercial service companies. In addition to this, some industries or institutions have their own in-house service groups to carry out radiographic inspections. The radiometry is also a non-invasive technique used for blockage detection in pipelines, holdup measurements and troubleshooting in industrial process columns. Several variants of tomography technique have also been developed by various organizations across the world, and the same are being used for industrial troubleshooting and research applications. The technique is also being extended to investigate flow dynamics in industrial process systems. The nucleonic gauges such as level, density, moisture, well logging gauges etc. are manufactured and supplied by commercial companies as part of the process plant. Some of the recent developments and important applications of the radioisotope techniques will be discussed during the presentation with specific case studies.

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Track Classification: Track 9: Tracers and radiotracers applications for studying industrial and environmental processes and flow visualisation

PLENARY SESSION 03
PS03 Panel Discussion on Education and Training in Radiation Science and Technology

IAEA-CN-332/479

Advancing International Integration and Strengthening Responsible Peaceful Uses of Nuclear Applications Through Specialized Curriculums

RAFFO CAIADO, Ana Claudia (Oak Ridge National Laboratory)

The U.S. Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL), in cooperation with the International Atomic Energy Agency (IAEA), has implemented a pivotal educational and collaborative initiative to advance understanding and applications of nuclear technologies for peaceful purposes, including how nuclear technology can be responsibly used for socio-economic development. The first edition of the International School on Peaceful Uses of Nuclear Applications was held in the fall of 2024 and addressed human health and the production of medical isotopes/radiopharmaceuticals, nuclear imaging, and diagnostics. This is a pilot initiative and is expected to be a cornerstone of the cooperative initiative between the IAEA and UT-Battelle, LLC, the managing entity of ORNL, focusing on a diverse array of nuclear applications and technologies and supported by the U.S. National Nuclear Security Administration.

The two-week educational experience was held on ORNL campus and designed to introduce early career professionals from developing countries to specific topics of peaceful uses of nuclear technologies and nuclear derived techniques, broadly defined. The School combined expert lectures, practical exercises, technical visits, and hands-on experiences to acquaint the participants with the latest scientific and technological advances, as well as regulatory infrastructure for the safe, secure, and responsible application of nuclear technologies.

The School will be held every other year, each time addressing a different theme and focusing on a particular aspect of peaceful applications of nuclear technology and techniques that impact socio-economic development. Future themes will include: agriculture and food security; water management and isotope hydrology; environmental monitoring and waste management; and industrial applications and non-destructive testing.

Key components of the collaborative program between DOE/ORNL and the IAEA include: development and delivery of specialized educational courses to equip participants with foundational skills and knowledge pertaining to the peaceful uses of nuclear technologies; sharing of best practices, publications, and experiences to enhance understanding and implementation of nuclear technologies in various sectors; engagement in missions to assess and support country-specific requests, ensuring tailored assistance in the safe, secure, and effective application of nuclear technologies; and collaboration on research initiatives to drive innovation and address global challenges through nuclear science and technology.

This initiative underscores the commitment of both the U.S. Department of Energy and the IAEA to promote the peaceful uses of nuclear technology, which reinforces international cooperation for sustainable development. The International School on Peaceful Uses of Nuclear Applications is not only a platform for knowledge dissemination but also a catalyst for fostering global partnerships and advancing scientific and technological progress.

Participants of the ICARST-2025 conference are invited to learn more about this program, contribute to its development, and explore opportunities for collaboration. This School exemplifies how strategic partnerships and educational initiatives can drive the peaceful and beneficial use of nuclear technology worldwide.

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Track Classification: Track 14: Education and training in radiation science and technology

IAEA-CN-332/800

Challenging Students to Propose Innovative Solutions for the Environnement Using Particle Accelerators

DELERUE, Nicolas (CNRS)

Sometimes having a fresh look on a problem can bring innovative solution. As part of a project funded by the European Commission, we organised challenges for students and young professionals called "Challenge Based Innovation" (CBI). During these challenges the participants are presented with a problem and given high-level seminars on the problem as well as particle accelerator technology and are invited to suggest innovative solutions to solve the problem using accelerator technology. For two consecutive editions the topic was "Accelerators for the environment" and this led to interesting proposals by the participants.

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Track Classification: Track 14: Education and training in radiation science and technology

IAEA-CN-332/811

Skills as the Cornerstone for Nuclear Science, Technologies and Applications Development. France Experience and Commitments.

PERRETTE, Xavier (INSTN (National Institute for Nuclear Science and Technology))

Skills as the cornerstone for nuclear science, technologies and applications development. France experience and commitments. The French workforce involved in nuclear science and its various applications is about 250000 persons. In the middle of the twentieth century, the pioneers who worked on the first ZOE reactor where 100! Since the very early ages of France nuclear journey, skilled people where considered the most precious asset on which to build the safe use of nuclear technologies. This is true for the definition and monitoring of the national regulation, for the engineering of processes, for the construction of nuclear plants and laboratories, for their operation and maintenance, for research, for clinical applications.

The National Institute for Nuclear Science and Technologies (INSTN) was created as the first higher education and training institute with the mission of supporting skills development for nuclear specialists. Since the very beginning, INSTN has been dealing with two main domains: nuclear power and nuclear applications for human health. Today, INSTN is one among many education and training stakeholders in France. As the "CEA internal school, INSTN continues to play a peculiar role in the French nuclear landscape and has strong connections to academia and the industry (GIFEN).

International cooperation is in our DNA. There is a long tradition of skills transfer and capacity building in nuclear power as with China and South Africa for already long-lasting cooperation. Recent opportunities are under investigation with nuclear countries like India, and with many nuclear emerging countries.

Radiation technologies are an asset to deal with food security, water management and human health. Capacity building actions are gathering momentum year after year. Research and development also offer cooperation opportunities. As an illustration, the IMPACT research and education chair aims at developing new biomaterials and innovative manufacturing processes. IMPACT is open to enlarging existing international cooperation.

France has always been a strong support to the IAEA work and is committed to pursue this support. The number of IAEA collaborating centres is an indicator of this commitment: INSTN, ASNR, Art Nucleart, University Paris Saclay.

INSTN has been an IAEA collaborating centre since 2016. Workplans are defined with NA, NE, NSNS. Many training events are implemented yearly with the support of the IAEA, the French Government, and the French nuclear value chain stakeholders.

The certification course on radiotracers residence time distribution and column scanning techniques is an example of such courses. IAEA and INSTN have jointly offered the course each year since 2017 with the support of ISTRA. Almost 150 people from all regions could get certified and implement nuclear technologies to tackle societal challenges and development issues in their home country.

INSTN and IAEA have renewed the cooperation until 2029 and we are confident to jointly provide strong and effective support to Member States engaging their nuclear journey. Our cooperation will become multiparties, involving partners in beneficiary member states. These partners and regional champions will progress towards autonomy in long lasting and balanced partnerships.

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Track Classification: Track 14: Education and training in radiation science and technology.

IAEA-CN-332/835

Engaging Youth Through Innovative Learning Strategies in Nuclear Science Education TC Project

MISHAR, Marina Binti (TCAP-Asia and the Pacific Section 2, IAEA)

The goal of this TC project is to inspire and equip the next generation of nuclear science professionals by making learning more engaging, accessible, and interactive. To achieve this, the project empowers educators with innovative teaching tools and strategies, enabling them to effectively engage students in nuclear science. It promotes co-curricular and extra-curricular activities that allow students to apply classroom knowledge in more creative and engaging ways. Key approaches include the use of the Minecraft Education Platform for immersive learning, the International Nuclear Science and Technology Olympiad to foster academic excellence, and student-produced videos on IAEA strategic initiatives such as NuTec Plastic as part of a creative competition. By strengthening educators' capacity to deliver dynamic learning experiences, the project enhances students' understanding and enthusiasm for nuclear science. The session will highlight best practices and gather insights to further improve educational outreach in the field.

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Track Classification: Track 14: Education and training in radiation science and technology

IAEA-CN-332/827

Training Opportunities at the Nuclear Sciences and Applications Laboratories: Enhancing Access to Capacity-Building

RUIZ DE NEUMAYR, Giselle (NA Laboratory Coordination Group, IAEA)

The IAEA's Nuclear Sciences and Applications (NA) Laboratories play a pivotal role in advancing global capacity-building efforts in the peaceful applications of nuclear technologies. The 12 NA Laboratories, located in Vienna, Seibersdorf, and Monaco, provide hands-on training in key areas, including environmental monitoring, water resource management, food safety and security, human health, and industrial applications.

The training offered at these laboratories enhances technical expertise and promotes the safe and effective use of nuclear technologies. In response to the growing demand for specialized training, the Department of Nuclear Sciences and Applications has developed the NA Training Catalogue - a strategic resource consolidating information on available courses. While the NA Laboratories collectively cover a broad spectrum of nuclear applications, the first edition of the Training Catalogue focuses on the nine Austria-based laboratories, detailing 61 specialized training courses that can be provided by these laboratories. It improves accessibility, coordination, and visibility of training courses, ensuring that professionals can better leverage nuclear technologies to address national and global challenges.

With the printed catalogue expected to be launched around ICARST, this session will introduce its structure and objectives. A digital version will provide a continuously updated and comprehensive resource, along with an annual training calendar.

By strengthening capacity-building efforts, fostering strategic partnerships, and enhancing training accessibility, this initiative directly supports the IAEA's mission to promote the safe, secure, and sustainable use of nuclear and radiation technologies worldwide.

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Track Classification: Track 14: Education and training in radiation science and technology

IAEA-CN-332/830

IAEA E-Learning Courses on Applications of Ionizing Radiation: Exploring Science & Technology

CASIMIRO, Maria Helena (NAPC-Radiochemistry and Radiation Technology Section (RCRTS), IAEA)

The Radiochemistry and Radiation Technology Section (RCRT), from Division of Physical and Chemical Sciences Department of Nuclear Sciences and Applications (NAPC), of the International Atomic Energy Agency (IAEA) is developing a comprehensive e-learning portfolio to advance education and training in radiation technologies. The goal of this program is to offer several courses, such as irradiation of polymers, radiation technologies for environmental applications, cultural heritage applications, non-destructive testing in civil engineering and cultural heritage diagnostics, and others. These courses will be available to participants from all IAEA Member States, fostering international collaboration and capacity building.

The first course, focusing on irradiation of polymers, has already been successfully launched, with additional courses to follow soon. Each course is structured into modular components, many of which are designed to be reused across multiple courses to ensure consistency and efficiency. The platform includes interactive elements to provide participants with both practical and theoretical insights into radiation technologies. Basic science, real-world applications, and targeted assessments further enhance the educational experience.

This e-learning portfolio will also serve as a prerequisite for participants attending various in-person educational programs, fellowships, and other events, ensuring that all attendees arrive with a foundational understanding of the subject matter. With flexible, scalable, and modular training options, we aim to address the diverse needs of professionals, researchers, and students worldwide. This initiative will strengthen global expertise, foster sustainable innovation, and contribute to the safe and effective use of radiation technologies, aligning with the IAEA's mission to promote peaceful and beneficial applications of radiation science and technology.

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Track Classification: Track 14: Education and training in radiation science and technology

PLENARY SESSION 04
PS04 - Flagship Initiatives, Success Stories & Future Perspectives

IAEA-CN-332/806

Radiation-Assisted Recycling of Plastic Waste – From Vision to Laboratory Prototypes

GOHS, Uwe (STeRICon Gohs)

Radiation technologies fulfil the key principles of "green" chemistry and offer a wide range of possibilities in the processing of plastics via the controlled cleavage or formation of chemical bonds. The radiation technologies have been comprehensively proven in the production of high-performance polymeric materials and in the recycling of some plastic waste. Thus, radiation-assisted recycling technologies provide powerful opportunities for environmental rehabilitation, resource sustainability and circular economy. The vision of transferring landfills into the feedstock of the future by sustainably effective radiation-assisted recycling methods was first formulated at the IAEA Consultancy Meeting on "Emerging Application on Advanced Materials (2018, Vienna) and elaborated in detail at the Technical Meeting on the "Recycling of Polymer Wastes by Radiation (2019, Vienna).

To promote the development of scalable technologies for radiation-assisted recycling of plastic waste, the IAEA launched the coordinated research project on "Recycling of Polymer Waste for Structural and Non- Structural Materials by using Ionizing Radiation" in 2020. In addition, well-assessed priority areas such as radiation-assisted mechanical recycling for production of rubber particle-filled composites and wood-plastic composites for use in the construction industry and polytetrafluoroethylene micro-powder for use as a high value additive in paints, oils, greases and polymers as well as radiation-assisted chemical recycling have been proposed.

Currently, 55 Member States are collaborating in three regional technical cooperation projects to develop novel radiation-assisted recycling processes for plastic waste. To encourage and support all participating Member States in the development of in-line radiation technologies as preferred production methods for economic and efficient environmental solutions, the IAEA has developed the "Guideline for Integrating Electron Beam Technology into Plastic Waste Recycling". Member States and the IAEA use this guideline and the integrated tools for continuous monitoring of the project status by assessing the economic and environmental potential as well as the technology readiness level. This presentation summarizes the exciting journey from the vision of transferring landfills to the feedstock of the future, through the obstacles and gaps, to the laboratory prototypes produced by sustainable effective radiation-assisted recycling methods.

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Track Classification: Track 4: Advanced materials: from fundamentals to applications

IAEA-CN-332/838

Irradiation Technology: A Key Driver for Food Safety and Economic Advancement

MEJRI, Arbi (High dose dosimetry Laboratory. National Center for Nuclear Sciences and Technologies)

Irradiation technology has emerged as a pivotal innovation in the realm of food safety and economic advancement. This process involves exposing food products to ionizing radiation, effectively eliminating harmful pathogens, parasites, and spoilage organisms, thereby extending shelf life and ensuring consumer safety. The application of irradiation not only enhances food safety by reducing the risk of foodborne illnesses but also plays a significant role in minimizing food waste, a critical issue in global food security. Furthermore, the economic implications of this technology are profound; it opens new markets for irradiated products, supports agricultural sustainability by reducing losses, and fosters international trade by meeting stringent safety standards. As consumer awareness and demand for safe, high-quality food continue to rise, irradiation technology stands out as a key driver in promoting public health and stimulating economic growth within the food industry. This abstract highlights the dual benefits of irradiation technology, emphasizing its essential role in shaping a safer and more sustainable food system.

Keywords: irradiation technology, food waste, safety, economic growth

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Track Classification: Track 12: Recent radiation processing applications in food and agriculture

IAEA-CN-332/837

Outsanding Results and Impacts of the Regional Project in Europe

KOVÁCS, Andras (HUN-REN Centre for Energy Research)

Radiation processing dates back to the mid-fifties of the previous century and has become a worldwide used standardized technology by the turnover of the millennium. It involves (1) radiation sterilization of single use medical devices and pharmaceuticals to save human health, (2) food irradiation to achieve better quality food and to avoid food losses, (3) production of advanced high quality materials to improve quality of life, (4) protection of cultural heritage objects and archaeological and historical relics helping world's population to enjoy art treasures in the future, (5) environmental preservation for the treatment of wastewater, flue and greenhouse gases and (6) the recycling of plastic waste.

Due to the varying technical level of this technology worldwide, the IAEA decided to initiate a TC project in the European region twenty years ago to assure standardized radiation technology based on the existing scientific and technical knowledge, experience and infrastructure. This project involved extensive IAEA support from introducing radiation applications through supporting the extension of existing technologies up to maintaining the ongoing high quality radiation processes. The original project started in 2005 with the participation of 10 Member States establishing a cooperative network and utilizing the strong technical, administrative and financial support of the IAEA. By now 27 Member States take part in the program, which involves technological development, technical assistance and human capacity building covering training courses, workshops, scientific visits, national seminars, dosimetry intercomparison exercises and IAEA supported participation at international conferences.

During the past two projects (RER1021 and RER1024) significant attention was paid (1) to quality assurance of the irradiation procedures, (2) to establish EB facilities in the MSs, (3) to produce advanced materials and (4) to introduce environmental protection technologies. Concerning QA/QC the aim was the use of standardized dosimetry methods and procedures in radiation process validation and control. To achieve these goals in the gamma and electron beam irradiation facilities in operation in the European IAEA TC Member States, a calibration verification procedure, followed by a dosimetry intercomparison exercise was carried out in the frame of the IAEA RER1021 program. Significant improvements were observed with respect to the dose control in the relevant irradiation facilities as compared to the previous exercises.

Strong efforts are being made in MSs having mostly experience in gamma radiation processing to introduce electron irradiation technologies in strong cooperation with the IAEA due to its carefully designed initiatives and preparations with the EB producers and the potential future users. The successful execution of this project, based on successful IAEA based regional and interregional cooperation, would result in a tremendous step forward in applying EB radiation technologies worldwide. The wider use of EB technologies in traditional radiation processing would not only mean a technological and economical boost, but it could also contribute to the realization of more effective radiation based environmental protection technologies.

The most important outcomes of these projects will be shown together with the longer term perspectives concerning the potential future regional and interregional cooperation programs.

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IAEA-CN-332/579

NDT Civil Structures Capabilities Development in the Latin America and the Caribbean Region with the IAEA's Support

BELINCO, Cesar (CNEA)

Latin America and the Caribbean have obtained many benefits from the IAEA Project: "Advancing Non-Destructive Testing Technologies for the Inspection of Civil and Industrial Structures".

The participating countries were Argentina, Bolivia, Brazil, Chile, Costa Rica, Cuba, Dominican Republic, Ecuador, Mexico, Peru, Uruguay and Venezuela. It was a 4-year project, started in 2018.

The main objectives of the project were:

• To support the establishment of accredited ISO 9712 certification systems in new countries, adding to the original list, at least four more countries, with established systems, for the end of the Project (2021).

• To increase the certification methods in those countries that have ISO 9712 certification systems available (Argentina, Brazil & Mexico), including UT TOFD & PA and Digital Radiography.

• To create Sub-Regional Centers on NDT for civil infrastructure to perform diagnostic under emergencies (earthquakes, floods, etc.) and to train and certify specialists from the region in NDT methods and techniques for civil infrastructure.

• To strengthen the neutronic NDT techniques in those countries that have that technology available.

• To create an NDT network of countries to collaborate in training, certification and to share experiences (with the support of the Pan American Federation of NDT).

In the present paper, the main activities conducted in this project are summarized, along with the infrastructure developments in the region, especially in the Civil Engineering NDT field, and the contribution of Argentina to the project.

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Track Classification: Track 16: Radiation sciences & technology success stories in support of attaining UN-SDGs

IAEA-CN-332/100

Improvement of Dosimetry Facilities for Radiation Processing Industry in Asia Pacific Region Through IAEA Regional Cooperation

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Background: Radiation processing industry based on gamma radiation, electron beam (EB) and X-Ray technology has gained significant attention for its application in various fields, including sterilization, wire cable crosslink, food preservation, medical devices manufacturing, and electric & electronic (E&E) enhancement. Accurate dosimetry system is a way to check the achievement of the irradiation process on a product which is essential to ensure its effectiveness. However, to establish and maintain the robust dosimetry facilities means requires expertise and resources. In this context, the regional cooperation offered by RCARO and the International Atomic Energy Agency (IAEA) provides a way to improve the dosimetry capabilities for radiation processing industry in the member states (MS) of Asia Pacific region.

Methodology: There are three types of MSs in term of capacity of their radiation processing facilities, namely advanced, intermediate and beginner. This study explores the potential improvement of dosimetry facilities for radiation processing operators in the intermediate and beginner MSs of Asia Pacific region through IAEA regional cooperation. The approach involved a review of current dosimetry practices, infrastructure evaluation and capacity-building initiatives sponsored by the IAEA in the region. Surveys and interviews were conducted with intermediate and beginner MSs to identify specific needs and challenges faced by them.

Results: From the study, two main factors are discovered from the existing state of dosimetry facilities in the intermediate and beginner MSs, which are the need for capacity-building and infrastructure advancements to meet international standards. Analysis of the IAEA supported activities indicates opportunities to exchange knowledge and provide training and technical assistance in dosimetry. Collaboration with the IAEA offers access to best practices, guidelines, and experts, that improves the quality management framework for radiation processing facilities.

Conclusion: Through IAEA/RCA regional cooperation, the intermediate and beginner MS can overcome the challenges by leveraging the expertise and resources within and outside the region. Funded by the IAEA, the capacity-building activities, knowledge exchange programs, and technical assistance through expert mission, contribute to the dosimetry capabilities enhancement and ensuring the efficacy of the irradiation processes. With full commitment and collaboration, the MS of the Asia Pacific region can strengthen its position in utilizing the radiation processing technology for various industrial and healthcare applications, contributing to economic development and public health improvement.

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Track Classification: Track 14: Education and training in radiation science and technology

ORAL ABSTRACTS

STREAM A

Science and Technological Aspects of Radiation Chemistry

IAEA-CN-332/788

Radiation Technologies for Environment Protection - Turning Rubbish into a Resource

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The paper refers to two main categories of waste are solid waste and wastewater, including sludge when it is reprocessed. Here we focus on MSW, which is the waste generated by householders, retailers and other small businesses, public service providers, and other similar sources. Managing MSW is generally a local service and is commonly the responsibility of local government. The same is true for municipal wastewater. Wastewater treatment plays a very important role in striving to reach internationally agreed UN sustainable development goals. The important fact is that a great amount of organic matter is generated in both streams and may be applied as an energy and fertilizer source. In present times, with increasing emphasis on circular economies. The targeted resources are water, biogas, and sludge, organic residuals containing nutrients and elements needed by plants (nitrogen and phosphorus). Municipal wastewater treatment plants (WWTPs) are considered resource recovery facilities. The use of untreated sludge or wastewater in agricultural activities poses a serious risk of bacterial and parasitic infection in human beings. One of the difficult problems to be solved is related to drugs present in wastewater at relatively low concentrations. One of the difficult problems to be solved is related to drugs present in wastewater at relatively low concentrations.Wastewater treatment systems are seen as major polluters not only of antibiotics but also of antibiotic-resistant microorganisms and resistance determinant genes. They are cumulated in sludge, which contains antibiotics, antibiotic resistance genes (ARGs), and antibiotic-resistant bacteria (ARBs) and comprises parasites and their eggs. To overcome such issues, the application of ionizing radiation processing, especially electron beam (EB), can be considered a promising method. Using ionizing radiation to clean up sewage sludge can make it suitable for use in agriculture.Sludge is a substrate for biogas plants using anaerobic fermentation in a two-stage system, and a generator provides electricity for an accelerator. Another component of the MSW is polymeric materials (plastics and rubbers), which comprise a steadily increasing proportion of the municipal waste going into landfills. Due to the ability of ionizing radiation to alter the structure and properties of bulk materials and the fact that it is applicable to essentially all polymer types, irradiation holds promise for impacting the polymer waste problem. Three main possibilities for use of radiation in this application are: 1) enhancing the mechanical properties and performance of recovered materials or material blends, principally through crosslinking or through surface modification of different phases being combined; 2) treatment causing or enhancing the decomposition of polymers, particularly through chain scission, leading to recovery of either low molecular weight mixtures or fine powders for use as chemical feedstocks or additives; 3) production of advanced polymeric materials designed for environmental compatibility. These and other opportunities are discussed in the paper.

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R.L.Clough Polymer Recycling; Potential Application of Radiation Technology.Organic Materials Department Sandia National Laboratories, M.S. 1407, Albuq., N.M., 87185.

IAEA-CN-332/366

On the Competition Between Cross-Linking Agents and Anti-Oxidants in Radiation-Curable EVA-Blends of Technological Importance

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Radiation cross-linking is a well-established method to improve the performances and customize radiation-curable plastic-based insulating sheaths produced for various industrial sectors. In spite of their use for more than 50 years in the wire and cable industry, there is still a need for a deeper understanding and better control over the different stages of the fabrication process that include the selection of the plastics fillers and additives, the search for optimized composition, the determination of efficient conditions for blending, shaping and final radiation processing. The precise quantification by complementary analytical methods of the amount of extractable additives such as cross-linking agents and stabilizers was performed in plastic blends at various stages of their preparation and after electron beam treatments at doses up to 300 kGy. The competing effects of cross-linkers and stabilizers in EB-irradiated model EVA blends will be discussed more specifically. In particular, it was shown that: (i) stabilizers do not inhibit the curing process but have a retarding effect on the consumption of cross-linkers, (ii) type I crosslinkers (acrylates) are initially more reactive than those of type II (allyl derivatives) and (iii) the dose-dependance of the consumption of primary stabilizers (phenol-type) is stronger that of secondary anti-oxidants. The analytical data recorded from model formulations at various stages of their preparation and radiation curing can be correlated to the evolution of various thermophysical properties of practical interest, as well as to thermo-oxidative ageing.

IAEA-CN-332/815

Current Status of Radiation Processing Techniques for Functionalization of Polymeric Materials

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The development of efficient polymer modification techniques is important from industrial, environmental, and economic perspectives. The processing technology of polymer materials using radiation is not as costly as generally imagined, and the resulting materials are often of high quality. In addition, radiation methods do not leave residues derived from metal catalysts after polymerization and can be sterilized at the same time. This advantage allowed us to quickly develop materials for health applications, such as water purifiers for Cs removal and masks for COVID-19. And these achievements suggest that radiation-based technologies can be a powerful tool in pandemic situations. Meanwhile, the shortage of manpower and researchers in materials development has recently led to informatics-based research. Although these methods may be effective in designing new functional groups, predictions often fail to synthesize optimal compounds. Therefore, it is still important to establish techniques that enable early design of realistic materials. In this presentation, we will introduce radiation processing techniques and their analytical methods that are excellent for improving existing polymeric materials.

IAEA-CN-332/338

Physico-Chemical Properties of Catalysts for the Mineralization of Sulfamethoxazole in a High Ionizing Radiation Treatment

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Photocatalysts with AOP have been used for the decomposition of recalcitrant organic pollutants. However, several technical issues associated with energy band gap of catalysts still limit the practical application of photocatalysts with sunlight and UV. Some catalysts with large energy band gap have been successfully used in the radiocatalytic systems using gamma radiation and electron beam. However, there has been little systematic studies for an appropriate radiocatalyst in the radiation treatment. Kinetic studies were conducted to evaluate the physicochemical properties (energy band gap, conduction band, valence band, electron mobility and stability) of catalysts suitable for the radiocatalytic system using high energy sources and the radiocatalytic oxidation performance for sulfamethoxazole. Unlike the photocatalytic process (activating the catalysts with energy band gaps lower than 6.2 eV), the radiation system using electron beam and gamma ray could activate comparatively large energy band gap (< 1,240 keV) and showed a good oxidation performance for TOC removal of sulfamethoxazole. Metal oxide catalysts showed excellent stabilities (self-degradation lower than 0.01 % at 50 kGy) due to their high thermodynamic stability. The radiation technology has a wide range of selection for catalysts, and can be an effective alternative-treatment system for the mineralization of recalcitrant organic chemicals.

IAEA-CN-332/270

PFAS Remediation: High-Energy Electron Beam Treatment for Water and Filter Matrices

A. Smeets (Ion Beam Applications) – Belgium

PFAS, or per- and polyfluoroalkyl substances, are highly stable chemicals used in various products due to their unique properties. Their environmental persistence and health risks are major concerns. Traditional remediation methods, like activated carbon filters, effectively adsorb PFAS but do not destroy them, requiring thermal treatment for regeneration, which is costly and environmentally taxing. Exposure to high-energy electron beam (E-beam) looks like a promising alternative treatment.
E-beams break down PFAS through interactions with water (water radiolysis), generating free radicals and secondary electrons that initiate PFAS degradation in by-products including PFAS short chains. This method promises efficient PFAS degradation at ambient temperatures, reducing harmful by-products and environmental impact. However, a high dose treatment as well as the use of water together with carbon looks mandatory. E-beam degradation of PFAS needs to be better understood and optimized in order to offer a sustainable and efficient alternative way of regenerating PFAS-contaminated filters.
The study evaluates the effectiveness of e-beam treatment on water and activated carbon filters, examining factors like dose, dose rate, pH, dissolved oxygen and PFAS concentration. The process of destroying PFAS by irradiation is complex and includes different degradation pathways. The study includes also the development of a radio-kinetic model based on radiation induced degradation reaction mechanisms as well as on experimental results allowing the prediction of optimal treatment conditions.

IAEA-CN-332/570

Radiolytic Degradation of Two Emerging Pollutants: Kinetics Comparison, Mechanism Pathways, Toxicity Assessment and Effect Parameter Studies

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Due to the climate change, several countries have been experiencing droughts these years. This drought has a negative impact on water for agriculture and domestic uses. Saving water is becoming an emergency. Effective methods are becoming necessary to remedy water problems in the long term. Gamma irradiation, as an advanced oxidation method, has been providing a good response to wastewater treatment over this decade.
The studies of the gamma irradiation of two emerging pollutants: Myclobutanil, a herbicide, and Fluoxetine, an antidepressant, showed that doses greater than 1 kGy could destroy these compounds and their intermediates. The degradation of these molecules followed a pseudo-first-order kinetic, as reported in the majority of the studies. The by-products were identified by the LC-MS/MS technique to purpose a possible degradation pathways. The toxicity study was conducted to test the effect of one pollutant and its by-products on rats ; no increase in toxicity was observed. To study the effects of operational parameters by gamma irradiation, Box-Benhken response surface methodology was applied as an experimental design. The ionizing radiation system provides a promising alternative solution for the removal of pollutants for industrial applications that guarantees the high quality of the effluents prior to their discharge to the environment or for agriculture reuse.

IAEA-CN-332/791

Radiation Chemistry as a Tool to Accelerate and Understand Ageing Processes in Lithium-Ion Batteries

S. Le Caër (CNRS, Université Paris-Saclay, CEA Saclay) – France

Understanding ageing phenomena in batteries is crucial to the design of efficient, safe, and reliable energy storage devices as a part of the current green energy transition. Among the different aspects of a battery, the behavior of the electrolyte is a key parameter. However, studying battery ageing processes is costly in terms of technical and human resources. In this context, we have demonstrated the value of radiation chemistry (or radiolysis) for accelerating electrolyte degradation processes, and thus gaining a better understanding of them. In addition, radiation chemistry enables time-resolved experiments to be carried out, giving access to the nature and kinetic behavior of the first species produced during radiation/matter interaction.

We will show here that radiation chemistry is a valuable tool to screen the behavior of various electrolytes within a few hours. Indeed, the rapid radiolysis of electrolytes leads to the production of the same gases as produced by electrochemical cycling (i.e., H_2, CO_2), and the ranking of electrolytes by their H2 production yields similar performance ratings to those reported in the literature. Therefore, this direct comparison of electrolytes alone, lasting a few hours without any manufacturing operations such as the fabrication of electrochemical cells, demonstrates that controlled irradiation makes it possible to predict battery cycling behavior. Additionally, mechanisms involved in the degradation processes of different electrolytes can be proposed.

Finally, radiolysis can also significantly accelerate calendar ageing phenomena. Using electrochemical impedance spectroscopy (EIS), we studied symmetrical coin cells containing an electrolyte between two identical electrodes, with or without various additives. We will show here that a few hours of irradiation are enough to simulate the equivalent of several weeks of calendar ageing.

AEA-CN-332/817

Application of Gamma Irradiation for the Preparation of Pseudocapacitive Supercapacitor Materials

G. Wu, K. Zhang (Shanghai Institute of Applied Physics, CAS) – China

Supercapacitors are characterized by its rapid charge-discharge capabilities, exceptional cycling stability, and high energy densities, making them essential in applications such as portable electronics, electric transportation, power grids, and renewable energy storage. They are primarily classified into electrical double-layer capacitors (EDLCs) and pseudocapacitors (PCs), with the latter utilizing Faradaic redox reactions to achieve superior energy storage performance [1-3]. PCs, typically based on transition metal oxides or conducting polymers, store energy through the fast and reversible process of Faradaic charge transfer at the electrode surface. This mechanism leads to higher energy density, greater energy storage capacity, and improved cycling stability.

Transition metal oxides (TMOs) have attracted significant attention as pseudocapacitive materials due to their high theoretical capacities and multiple oxidation states. However, challenges such as limited electrical conductivity and suboptimal ion diffusion hinder their practical application. To address these issues, defect engineering—specifically the introduction of oxygen vacancies—has been employed to enhance electronic conductivity and electrochemical activity [4-6]. Moreover, anchoring metal single atoms onto TMOs has been shown to facilitate charge transfer and introduce new active sites, thereby improving overall performance.

Conductive metal-organic frameworks (MOFs) have emerged as promising materials for supercapacitor electrodes, particularly for negative electrodes, due to their tunable porosity, high surface area, and intrinsic conductivity. Their structural versatility allows for the design of materials with tailored electrochemical properties, thereby enhancing charge storage and transport capabilities.

Ionizing radiation techniques, such as gamma irradiation, offer a unique approach to material synthesis and modification under ambient conditions. These techniques generate reactive species capable of inducing in situ defect formation and structural modifications, thus enhancing the electrochemical properties of materials. For example, gamma irradiation has been utilized to introduce oxygen vacancies in TMOs, resulting in improved pseudocapacitive performance. Similarly, the structural integrity and conductivity of MOFs can be enhanced through controlled irradiation processes [7-12].

This study investigates the potential of gamma irradiation technology in the fabrication and modification of pseudocapacitive materials, focusing on transition metal oxides for positive electrodes and conductive MOFs for negative electrodes. The synergistic effects of these materials, processed through ionizing radiation techniques, are evaluated to develop high-performance supercapacitor electrodes with enhanced energy storage capacities, rapid charge-discharge rates, and prolonged cycling stability.

IAEA-CN-332/332

Radiation Processing of Biomaterials as a Sustainable Solution for the Universal Health System

A. Lugão (Instituto de Pesquisas Energéticas e Nucleares, IPEN) – Brazil

The sustainable development goal 3 – "ensuring healthy lives and promoting well-being for all at all ages" – cannot be met without the development of affordable advanced technologies. However the focus of the health industry is the development of extremely sophisticated solution at the highest possible cost. The increase in the total health care cost as percentage of GDP from 1960 to 2010 increased from 5% to 17% of the GDP for the USA. For most European countries the increase was from 4% to 9% (1). The expenses on retail drugs per capita in the USA were estimated at 100 USD in 1960 and jump to 1100 in 2020.

We developed at IPEN a hydrogel wound dressing with silver nanoparticles using simultaneous crosslinking and sterilization, based on the classical process developed by prof. Janusz Rosiak. However, a new simultaneous step was added for the hydrogel with silver nanoparticles, ie. the reduction of the silver ions accomplished by reducing species of water radiolysis (H^+, eaq^-). This so called one pot process allowed the production of large sheets of hydrogel by a fraction of a USD. These dressing were transparent to allow the inspection of the wound, soft and flexible to reduce or eliminate the pain and mechanically strong to allow easy manipulation by the nurses. The use of simultaneous processes, i.e., synthesis and sterilization in simultaneous way is undoubtedly a solution to reduce the cost of production. These dressing specially prepared were used recently to treat wounded animals rescued from the big flood that hit the south of Brazil as shown in figure 1.
Figure 1. Rescued horse with immersion syndrome and hydrogel specially developed for those animals.

IAEA-CN-332/723

Influence of Ionizing Radiation on Hydrophilic Polymers Irradiated In Solid State and Aqueous Solutions

S. Kadlubowski (Lodz University of Technology, Institute of Applied Radiation Chemistry – Poland), P. Ulanski (Institute of Applied Radiation Chemistry, Faculty of Chemistry, Lodz University of Technology – Poland), T. Balogh (Instituto de Pesquisas Energéticas e Nucleares, IPEN – Brazil)

Radiation is an effective and established tool to sterilize medical and healthcare products including a wide range of single-use medical products and devices. Sterilization is mostly done using gamma sources, however a transition to accelerator-based sterilization is being observed. Lack of the knowledge of radiation effects on polymers for electron beam is one of the reasons to impede the spreading use of these technologies.

Increasing need of the knowledge of sterilization or re-sterilization of medical devices is the other reason to continue a detailed research study on influence of ionizing radiation on polymer-based products used in medicine.

The purpose of this work is to expand our understanding of radiation effects on selected polymers and polymeric materials commonly used in medical devices by comparing gamma and electron beam irradiation. The analyzed polymers were: poly(ethylene oxide), poly(N-vinyl-2-pyrrolidone) and poly(acrylic acid). Basic physico-chemical properties of unirradiated material have been examined with the use of static- and dynamic light scattering as well with gel permeation chromatography (triple detection: multiangle light scattering, refractive index and viscosity have been used to obtain absolute values). The next stage of studies was devoted to comparison of effect of irradiation on selected polymers with three different dose rates (gamma and electron beam irradiation), both in a solid state and in aqueous solution. In case of irradiation in the solution saturation with inert gas (argon) has been also analyzed.

IAEA-CN-332/654

Gamma Irradiation Synthesis of rGO-Ni/NiO Nanocomposites with Supercapacities Properties

S. Sakata, D. V. da Silva, K. Oliveira, M. Duarte, R. N. Faria Jr (Instituto de Pesquisas Energéticas e Nucleares, IPEN) – Brazil

Introduction

Reduced graphene oxide/nickel (rGO-Ni) nanocomposites possess remarkable electronic characteristics, and exhibit promises for diverse applications, notably in the domain of supercapacitors. As a result, in the last few years, several works regarding the synthesis of rGO-Ni nanocomposites, such as chemical reduction or thermal reduction, have been reported in the literature. However, these traditional methods usually comprise toxic chemical reducing reagents or require high temperatures and pressure. In the present study, we describe an attractive and green process for obtaining rGO-Ni nanocomposites using gamma radiation, without the use or generation of toxic residues and undesirable products.

Methodology

The GO dispersion in the presence of $Ni[(NH_3)_6]\ Cl_2$ was subjected to gamma radiation, in an alkaline solution of deionized water/isopropanol (1:1), at doses of 80 kGy and a dose rate of 8,. kGy/h , in a N_2 media to obtain rGO-Ni. XRD results confirmed that the Ni_2^+ and GO were simultaneously reduced by the gamma irradiation process. X-ray photoelectron spectroscopy (XPS) revealed the oxidation of the metal Ni on the GO surface. The morphology of the rGO-Ni was evaluated by TEM, and it was observed nickel nanoparticles evenly distributed over the rGO sheets. To study electrochemical behavior, screen-printed electrodes (SPE) were modified with the rGO and rGO-Ni and the cyclic voltammograms (CV) showed reversible behavior for all samples in the presence of $K_3[Fe\ (CN)_6]$. All rGO-Ni/SPE showed a remarkable enhancement in the anodic peak currents (Ipa) and electroactive area in comparison with the bare SPE. Moreover, it was observed that a directly proportional relationship between Ipa value and the radiation dose applied on nanocomposite synthesis. The CV curves of rGO-Ni prepared at 80 kGy exhibited better pseudocapacitive behavior compared with the rGO in same condition. The maximum specific capacitance of rGO-Ni was ~85 $F \cdot g^{-1}$ which is higher than that of rGO (~8 $F \cdot g^{-1}$) at the same scan rate.

Conclusion

These findings point out the potential applications of rGO-Ni nanocomposites in devices such as supercapacitors.

IAEA-CN-332/197

Preparation of Silver-Copper Nano/Diatomite by Irradiation Method in Order to Treat the Pathogenic Bacteria for Catfish (Pangasianodon hypophthalmus)

D. Nguyen (Center of Nuclear Technology, Vietnam Atomic Energy Institute), C. Thuy Nguyen (Research Institute for Aquaculture No.2 (RIA 2)), H. Thi Truong (Van Lang University), L. Kim Nguyen, T. Chi Nguyen (Research and Develoment Center for Radiation Technology) – Vietnam

Nanocomposites of Ag-Cu nanoparticles/DA-CTS were synthesized by electron beam irradiation using chitosan as a binder. The antibacterial activity of Ag-CuNPs/Diatomite-CTS nanocomposites was investigated against Edwardsiella ictaluri and Aeromonas hydrophila bacteria. The characteristics of Ag-Cu nanoparticles/DA-CTS nanocomposite were determined by various analytical techniques. The TEM showed that the formation of particles on a Diatomite substrate with, the higher the concentration of metal ions, the larger the size of the particle. At a 1000 ppm concentration (Ag^+, $Cu_2{}^+$), the size of the particle is determined to be about 42 nm and gradually decreases until the metal ion concentration reaches 250 ppm, at which point the average size of the particle is about 6 nm. Inductively Coupled Plasma: Atomic Emission Spectroscopy showed that the addition of chitosan to the DA matrix enhanced the coordination of metal nanoparticles on the DA matrix. The concentration of chitosan at 1.5% is suitable to improve the coordination of AgNPs and CuNPs on DA. The minimum bactericidal concentration (MBC) of Edwardsiella ictaluri and Aeromonas hydrophila was determined to be 10 and 20 mg/kg, respectively. Compared to AgNPs/Diatomiate-CTS and CuNPs/Diatomite-CTS nanocomposites, Ag-CuNPs/Diatomite-CTS nanocomposites were most effective against the catfish pathogens Aeromonas hydrophila and Edwardsiella ictaluri. This is a promising material for safe and efficacious decontamination in an aquaculture environment.

IAEA-CN-332/462

Low-Energy Electron Beam Modification of Electrospun Bioactive Non-Woven Nanofibers from Silk Fibroin Polypeptide and its Plends with Plant Extracts

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Low-energy electron beam (LE-EB) irradiation process is a practical and green method for modification of non-woven nanofibrous thin membrane in a finishing process. A dual mild process using an aqueous system for electrospining and LE-EB induced chemical reaction have been proposed for fabrication of the strengthened silk-fibroin/polyehtylene oxide (SF/PEO) non-wonven nanofibers through radiation-induced cross-linking mehcanism [1]. In addition, the antioxidant activity of SF can be enhanced by electron beam irradiation [2]. In the present work, the fabrication of plant extract, e.g., turmeric (Curcuma longa L.) incoperated non-woven SF/PEO nanofibers and the modification of their structures using LE-EB are proposed as new scientific and technological challenges. Different ratios of SF/PEO/turmeric and the electrospining parameters were varied and optimized to obtain the uniform nanofibrous membrane. The morphologies of the SF/PEO/turmeric nanofibers was observed by SEM and the nanofiber diameter was ~200 nm. The cross-linked structure of the nanofibers was created by LE-EB (180 kV) irradiation with the absorbed doses in the range of 0-200 kGy under N_2 atmosphere. The maximum gel fraction was ~70% at the dose of 50 kGy. The swelling ratio of SF/PEO/turmeric nanofiber was ~20 g/g. Chemical functional groups, thermal properties and viscoelastic properties of SF/PEO/turmeric nanofibers were characterized by FT-IR, TGA, DSC, Rheometer. The mechanical properties of SF/PEO/turmeric nanofiber were significantly improved after LE-EB irradiation. The turmeric plant extract release and bioactive characteristics of the SF/PEO/turmeric nanofibers were assessed for healthcare applications.

IAEA-CN-332/692

The Role of Electron Beam Irradiation in Tailoring Porous Carbon Fibers for Enhanced Battery and Energy Storage Applications

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Radiation cross-linking is a well-established method to improve the performances and customize radiation-curable plastic-based insulating sheaths produced for various industrial sectors. In spite of their use for more than 50 years in the wire and cable industry, there is still a need for a deeper understanding and better control over the different stages of the fabrication process that include the selection of the plastics fillers and additives, the search for optimized composition, the determination of efficient conditions for blending, shaping and final radiation processing. The precise quantification by complementary analytical methods of the amount of extractable additives such as cross-linking agents and stabilizers was performed in plastic blends at various stages of their preparation and after electron beam treatments at doses up to 300 kGy. The competing effects of cross-linkers and stabilizers in EB-irradiated model EVA blends will be discussed more specifically. In particular, it was shown that: (i) stabilizers do not inhibit the curing process but have a retarding effect on the consumption of cross-linkers, (ii) type I crosslinkers (acrylates) are initially more reactive than those of type II (allyl derivatives) and (iii) the dose-dependance of the consumption of primary stabilizers (phenol-type) is stronger that of secondary anti-oxidants. The analytical data recorded from model formulations at various stages of their preparation and radiation curing can be correlated to the evolution of various thermophysical properties of practical interest, as well as to thermo-oxidative ageing.

IAEA-CN-332/534

Nano-Magnetic Bioadsorbents for REEs Recovery via Gamma Irradiation Assisted by ILs

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Rare Earth Elements (REEs) are a set of 17 critical metallic elements with unusual properties (fluorescence, conductivity, catalytic and magnetic), making them an essential part of a large number of high-tech devices. Among many others, REEs find applications in computer hard drives, fluorescent lights, catalysts (petroleum and automotive industries), super magnets (in generators, cars, electrical engines), flat screens and batteries [1].

The increased use of REEs have led to higher environmental discharges and, consequently, greater human exposure, making them emerging pollutants that lack effective recycling methods [2,3]. Additionally, due to the scarcity of its natural resources, REEs are becoming a geopolitical issue, with a few countries controlling over 90% of the market. This highlights the need for efficient methods to recover REEs from waste products and from municipal, industrial and mining wastewaters, paving the way for effective circular economy practices.

Aiming to create effective nano-magnetic bioadsorbents for recovering these elements from low-concentration aqueous solutions, efforts are underway to integrate magnetic nanoparticles (MNPs) into natural polymers using gamma irradiation assisted by ionic liquids (ILs). The use of ILs takes advantage of its symbiotic role: i) assisting the polymer crosslinking and, ii) ability to interact with metallic ions. Chitosan, magnetite (Fe_3O_4) and the IL 1-butyl-3-methylimidazolium acetate ([BMIM][Ac]) are being used as precursors for preparation of the nano-magnetic bioadsorbents by gamma irradiation at doses ranging from 2 to 15 kGy using a dose rate of 0.5 $kGy.h^{-1}$.

Materials were characterized through FTIR, TGA, ICP-MS, SEM and the materials adsorbent efficiency was evaluated by XRF and UV-VIS spectroscopy. The materials prepared showed to be stable and presenting good recovery rates mainly for Europium (≈ 24%) and Yttrium (≈ 20%). The materials were tested with simulated wastewater containing the REEs. Additionally, the nano-magnetic adsorbents were also tested for the recovery of organic dyes, another high hazardous pollutants of water resources. In the case of the brillant green dye, the recovery rate is near 75%.

The results obtained so far are very promising. Contacts with municipal wastewater treatment plants are being established to test the materials in real conditions, with plans to scale up the system under development.

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IAEA-CN-332/413

Sustainable Approach and Synergistic Properties of Gamma Radiation-Assisted Conductive Polyaniline-Silver Nanocomposites: Fabrication and Characterization

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A sustainable and ecofriendly method was developed to enhance the thermal, electrical, optical, and antimicrobial properties of conductive polyaniline (PANI) by incorporating nanoscale metallic materials into the polymer matrix using gamma radiation. This approach not only improves PANI's properties but also contributes to green chemistry by avoiding harmful chemicals and minimizing environmental impact. The process began with the generation of a silver colloid through gamma irradiation of a silver nitrate precursor in the presence of polyvinylpyrrolidone (PVP) as a stabilizer. This step was crucial for producing stable, uniformly dispersed silver nanoparticles with sizes ranging from 7 to 17 nm. Gamma irradiation facilitated the reduction of silver ions to nanoparticles, ensuring a clean, efficient synthesis process without traditional chemical reducing agents. Subsequently, aniline monomers were polymerized within the colloidal medium. The polymerization utilized varying concentrations of dopants and silver, with ammonium persulfate (APS) as the initiator and hydrochloric acid (HCl) as the dopant. The resulting conductive polymer/silver nanocomposites (NCs) underwent extensive characterization to assess their properties.

Thermogravimetric analysis (TGA) showed that the inclusion of silver nanoparticles significantly enhanced the thermal stability of the NCs, which is crucial for high-temperature applications. Electrical measurements revealed a notable increase in DC conductivity of the NCs thin films with higher dopant concentrations, highlighting their improved electrical properties suitable for electronic applications. UV-Vis and Fourier-transform infrared (FTIR) spectroscopy provided insights into the optical properties and chemical structure of the NCs, confirming the successful integration of silver into the polyaniline matrix. Transmission electron microscopy (TEM) and scanning electron microscopy (SEM) were used to examine the morphology and distribution of the silver nanoparticles within the polyaniline matrix. Dynamic light scattering (DLS) and selected area electron diffraction (SAED) further verified the size distribution and crystalline nature of the nanoparticles. Energy-dispersive X-ray (EDX) analysis confirmed the elemental composition of the NCs. Antimicrobial tests demonstrated that the NCs exhibited significant antibacterial activity against Escherichia coli and Staphylococcus aureus, with the highest efficacy achieved at a PANI molar ratio of 1:1:0.83. This result underscores the NCs' potential in biomedical applications where antimicrobial properties are essential. The interaction between the conductive polyaniline chains and the free electrons surrounding the silver nanoparticles created a conjugated electron cloud within the NCs, enhancing conductivity and broadening their potential applications to include supercapacitors, sensors, photocatalysts, and antibacterial materials.

In summary, this study's sustainable approach effectively improved the thermal, electrical, optical, and antimicrobial properties of polyaniline by embedding nanoscale silver particles into the polymer matrix. The comprehensive characterization and promising results open new avenues for these conductive polymer/silver nanocomposites in advanced technologies, emphasizing their potential as multifunctional materials in energy storage, sensing, catalysis, and biomedicine. This method represents a significant advancement in both materials science and green chemistry.

IAEA-CN-332/617

Radiation Cross-Linking of Cassava Starch to Use as Absorbents for Removal of Phenol Red from Wastewater

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The development of smart materials that respond to external stimuli has garnered significant attention in recent years. This study focuses on the synthesis of temperature-responsive cellulose surfaces by grafting poly(N-isopropylacrylamide) (PNIPAAm) onto cellulose using gamma irradiation-initiated grafting (1,2). Gamma irradiation offers a unique advantage in initiating polymerization without the need for additional chemical initiators, ensuring a cleaner and more controlled modification process. The effects of irradiation dose and monomer concentration on the grafting efficiency and the properties of the resultant materials were systematically investigated. The grafting process was carried out using the Reversible Addition-Fragmentation Chain Transfer (RAFT) polymerization technique, a controlled polymerization method that allows for precise control over the molecular weight and distribution of the grafted polymers. This approach addresses the limitations of conventional polymerization techniques, which often result in broad molecular weight distributions and less predictable material properties. By utilizing gamma irradiation, we were able to achieve efficient initiation and grafting, leading to well-defined temperature-responsive cellulose surfaces (3,4).

The grafted cellulose samples were thoroughly characterized using Fourier Transform Infrared Spectroscopy (FTIR) to confirm the chemical structure, Scanning Electron Microscopy (SEM) to observe the surface morphology, and X-ray Photoelectron Spectroscopy (XPS) to analyze the chemical composition of the modified cellulose. These characterization techniques provided comprehensive insights into the successful grafting of PNIPAAm and the resultant changes in the surface properties of cellulose. Our findings demonstrate the feasibility and efficacy of using gamma irradiation-initiated RAFT polymerization to create well-defined, temperature-responsive cellulose surfaces. This novel approach not only enhances the functionality of cellulose but also opens new avenues for the development of advanced materials for various applications, including biomedicine and environmental sustainability. The ability to precisely control the grafting process and the resulting material properties highlights the potential of this method in producing high-performance smart materials.

Keywords: temperature-responsive, cellulose, PNIPAAm, gamma irradiation, RAFT polymerization, smart materials.

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IAEA-CN-332/364

Enhancing the Performance of Polymer Membrane Filters through Electron Beam Surface Engineering

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To enhance the antifouling properties of polymer membranes for water filtration application, surface hydrophilization is a commonly used approach. Electron beam treatment, unlike other physical activation methods such as plasma treatment or UV irradiation, offers deep penetration of electrons into the polymer material. This method shows promise for treating the entire surface of porous membranes, affecting the inner pore walls. Moreover, electron beam treatment does not require photoinitiators, catalysts, or other toxic reagents.

This presentation will provide a comprehensive overview of membrane surface engineering using electron beam irradiation, including surface hydrophilization, functionalization, and catalyst immobilization on various porous membrane types and polymers. The resulting membranes will be thoroughly analyzed and characterized, and subjected to functional tests, including upscaling, to assess their suitability for water treatment applications. The study also includes theoretical calculations, simulations, and experimental studies to elucidate the reaction mechanism. Overall, the electron beam engineering of membrane surfaces has been extensively investigated to facilitate the development of customized membrane surfaces.

IAEA-CN-332/105

Unlocking the Potential of Radiation Grafted Amine-contaning Adsorbents for CO2 Capture and Natural Gas Upgrading

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Removal of CO_2 from natural gas and biogas is essential for reducing greenhouse gas emissions and improving their calorific values. While adsorption is a promising technology for separation of CO_2, current adsorbents face challenges requiring development of new materials. Promising materials featuring amine-containing fibrous structures offer benefits like rapid gas diffusion, enhanced gas-solid interaction, and reduced regeneration time. Radiation-induced grafting (RIG) is a promising method for imparting permanent functional groups to polymer substrates such as polyethylene (PE)/polypropylene (PP) nonwoven fabrics. We report the development of fibrous polymeric adsorbents containing tetraethylenepentamine (TEPA), ethylenediamine (EDA) or hydrazone (HZ) by RIG of glycidyl methacrylate (GMA), vinylbenzyl chloride (VBC), or N-vinylformamide (NVF) onto PE/PP nonwoven sheets, respectively. The grafted intermediates were subsequently aminated. The properties of the obtained adsorbents were evaluated using FTIR, SEM, EDX, BET, XRD and TGA. The adsorbents showed greater selectivity for CO_2 over CH4 and their adsorption capacities were strongly dependent on pressure, temperature, and gas compositions. The EDA-containing adsorbent demonstrated the highest adsorption capacity (4.4 mmol/g) at 30 bar as shown in Figure 1. The adsorbents were stable, easily regenerable at 80°C, and highly promising for column and scaled CO_2 separation from natural gas and biogas.

IAEA-CN-332/432

Effect of EB-radiation on 3D-printed materials: the contrasting behaviors of poly(lactic acid) modeled by FDM and acrylate networks produced by SLA

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We are studying the effects of ionizing radiation on 3D-printed polymer-based objects fabricated by stereolithography (SLA) or fuse deposition modeling (FDM) that may induce significant changes of molecular weight and cross-link density depending on the response of the material in terms of scission and interchain coupling. Methacrylate-based networks produced by SLA exhibit strong differences in monomer conversion, thermophysical characteristics and tensile properties depending on printing orientation and radiation dose (<300kGy). Significant improvement of fracture toughness by EB-treatment was observed at 10kGy. Conversely, the evolution of tensile properties in PLA-based specimens produced by FDM reveals negative effects of irradiation with ultimate strength □ and elongation □ reduced to about 40% of their initial value at 100kGy. The extent of crystallinity □ measured for irradiated samples was in the range of 15-20%, whereas after annealing in optimized conditions □ is greater than 60%. Starting from samples irradiated at 75kGy (half of initial tensile properties), we have observed that a soft treatment at 60°C allows to recover part of the mechanical damage due to irradiation (+20% for □ and +50% for □). This remarkable result is attributed to some physical reordering around crystallites that heals part of the damages due to chain scission.

IAEA-CN-332/485

The Effect of Ionization Radiation on the Structure of Lignin

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Lignin, a multidimensional phenolic biopolymer built from phenylpropane units, is amongst the most abundant biopolymers on earth, constituting approximately 30% of the dry weight of softwoods and 20% of hardwoods. Lignification is associated with the development of vascular systems in plants, providing resistance to biodegradation and environmental stresses such as changes in the balance of water and humidity. Electron beam irradiation (EBI) of lignin has received little attention to date. The potential use of lignin as a phenolic resource in biorefineries is not fully understood. EBI was applied to selected lignin samples dissolved in water and in the dry state. The structural and chemical changes were analyzed, revealing the suitability, limitations, and potential purpose of EBI in biorefineries. Isolated milled wood, kraft, and sulfite lignin were subjected to up to 1,000 kGy of irradiation. The analysis included gel permeation chromatography, 2D heteronuclear single quantum coherence (HSQC) and 31P NMR, FT-IR spectroscopic analysis and gas chromatography-mass spectrometry analysis of dichloromethane extraction of aqueous samples. Dry samples resisted irradiation at lower dosages with subtle changes occurring in the molecular weight distribution as dosages increased. Alternatively, EBI of lignin dissolved in or treated with water caused significant changes in the size and structure, thus offering the potential of a pretreatment method for the degradation of lignin into value-added phenolic compounds.

IAEA-CN-332/790

Investigation on the Morphology and Properties of Melt Spun Poly(Lactic Acid)/Cellulose Fibers under Gamma Irradiation

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Currently, the field of synthetic fibers made of biodegradable polymers is the subject of many publications and still continues to attract researchers from both academia and industry [1]. Large surface area to volume ratio, flexibility and potential to be produced in large quantities are some of the advantages that make fibers available for many industrial applications [2]. One of the most promising synthetic biodegradable polymers is poly(lactic acid) (PLA). PLA can be produced in fibrous structures with distinct fibers properties via melt spinning, solution spinning or electrospinning processes. Based on the features of bioresorption and biocompatibility, PLA fibers are used for applications such as medical materials involving sutures, support for tissue engineering and three dimensional scaffolds [3]. In this regard, a few sterilization techniques are recommended for aliphatic polyesters, due to their sensitivity to moisture and degradation by hydrolysis [3]. Among them, gamma irradiation is one of the most suitable methods for sterilization of such products with high penetration ability. Nevertheless, the challenge is to elaborate biocomposite materials which remain stable without affecting molecular structure and properties as well as not resulting in toxicological side effects during both storage and medical usage.

Therefore, this paper reports some experimental data on the effect of gamma irradiation on both morphology and properties of neat poly(lactic acid) (PLA), PLA/microcrystalline cellulose (MCC) and PLA/cellulose nanowhiskers (CNW) fibers loaded at 1 wt% filler content in presence of PLA-grafted maleic anhydride (PLA-g-MA) used as the compatibilizer. Multifilament yarns were prepared by a melt-spinning process and subjected to gamma irradiation at various doses from 5 to 30 kGy keeping the dose rate at 1.92 kGy/h under ambient conditions. Chemical structure, morphology and property changes induced by gamma irradiation on the samples were evaluated by several techniques considering the filler aspect ratio effect. The results showed a dose-related increase in the scission index (SI) of the irradiated samples whatever the filler size, while thermal and tensile properties significantly decreased. However, the incorporation of cellulosic fillers in PLA fibers, in particular MCC, was found to hinder the radiolytic degradation process of the irradiated samples.

Keywords: Fibers, Polylactide (PLA), Cellulose, Gamma irradiation, Degradation.

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IAEA-CN-332/809

Recycling of Waste Tyre Rubber Containing Natural Rubber with the Aid of Ionising Radiation

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The production of synthetic polymers is growing worldwide. They can be produced from both non-renewable and renewable resources. Polymers produced from renewable resources can be integrated into the circular economy. Natural rubber is an excellent example of a polymer produced from renewable resources. This material is used in large quantities to make tyres, although tyres also contain synthetic rubber. Tyres enter the waste stream after a few years, but the problem of their recycling is only partially solved, even though they are a valuable material, partly derived from renewable resources. A significant problem is the cross-linked structure of GTR, as it cannot dissolve in the matrix and forms a separate phase. The phases work well together if there is sufficient compatibility between them.

Many methods have been developed to increase compatibility, but these typically use hazardous chemicals and are not considered green solutions. Ionizing radiation, however, can provide an environmentally friendly way to increase compatibility. If irradiation of the GTR is carried out in a medium containing oxygen, there is a good chance that active groups will appear on the surface of the GTR, leading to more favourable compatibility conditions with the matrix materials. Based on these results, we used gamma radiation in an air atmosphere for surface activation of GTR. The surface-activated GTR was then mixed with natural rubber and vulcanized.

The results showed that surface activation was successful: the irradiation resulted in an increase in strength and a nearly constant elongation at break. The effectiveness of irradiation was confirmed by spectroscopic studies.

IAEA-CN-332/025

Moringa Extract Loaded on PVA/Chitosan Edible Coatings using Gamma Irradiation to Control the Insect Infestation and Maintain the Quality of Semi-Dry Dates (Siwi cv.) During Storage at Room Temperature

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With increasing population growth and water scarcity, there is a need to benefit from all possible and safe ways to increase food production while preserving food for a longer period. Gamma radiation is a safe and clean means of preparing polymers and increasing crosslinking. Moringa extract loaded on edible films made of PVA/chitosan and prepared using ionizing radiation (gamma rays) at different concentrations (0, 2.5, 5, 10, 15%) was used to combat insect infestation and preserve Siwa date fruits during storage and marketing. The percentage of insect infestation, fruit weight loss, and moisture content were determined for six months of storage at room temperature. Total soluble solids (T.S.S.), pH and browning were also determined. The use of the paint treatment significantly reduced the rate of insect infestation, weight loss, moisture loss, and browning, and the best results were for fruits treated with a 15% concentration of moringa extract. T.S.S and pH were not significantly affected.

IAEA-CN-332/024

Gamma and Electron Beam Irradiation: Pioneering Bio-based Carbon Modifications for Advanced Energy and Environmental Applications

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The enhancement of activated carbon (AC) through gamma and electron beam irradiation has marked a significant milestone in the development of improved materials for energy storage and wastewater treatment. Gamma irradiation has been adeptly utilized to tackle the shuttle effect in lithium-sulfur batteries, a critical issue limiting their efficiency. This process successfully introduces functional groups to the surface of AC, derived from glutinous rice, promoting the chemical anchoring of polysulfides and achieving specific capacities of up to 4900 mA h g^{-1} with sustained performance over numerous cycles. Beyond energy storage, the same irradiation technique has been applied to AC for the adsorption of methylene blue from wastewater, showcasing a green methodology that circumvents the need for toxic chemical use. The treatment notably increases the nitrogen content and surface area of AC, enhancing its capacity for dye adsorption significantly. Electron beam irradiation (EBI) presents a complementary method, particularly in the pretreatment of biochar and activated carbon for electrochemical capacitors. With EBI doses ranging from 500 to 1500 kGy, the resultant structural defects in the biochar contribute to a marked improvement in its electrochemical properties, as evidenced by the increased specific capacitance in comparison to the as-received material. These irradiation technologies are revolutionizing the approach to AC modification, providing a non-toxic, efficient, and environmentally benign method that holds promise for scalability and industrial application. The modifications induced by gamma and electron irradiation not only enhance the material's performance but also broaden the scope of AC applications, making it an attractive candidate for various sectors seeking sustainable material solutions. This abstract underscore the pivotal role of irradiation in advancing the functionalization of carbon-based materials for enhanced performance in energy and environmental systems.

IAEA-CN-332/822

The State of Radiation Sterilization in Argentina: Challenges and Opportunities

M. Vogt, C. Lires, C. Cingolani, J. Pachado, M. Coman (Comisión Nacional de Energía Atómica) – Argentina

Radiation cross-linking is a well-established method to improve the performances and customize radiation-curable plastic-based insulating sheaths produced for various industrial sectors. In spite of their use for more than 50 years in the wire and cable industry, there is still a need for a deeper understanding and better control over the different stages of the fabrication process that include the selection of the plastics fillers and additives, the search for optimized composition, the determination of efficient conditions for blending, shaping and final radiation processing. The precise quantification by complementary analytical methods of the amount of extractable additives such as cross-linking agents and stabilizers was performed in plastic blends at various stages of their preparation and after electron beam treatments at doses up to 300 kGy. The competing effects of cross-linkers and stabilizers in EB-irradiated model EVA blends will be discussed more specifically. In particular, it was shown that: (i) stabilizers do not inhibit the curing process but have a retarding effect on the consumption of cross-linkers, (ii) type I crosslinkers (acrylates) are initially more reactive than those of type II (allyl derivatives) and (iii) the dose-dependence of the consumption of primary stabilizers (phenol-type) is stronger that of secondary anti-oxidants. The analytical data recorded from model formulations at various stages of their preparation and radiation curing can be correlated to the evolution of various thermophysical properties of practical interest, as well as to thermo-oxidative ageing.

IAEA-CN-332/726

Study on Ageing Related Deterioration of Polymer Catheters Irradiated with Electron-Beam

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Approval of catheters hinges on three critical factors: biocompatibility, mechanical, and thermal properties. E-beam irradiation is an efficient sterilization method used to eliminate harmful microorganisms from polymer-based catheters. While this process is effective, it can also cause physical and chemical changes in the polymer, particularly as the material ages. High-energy electrons from the E-beam interact with polymer chains, leading to chain scission (breakage) or cross-linking (bonding). These changes can affect the catheter's mechanical integrity, often resulting in embrittlement or surface cracking, which increases the risk of material failure. It is important to note that studies before ageing have shown that a sterilization dose of 25 kGy does not cause significant deterioration before aging. However, exposure to higher doses (50–100 kGy) can induce considerable alterations in surface morphology. In particular, increased hydrophilicity and surface cracks were observed after higher doses of irradiation. These surface cracks may facilitate the adhesion of pathogens, potentially leading to microbial colonization and an elevated risk of infection.

In this study, natural rubber latex Foley catheters were irradiated with a 3.5 MeV E-beam at a pulse current of 250 mA. They were then analyzed for changes in surface morphology (E-SEM), glass transition temperature (DSC), microplastic release in water, and microbial growth. After 1.5 years of aging, the irradiated catheters were reassessed and compared with both pristine catheters and those immediately post-irradiation. The comparison helps to understand how aging affects degradation in polymer catheters exposed to different levels of E-beam irradiation. The findings will provide valuable insights into the long-term stability and performance of E-beam-sterilized catheters, highlighting how doses above the sterilization threshold can compromise the material's biocompatibility and structural integrity.

Acknowledgement
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IAEA-CN-332/802

ISO 11137-1; What's New in the 2025 Version?

A. Croonenborghs – Sterigenics - USA

Since the installation of the first irradiators for sterilization of single-use healthcare products in the 1960's, this application of ionizing radiation has evolved into a mature industry where now roughly 40% – 50% of all single-use healthcare products are radiation sterilized.

With the development of ever more complex healthcare products as well as supply chain pressures, new challenges for developing – establishing and controlling a radiation sterilization process have come across the industry.

ISO 11137-1 is the standard that sets the requirements for radiation sterilization of medical devices. Following the 2006 publication, 2 amendments were made and in 2025 a new version is published.

The presentation will highlight key aspects of the 2025 document and how they help fostering change and innovation.

IAEA-CN-332/420

Filling Data, Education and Tool Gaps that Impede Transition to E-beam and X-Ray – Progress Update of an International Collaborative Team

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Team Nablo is an international collaborative group that began activities in earnest in 2018. Their main goal is to identify and fill the data, education, and tool gaps that impede companies desiring to transition products from cobalt-60 gamma and ethylene oxide (EO) gas sterilization methods to the accelerator-based alternatives of electron beam (e-beam) and X-ray.

Market forces are increasingly pushing manufacturers of polymer-based medical products and biopharmaceutical production components to consider alternatives to cobalt-60 gamma-rays and EO for sterilization. These market forces include the risks in the future supply and procurement costs for cobalt-60, the increased regulations involving both cobalt-60 and EO use, the closing of some large EO sterilization facilities, and the estimated minimum ~8% annual growth in product volume requiring sterilization.

This presentation summarizes Team Nablo activities and successes in the first five years, which includes 1) The irradiation and post-irradiation testing (functionality, mechanical, chemical and coloration) of over 15 separate medical products, involving over 30 types of polymers, 2) How source type, dose level, dose rate level, temperature, atmosphere and e-beam energy influences these ionizing energy effects, and 3) The development of PUFFIn, a much simplified software tool to allow prediction of dose distribution in products and how source type and packaging influence this dose distribution..

IAEA-CN-332/102

Industry Collaboration to Enhance the Security and Sustainability of Radiation Processing

M. Comben – International Irradiation Association (IIA)

The International Irradiation Association ('iia') supports industry's engagement through its Gamma Working Group ('GWG') that is made up of leading operators of gamma irradiators. Since mid-2020 the GWG has been working with Sandia National Laboratories (SNL) and the World Institute for Nuclear Security (WINS) to develop new security systems and best practice guidance that is tailored for the gamma irradiation industry.

Industry, through the GWG, has been supporting SNL in the development of a novel protection system that visually hides cobalt-60 sources within an irradiator pool in the event of an attack. The group has also worked with SNL on a cybersecurity vulnerability assessment at a gamma irradiator that will result in the development of cybersecurity guidance specific for the irradiation industry.

Industry, through GWG, has contributed real life experience to the development of joint iia/WINS security best practice for gamma irradiation facilities. A methodology to assess security arrangements has since been published following a trial of the processes by a GWG member to ensure its suitability for use at gamma irradiation facilities.

Industry engagement and collaboration between stakeholders is critical when developing new arrangements to enhance security. This will help to remove any objections to implementation and improve the chance of new systems and processes being adopted by industry.

IAEA-CN-332/816

The Role of Extracts from Irradiated Agro-Industrial Byproducts in Microbial Control of Minimally Processed Fresh Food

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Background of the study
The growing demand by consumers for healthier food has driven the food industry to seek new, cost-effective, and natural alternatives to synthetic preservatives. On the other hand, the antimicrobial resistance is currently a serious global problem since some antibiotics could be non-effective in the treatment of infectious diseases, becoming increasingly urgent to find solutions to deal with this problematic. In this context, the natural bioactive compounds present in food and agro-industrial wastes can be potential effective agents for these purposes.

Methodology
In this work, ionizing radiation, gamma and electron beam radiation, was applied to different food and agro-industrial wastes (oregano; lettuce; avocado – pulp and peel; olive pomace; pineapple wastes – core, pulp and peel; eggshell membrane) to evaluate its feasibility in improving the extractability of bioactive compounds, as well as the bioactivities of the obtained extracts.

Results
E-beam radiation was used to study the stability of aqueous and ethanolic lettuce extracts during storage at -80 ºC. Low energy electron beam (LEEB) at 4 kGy generally improved total phenolic and flavonoid contents of lettuce ethanolic extracts stored up to 28 days, while the aqueous extracts from irradiated lettuces demonstrated higher antidiabetic and antiproliferative activities. Water demonstrated to be the most adequate solvent to extract phenolic compounds from oreganos and LEEB at 5 and 10 kGy indicated to enhance the antioxidant activity by DPPH radical scavenging activity. Furthermore, high energy electron beam (HEEB) could increase the antioxidant activity of eggshell membrane and egg white powder using irradiation doses up to 500 kGy, as well as isolated egg proteins lysozyme and ovalbumin. Enhanced antimicrobial and antiproliferative activities could also be highlighted for irradiated samples. Gamma irradiation at 5 kGy was suitable to improve at least 2-fold the extractability of bioactive compounds from olive pomace with higher antioxidant, antimicrobial, antidiabetic, anti-inflammatory and antiproliferative properties. The obtained natural extracts were tested as potential preservatives by delaying the oxidation of fresh-cut apples, achieving promising results for growth inhibition of bacteria, filamentous fungi and coliforms along 12 days of refrigerated storage. Avocado is a very perishable food and, consequently, high amounts of wastes are generated. Gamma irradiation at 4 kGy suggested an increased extractability of bioactive compounds from peel, also improving its antioxidant and antimicrobial potential.
For the processing pineapple wastes, aqueous extracts obtained at room temperature seemed to contain higher phenolic compounds concentrations and antioxidant activity in comparison with the ethanolic extracts, and a preservation of these parameters were observed using gamma radiation at 4 kGy.

Conclusion

The outcomes of this comprehensive work can contribute to foster the use of ionizing radiation as a sustainable process, while providing helpful information in developing new ingredients for food and pharmaceutical industries and paving the way to the implementation of the circular economy concept.

IAEA-CN-332/524

Study on Effect of Irradiation Sterilization on Tibetan Medicine Shiwei Ruxiang Pill

P. Gao, A. Meng, G. Wu, H. Chen, M. Huang (Sichuan Institute of Atomic Energy) – China

Tibetan medicine is an ethnic medicine with relatively complete theory and clinical system with a history of more than 3,800 years, but it is mostly produced with the crude drug powder, which is easy to introduce serious microbial pollution problems. The current Tibetan medicine sterilization mainly relies on traditional moist heat, dry heat and other methods, but these methods are easy to destroy the heat sensitivity, volatile active ingredients of medicine, and influence the clinical treatment effect. As a "cold sterilization" technology, irradiation is a good alternative. This project evaluated the feasibility of irradiation technology in the sterilization of Tibetan Medicine Shiwei Ruxiang Pill (SRP). The study on effect of microorganism, active ingredient, fingerprint, appearance quality and other parameters by different γ radiation doses (3, 7, 10 kGy) were be carried out.

The results are as follows. (1) The total number of molds and yeasts in SRP before irradiation reached 8.3×103 CFU/g, which was significantly exceeded, while the microbial content of the samples reached the requirements of the pharmacopoeia under 7 kGy irradiation treatment, and the total number of microorganisms of the irradiated samples remained stable after 1 month of storage, so the optimal irradiation dose was 7 kGy. (2) The similarity of the fingerprints of SRP with different irradiation doses was greater than 0.998, and the fingerprints between irradiated and nonirradiated samples had no significant changes. (3) There was no significant difference between the 3 kGy irradiation and the non-irradiated (0 kGy) groups before and after irradiation ($P>0.05$), and the average content of gallic acid after 7 kGy and 10 kGy irradiation treatment increased by 3.98% and 3.17%, respectively, compared with the non-irradiated group. (4) There was no significant difference between the 3 kGy irradiation dose and the non-irradiated (0 kGy) group after one month of storage at room temperature ($P>0.05$), and the average content of gallic acid after 7 kGy and 10 kGy irradiation increased by 2.94% and 1.68%, respectively, compared with the non-irradiated group. After a certain dose of 60Co-γ irradiation treatment, the gallic acid content of SRP showed an increasing trend compared with the non-irradiated group. (5) Irradiation at doses lower than 10 kGy had no significant effect on the color of SRP. The effect of irradiation on the odor of SRP increased with the increase of irradiation dose, and compared with 10 kGy, the odor of the samples treated with 3 kGy and 7 kGy irradiation had the least change compared with the non-irradiated group. In conclusion, irradiation technology can be used as a safe, effective, and stable sterilization methods to ensure the quality improvement of Shiwei Ruxiang pills and otherTibetan medicines containing crude drug powder.

IAEA-CN-332/611

Does Exposure to Sub-Lethal Electron Beam Doses Cause Stress-Induced Bacterial Conjugation?

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Bacterial conjugation involves the transfer of plasmid DNA from one donor bacterium to another recipient bacterium through direct contact and is prevalent in environments like soil, water, and biofilms. The mechanism of conjugation mediates the propagation of numerous metabolic features, such as pathogenicity, biofilm formation, and, most critically, resistance to antibiotics. Pathogens such as Streptococcus pneumoniae, Acinetobacter baumannii, and Staphylococcus aureus that are found in natural and man-made environments have developed multi-drug resistance. Ionizing radiation technologies such as electron beam (eBeam) and gamma are routinely being used in various commercial applications, such as medical device sterilization, wastewater treatment, and food preservation. There is a high probability that microbial populations will be exposed to sub-lethal doses. We hypothesize that exposure to sub-lethal eBeam doses will influence bacterial conjugation processes. This study investigates how sub-lethal eBeam doses affect bacterial conjugation and transfer of antibiotic resistance-coding plasmids using a model non-pathogenic Escherichia coli conjugation system.

Ongoing studies indicate that sub-lethal exposure to chemical sterilants causes varying effects in transconjugant development. E. coli BB4(F+) is a donor strain carrying a tetracycline resistance gene associated with the fertility (F) plasmid, while E. coli SCS1(F-) serves as the recipient with an ampicillin resistance gene. These strains are being subjected to various sub-eBeam doses and evaluating the creation of transconjugants that exhibit the tet-amp-resistance phenotype. These studies will be conducted using eBeam doses ranging from 0.2 kGy to 1 kGy. By examining a range of doses, we can better understand how increasing sub-lethal dose exposure affects bacterial conjugation efficiency.

IAEA-CN-332/444

Antibacterial surfaces by electron treatment of polylactide

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Antimicrobial surfaces are playing an increasing role as they help to minimize contamination and reduce the spread of pathogens. For medical products, especially for packaging purposes, biopolymers are becoming increasingly popular due to their sustainable properties. Some of the commonly used biopolymers is polylactide (PLA).

Ionizing radiation such as electron treatment is used for the modification of polymers and biopolymers. The main applications are cross-linking, degradation, grafting, curing of coatings, and sterilization. Sterilization aims on preventing microbial contamination by inactivation of microorganisms. In addition, radiation-based grafting is used to produce antimicrobial polymer surfaces since it enables the coupling of antimicrobial substances such as silver nano-particles to the polymer surface so that an antimicrobial coating can be produced.

In this study, PLA with bacteriostatic or bactericidal properties is shown for the first time. It was prepared by low-energy electron treatment at low dose rate without any use of additional chemical processes or substances such as silver. Compared to conventional methods, this novel method offers a sustainable and environmentally friendly process for the preparation of bacteriostatic or bactericidal surfaces. A further advantage of this novel method is related to the edge-layer electron treatment that does not modify the volume properties of PLA.

IAEA-CN-332/694

Effect of Ionizing Radiation on Physicochemical and Biological Properties of Poly(trimethylene carbonate) and Poly(lactic acid) Copolymers

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Biodegradable and biocompatible aliphatic polyesters and their copolymers are getting more widely used as biomaterials, as their physicochemical properties and biodegradation profile can be tailored. Since sterilization is challenging, ionizing radiation may be a method of choice.
This work presents a study on a polymerization synthesis of poly(trimethylene carbonate) (PTMC) and poly(D-lactic acid) (PDLA) copolymers, evaluation of the effect of ionizing radiation on their chemical structure and on selected properties relevant to biological applications, potential toxicity assessment and in vitro simulated biodegradation.

The research resulted in elucidation of the mechanisms of changes in PTMC-co-PDLA exposed to ionizing radiation. In copolymers comprising flexible TMC segments and rigid DLA blocks, the processes initiated by ionizing radiation of crosslinking and degradation of TMC segments and degradation of DLA segments occur simultaneously. The breaking of ester bonds and the formation of an alkoxy radical characteristic of polyesters result in a decrease in the molecular weight of macromolecules. Radicals generated simultaneously on carbonate segments cause crosslinking and degradation reactions, out of which the former process mainly involves radicals on the beta atom with respect to the carbonate group, while stabilized allylic radicals are responsible for the degradation process. The outcome of copolymer irradiation depends on its molar composition and microstructure.
PDLA-co-PTMC copolymers, sterilized by ionizing radiation (as well as irradiated with a dose several times higher), cause no negative cellular reactions and to be non-(geno)toxic to the cell lines of murine and human fibroblasts and to human endothelial cells. This was demonstrated with XTT, LIVE/DEAD and comet assay. Results of hydrolytic, as well as oxidation- and enzyme-assisted in vitro simulated biodegradation, showed that the biodegradation mechanisms depends on the copolymer molar composition, as the lactide part is susceptible for hydrolysis but the carbonate component to enzyme-catalyzed processes. General conclusion states that PDLA-co-PTMC copolymer biomaterials can be modified and sterilized using ionizing radiation.

IAEA-CN-332/834

Irradiation Technologies for Vaccine Development

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Vaccines are the most economical strategy for the prevention of infectious diseases and a solution to antimicrobial resistance. Nonetheless, despite an advancement in our understanding of host-pathogen interactions and the progress in different advanced technologies for vaccine development, there is a scarcity of effective vaccinations against several human and animal diseases. The need to develop and produce vaccines more rapidly for emerging and re-emerging infectious diseases is a challenge; and innovative methods are essential to avoid immune evasion by pathogens. Chemical inactivation of pathogenic microorganisms is presently the most widely used inactivating method in the vaccine industry. Nonetheless, irradiation-induced inactivation has several potential advantages over chemical inactivation. Chemical treatment alters the quaternary structure of pathogen epitopes that can elicit an effective host immune response. Irradiation, conversely, maintains both the conformational and structural integrity of pathogen epitopes that are capable of eliciting an effective immune response in the vaccinated individual upon infection. Recently, there has been a renewed interest in using nuclear radiation for vaccine production, attributed to advancements in irradiators that deliver precise radiation doses in shorter time frames, coupled with an improved understanding of the immune system that facilitates a better understanding of vaccination responses. Recent technological advancements have facilitated the application of the electron-beam (e-beam) technology and alternative irradiation techniques to inactivate pathogens, hence enabling a transition from using radioactive materials to produce irradiated vaccines. In the last decade, the IAEA, via the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, has spearheaded research and development on the application of irradiated vaccines for more than 25 animal and zoonotic pathogens. The addition of e-beam technology in this field will enable an easier transition of the current work to include GMP practices and the commercial production of irradiated vaccines for large scale use.

IAEA-CN-332/757

The changing landscape of tissue banking

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The IAEA began to support radiation sterilisation of tissues back in 1970s, the time the tissue banking itself was in the early stages globally. At that time given the nature of the biological tissues the use of radiation sterilisation was not adopted globally, until the introduction of low dose radiation sterilisation was introduced. Radiation sterilisation is now the method of choice in tissue banking.

The most widely used tissues in the countries supported by the agency was amnion for wound dressing as placenta was the readily available tissue from living donors. However, amnion was considered inferior to skin allografts and was not taken up globally. However, after 5 decades have passed the amnion allograft has returned, under the name "birth tissue", for cornea repair.

The radiation sterilisation, the advancement in processing technology and the development of various tissue donation models have made tissue banking a global industry worth billions of dollars. The regulatory line between tissue and medical device has also become narrower. The supply chain from donation to availability of tissue allografts can now be managed effectively within the legal and regulatory framework across the borders. This offers an opportunity to the agency to reengage with tissue banking.

IAEA-CN-332/451

Enhancing Irradiation Capacities for Tissue Engineering and Tissue Banking in Latin America and the Caribbean: The Impact of an IAEA Regional Project

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The RLA1018 Project: Strengthening Irradiation Capacities of Tissues Used as Scaffolds in Tissue Engineering for Regenerative Medicine had a positive impact on the Latin America and Caribbean region. Despite being largely conducted during COVID-19 lockdowns, this project did not hinder the thirteen participating countries from achieving their goal of enhancing irradiation capacities for tissues used in tissue engineering for regenerative medicine.

During the project, numerous events were organized, both virtual and in-person, along with the creation of promotional materials in both print and digital media. These activities contributed to increasing the visibility of the "Code of Practice for the Irradiation Sterilization of Human Tissues for Clinical Use: Requirements for Validation and Routine Control," strategies for radiation-assisted production in tissue engineering products, training courses for healthcare professionals, as well as participation in national and international congresses and scientific events. These initiatives strengthened interaction among participants and successfully established an active network in the field of regenerative medicine, promoting ongoing collaboration among professionals in the Latin America and Caribbean region.

IAEA-CN-332/409

Radiosterilized Pig Skin, Silver Nanoparticles and Skin Cells as an Integral Dressing Treatment for Burns: Development, Pre-Clinical and Clinical Pilot Study

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Radiosterilized pig skin (RPS) has been used as a dressing, it allows the attachment of mesenchymal stem cells (MSC) to create constructs. The use of silver nanoparticles (AgNPs) could be an alternative to the use of antibiotics. RPS can be impregnated with AgNPs to develop nanomaterials (NM) to prevent wound infections. The goal of this study was to assess the use of RPS as a scaffold for fibroblasts (Fb), keratinocytes (Kc), and MSC in the treatment of second-degree burns (SDB). This protocol was approved by the Research and Ethics Committee (INR 20/19 AC). TEM and DLS analysis of the AgNPs showed an average size of 10 nm. MIC and Kirby–Bauer assays indicated that AgNPs exhibit antimicrobial activity against S. aureus from burned patients; a log reduction of 1.74 ± 0.24 was achieved against biofilm formation. The NM at 125 ppm (RPS-AgNPs125) facilitated wound healing in a mouse model and enhanced ECM deposition. No silver was detected by EDS in the skin, or organs by ICP-MS of the mouse. Calcein/EthD-1, MTT, and SEM analysis demonstrated that Fb, Kc, and MSC could attach to RPS with over 95% cell viability. Kc and Fb release FGF above control levels. An autologous RPS-Fb-Kc construct was implanted in a patient with SDB and compared to the gold standard (GS). The patient exhibited favorable recovery compared to GS and improved moisture index. In conclusion, RPS can be used as a scaffold for the culture of Fb, Kc, and MSC, developing a cellularized construct that enhances wound healing in burn patients.

IAEA-CN-332/300

Morphological Analysis of Micro Computed Tomography (micro-CT) Images of Human Tendon Tissue Sterilized by Ionizing Radiation

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There is a growing interest in the advancement of less invasive surgical techniques, especially in tendon and ligament reconstructions, which has driven research into the use of allografts sterilized by ionizing radiation. The use of these allografts eliminates the need for a second surgical approach to remove autologous grafts, reducing post-operative morbidity, surgical time and the risk of infections. The application of this technique as a final sterilization method is safe and leaves no residue, promoting reliability and effectiveness in the procedures. This approach is assisting medical practice by ensuring high levels of safety and success in interventions, further encouraging the development and adoption of more reliable approaches in orthopedic surgery. The present study aimed to evaluate the effects of applying ionizing radiation, produced by a Co-60 source, on pre-processed human tendon samples, kept at temperatures of -80 °C from multi-organ donors, obtained through collaboration with Tissue Banks. The doses applied in radiation processing were 12.5 kGy, 15.0 kGy and 27.5 kGy, with their respective non-irradiated control. The samples were evaluated using Micro Computed Tomography (micro-CT) and the results were compared with previous histological, optical and biomechanical tests, with the aim of analyzing possible morphological and structural changes. Analyzing the images generated by the micro-CT confirmed the data previously obtained by the same group, where it was possible to observe a slight structural modification at the dose of 12.5 kGy, corroborating the data obtained in the biomechanical tests. Based on the analyses, we can conclude that the samples irradiated at 15.0 and 27.5 kGy presented characteristics similar to the non-irradiated control. This study contributes significantly to the understanding of the effects of ionizing radiation on human tendon allografts, highlighting the importance of an adequate dose to preserve the structural and biomechanical properties essential for the success of surgical reconstructions.

IAEA-CN-332/152

Immunosuppression by Ionizing Radiation for Promoting Stem Cell therapy using expanded in vitro bone marrow Mesenchymal Stem Cells Compared to Differentiated Beta Cell for Regenerating Alloxan Damaged Beta Cells in Rats

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Advancement of knowledge in the field of regenerative medicine revealed the therapeutic potential of different bone marrow stem cells in pancreatic regeneration. Accordingly the present study was carried out to compare between the potential of Mesenchymal Stem Cells (MSCs) or early differentiated pancreatic cells in repairing pancreatic damage induced by Alloxan and ionizing radiation. Hence, pancreatic β-cells damage was induced using alloxan and ionizing radiation in male Albio rats. Mesenchymal cells and early differentiated pancreatic cells were separated from bone marrow and differentiated in vitro were injected into the alloxan and ionizing radiation treated rats. Rats were monitored for Insulin 1, glucagon and glut-2 mRNA expression together with markers of oxidative stress 15 and 30 days post stem cells injection. Diabetic rats showed a significant decrease in insulin and Glut2 gene expression and a significant increase in glucagon gene expression in pancreatic tissue compared to the control. The expression alteration in insulin-1 and Glut2 and glucagon genes improved after treatment with MSCs or early differentiated pancreatic cells whether exposed to ionizing radiation prior the cell therapy or not. Treatment with MSCs showed significant increase in insulin and Glut2 gene expression after 15 days compared to treatment with early differentiated pancreatic cells. However, 30 days post treatment with MSCs, insulin and Glut2 gene expression were significantly lower compared to treatment with early differentiated pancreatic cells. Adult stem cells isolated from bone marrow have the potency to differentiate into pancreatic cells in vitro. Cells therapy using MSCs or early differentiated pancreatic cells showed an obvious improvement for diabetes mellitus with longer efficient effect, when using . Exposure to 6 Gy ionizing radiation assisted in homing cells to the damaged pancreatic tissue. Further research is recommended to be continued in stem cell therapy, which is a fruitful area of useful applications in the treatment of many diseases.

IAEA-CN-332/226

Low Temperature Irradiation for Disinfestation of Paper Documents

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Gamma irradiation has been used in several countries for the large-scale treatment of paper documents heavily infected with fungi. Radiation treatment is fast and effective compared to other disinfection options available today. Irradiation of paper documents is not yet widely accepted due to concerns about radiation-induced degradation of the paper. It is well known that irradiation reduces the degree of polymerization of cellulose, especially for new/unaged paper, but several studies have shown that there are no significant changes in the macroscopic properties of the paper (mechanical strength, color, Ph, etc.) for a range of relatively low doses: 5 to 10 kGy or 8 +/- 2 kGy, according to different references). This dose range have been found to be sufficient to inactivate most fungal attacks and to ensure both the long-term preservation of large collections of paper documents and the safety of the personnel working with them. However, recent studies showed that certain fungal strains, which mai affect paper documents, shows an unusual high radiation resistance at low dose rates, which may be encountered in small, research or pilot scale gamma irradiators.

In some special applications of radiation sterilization (tissues for transplantation, collagen or pharmaceutical ingredients) it has been shown that radiation-induced degradation of biopolymers is significantly reduced by performing irradiation at low temperature (in dry ice or liquid nitrogen). The purpose of our study is to evaluate the inhibition of the degradation of paper documents when irradiated at low temperature to increase the maximum dose. Doses higher than 10 kGy may be required: i) if the initial contamination is extremely high and/or ii) if the radiation resistance of some fungal contaminants is higher than usual.

Our results, obtained for the irradiation of the reference paper (pure Whatman cellulose paper) at doses up to 30 kGy, show a reduction of the degrading effects if the irradiation is carried out at -79°C. Preliminary results were obtained by mechanical testing (tensile strength), thermal analysis (DSC) and vibrational spectroscopy (FT-IR).
In addition to increasing the maximum dose for disinfection treatment, low-temperature irradiation of paper documents could be combined with freeze-drying procedures (for wet documents) or used to further minimize the risks of degradation of highly valuable (old) documents.

IAEA-CN-332/262

Electron Beam Irradiation for Preservation of Old Prints

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Application of electron beam (EB) accelerators for disinfection of cultural heritage (CH) objects is still new approach. This is caused mainly by some limitation of EB technology in treatment of CH objects. However, careful selection of the objects and appropriate application of the EB irradiation allows to perform disinfection of CH artefacts with EB successfully. To apply EB irradiation to CH objects we need to take into account size of the object and the density of the material the CH object is composed of. Size of the object that may be treated is limited by the width of the conveyor (~ 0.5 m). The higher density of the object material we have the lower penetration of the electrons in the object is. Therefore, thin objects or objects made of low density materials are the most suitable for EB treatment. Additionally, proper packaging of CH objects is also very important issue. Moreover, accelerators with higher beam energy (10 MeV) are recommended in this application to provide sufficient penetration of the electrons in the material.

The scope of paper is to investigate the influence of electron beam irradiation used for microbiological decontamination process on old prints. In the first step modern handmade paper is being studied as the model material. The paper samples were irradiated in wide range of irradiation doses with 10 MeV electron beam accelerator. Simultaneously, dosimetric analysis necessary for the proper realization of the process (dose control with calorimetric analysis, determination of electrons energy, determination of dose distribution in the material) was carried out. Selected mechanical (tensile and tear tests) and physical properties like pH, colour changes etc. of unirradiated and irradiated paper samples were characterized. Moreover, different analytical methods as Scanning Electron Microscopy (SEM), Energy-dispersive X-ray Spectroscopy (EDS), Electron Paramagnetic Resonance (EPR) were applied to collect information on paper morphology and composition as well as radicals created in the material upon irradiation process. All test were performed according to the ISO and TAPPI standards. Applied methods provided information on the influence of different irradiation doses on the handmade paper what is crucial for the selection of the appropriate dose applied for the paper-based object disinfection.

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Gamma Irradiation for Treatment of Historical Carpets - A Study of Natural Dyes

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The biodeterioration of cultural artefacts of organic origin is a process caused by the attack of organisms, which thrive and feed on these materials. The agents of deterioration, such as bacteria, fungi, molds, and insects, cause pronounced problems in the conservation and protection of cultural heritage items. The disinfestation and decontamination by ionizing radiation have emerged as successful alternatives to conventional methods. Carpets and rugs are important visual documents of Turkish culture and cultural wealth. They are communication tools for physical and emotional activities in human life from birth to death; therefore, they contain very precious information regarding artistic, social, commercial, religious, and practical daily life. These rugs and carpets are generally woven with woolen threads and dyed with natural dyes. Therefore, the knowledge of the chemical composition of these historical objects and the effect of ionizing radiation on the natural colorants is of great importance in the process of their decontamination and conservation. In this study, wool yarns were dyed with natural dyes prepared by traditional methods using various plants (Reseda lutea, Rubia tinctorum, and indigo). These samples were exposed to ionizing radiation using a cobalt-60 irradiator (Ob-Servo Sanguis) at doses of 0, 1, 3, 5, 7, and 10 kGy. The characterization of irradiated and non-irradiated samples was performed using chromatographic techniques involving UV-Vis and mass spectrometric detection. The radiation induced the color change was investigated using CIE colorimetry in the CIE Lab Lab* system. In addition, the combined effect of ionizing irradiation and green antimicrobial agents on color and chemical properties of dye was assessed.

IAEA-CN-332/315

First Brazilian Successful Case of Consolidation by Ionizing Radiation of a Polychrome Wood Sculpture – Research and Application

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Consolidation by ionizing radiation is a powerful technique that could be the last change for severely degraded wood sculptures. Wooden sculptures are biodegradable, generally attacked by xylophagous insects, creating internal porosity and consequently weakening the structure. The consolidation process is based on the impregnation of a radiation curing resin by pressure into a porous object followed by irradiation treatment with gamma rays to induce polymerization and crosslinking of the impregnated polymer. However, the radiation curing resin formulation must be selected through preliminary tests to avoid volume expansion between other during the curing process. Irradiation parameters are restricted with respect to dose rate and total absorbed dose. In this work, several formulations of polyester resins, methyl methacrylate and styrene were studied under different gamma irradiation conditions, as well as absorbed dose and dose rate. A polychrome wooden sculpture from the Bandeirantes Palace Museum, Sao Paulo – Brazil was characterized by nondestructive tests such as X-rays and tomography and selected for application of the consolidation method with 50%/50% polyester-styrene resin. A special device tank build on stainless steel and valves was developed to perform the impregnation. The sculpture was placed and fixed inside the impregnation tank. A very low vacuum of about 10 mbar was applied to the system to introduce the radiation curing resin from the bottom to avoid air bubbles or voids. After the first impregnation stage, a positive pressure of around 5 bar was applied using nitrogen for approximately 24 hours in the closed system. Finally, the excess resin was removed and stored in a reservoir tank. The impregnated sculpture was irradiated using a dose rate of 1 kGy.h-1 with a total absorbed dose of 40 kGy in the Multipurpose Gamma Radiation Facility at the Nuclear and Energy Research Institute – IPEN, Brazil. It was necessary to interrupt the irradiation with 2 kGy to remove excess resin from the surface of the sculpture at the gel transition point. After the consolidation process, the sculpture was characterized with non-destructive tests and restored.

IAEA-CN-332/081

The Use of Radiation Technology for the Protection of the Archeological Site of Vinča from the Neolithic Age

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The Vinča culture represents the early Neolithic culture of Europe between the fifth millennium BC and the fourth millennium BC. It was the most technologically advanced prehistoric culture in the world. The discovery of the so-called "Vinča letter" is particularly significant and interesting. Vinča script, also known as Vinčanica or Serbica, is the name for a series of symbols, i.e., letters, found at prehistoric sites in Southeastern Europe, more precisely in Serbia and Romania. Some scientists argue that it is a script of the Vinča culture. In order to gain more knowledge about perhaps the oldest script in human civilization, the Government of the Republic of Serbia decided to conduct extensive excavations in the territory of the municipality of Vinča. Excavations are scheduled to begin next year. A handful of Neolithic objects are expected to be found.

The paper describes the conservation plan of excavated cultural heritage objects using gamma radiation. The radiation conditions are described. After determining the stability of the samples relative to the effect of gamma radiation and determining the appropriate dose of radiation, the conservation process will start.

IAEA-CN-332/407

PUFFIn – A Simple Dose Distribution Simulation Software Tool for Gamma, X-Ray, and Ebeam Irradiation Processes

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PUFFIn (PENELOPE User Friendly Fast Interface) was designed as a fast and simple Monte Carlo simulation tool for the transport of photons and electrons, with a primary purpose as a learning and education tool. It is expected to help fill education and knowledge gaps in the industry, as identified in reports by Fermilab (2017) and the IAEA (2020). PUFFIn can be used for multiple geometry types, from simple, single material simulations, to full 3D configurations created from CAD input files or images from X-Ray Tomography scans. The original version of PUFFIn was geared toward applications involving sterilization of static medical products irradiated with gamma, X-ray or electron beam (ebeam). However, recently PUFFIn was used to simulate dose to food/agricultural products irradiated with low-energy ebeam.

A future version of PUFFIn is planned for modeling self-contained, cabinet gamma-ray and orthovoltage X-ray irradiators used in research facilities and hospitals. PUFFIn could also be used for applications involving crosslinking of cables, sterilization of soil and water, radiation hardening of electronics and radiation shielding of facilities.

IAEA-CN-332/673

Developing of Machine Learning Models for the Optimization of Radiation Synthesis

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Machine learning (ML) is a pivotal field in the realm of artificial intelligence. It is dedicated to developing and studying statistical algorithms that can learn from data, generalize to unseen data, and perform tasks without explicit instructions.

We are developing ML models to optimize experimental conditions for the following projects:
Radiation synthesis of polyacrylic-alumina-based nanogels for binding free chloride ions in concrete
Radiation synthesis of novel materials for body armor applications
Radiation grafting of amines onto nylon and fluorinated polymers for CO_2 capturing

The radiation chemistry of polymers is a complex and time-consuming process involving much trial and error. Numerous experimental parameters, such as dose, dose rate, temperature, pH, etc., need to be considered, along with the unique radiation chemistry of the materials in question. Finding ways to speed up the discovery of new experimental designs or configurations to maximize desired results, such as the degree of grafting or chloride binding by radiation-synthesized nanogels, while minimizing undesired outcomes, such as side reactions, is challenging. Machine learning may be employed to guide informed experimental designs.

Our main strategy involves using Bayesian optimization and Gaussian processes, which are powerful statistical methods for building models (refer to Figure 1). These methods have shown their potential to help researchers identify the most appropriate experimental parameters. Our end goal is to describe our systems using neural differential equations, creating a framework for optimizing desired variables and enabling more precise experimentation and analysis.

This research process is iterative and adaptive. We will collect published datasets to build our optimization models in parallel with our experimental studies. As we progress, we will continuously update these datasets to construct and enhance our models based on the most recent results. These transformed datasets are then divided into training and testing subsets. We will evaluate model accuracy and perform statistical analysis to prevent bias.

IAEA-CN-332/797

The Creative Aspects of Irradiation in the Example of Polymerization and Crosslinking by Computer Experiment

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Polymerization is a process were long macromolecules and synthesized by step by step addition of monomer units. Crosslinking means cross-connection of macromolecules to form more complex polymer objects such as polymer networks [1]. Both types of reactions are extremely important for both chemistry and materials science. If the reaction is performed in water environment irradiated by an electron source, then the created OH radicals work as a reaction initiators. To investigate and explain some results obtained experimentally we have proposed using a Monte Carlo computer simulations. The presented results were supported by molecular dynamics and quantum calculations. One of the models used was Dynamic Lattice Liquid (DLL), a model originally proposed by T. Pakula [2] as a lattice method that treats matter as a coarse-grained system with realistic time scale with motion based on the concept of cooperative movement. The model was already successfully applied in polymer problems: static and dynamic properties of bottle brushes [3], polymer stars with highly compact multifunctional cores [4], polymer brushes on flat surfaces [5,6], polymer opposing brush structures, and dynamics [7], precisely defined bottle brushes under good solvent conditions that are directly compared with experimental studies [8].

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STREAM B

Radiation Sources and Industrial Applications

IAEA-CN-332/819

Direct Air Capture is the Only Solution to Remove Excess CO_2 From the Atmosphere

O. Güven (Hacettepe University) – Türkiye

2023 UN emissions gap report revealed that the world is on track for 2.9 ºC of global warming before the end of this century. Although actions such as expanding the use of renewal energy, introducing more green technologies, increasing the number of electric vehicles, and stopping deforestation are being taken, these concerted efforts per se are far away from reaching the 1.5 ºC target. Our planet's atmosphere is not only under the threat of CO_2 released from point sources such as power plants, cement factories, and other anthropogenic activities, but more from the unaccounted and uncontrolled sources.

Capturing CO_2 at the emissions source is meant to prevent new carbon emissions entering into the atmosphere. Direct air capture (DAC) however seeks to remove historic CO_2 emissions accumulated over many decades and new releases from unaccounted and uncontrolled sources. These sources include but are not limited to i) Forest fires, ii) Volcanic eruptions, iii) Earthquakes, iv) Space industry emissions, v) Military emissions, vi) Military conflicts, vii) Permafrost carbon emissions, viii) Seabed thrawling. The contributions from each of these sources will be elaborated in this presentation. Because of the distributed nature of their locations these emissions can only be treated by DAC of CO_2 from the atmosphere. The unprecedented emissions from these unaccounted sources as well as the risk of unpredictable emissions could only be handled by direct removal of CO_2 from the ambient air. Because of the ratio of air to CO_2 molecules (2500:1), large volumes of air need to be processed to separate meaningful amounts of CO_2. The only feasible technique to achieve this involves either absorption or adsorption on a sorbent. The current research in the world has been focussed on the development of new techniques or sorbents to remove exessive amoutn of CO_2 accumulated in the atmosphere.

The carbon capture and carbon removal processes should not be considered, as some claim, as a greenwashing of controversial use of fossil fuels but as a long-term solution to reduce huge amounts of CO_2 accumulated historically and continuously generated from anthropogenic and natural activities. According to the estimates made by the National Academy of Sciences, in order to meet the Paris Agreement goals, 10 billion tons of CO_2 have to be removed globally each year by 2050 and 20 billion tons to be removed each year by 2100. The launching of a new Coordinated Research Project (CRP) by the IAEA on this subject should therefore be considered as a very timely and important step towards drawing the attention of the Member States in developing radiation-based solutions to mitigate this universal poblem.

IAEA-CN-332/569

An irradiation platform to educate, promote and disseminate the benefits of using electron accelerators

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One major way to promote and disseminate the benefits of using electron accelerators is through education and training, thus, creating new competences.

In this respect, Aerial runs a platform of irradiation facilities based on electron accelerators, producing low, medium and high energy electron and X-ray beams. This platform is strictly dedicated to performing experimental and theoretical trainings, irradiation trials, studies and research projects on applications of current interest as well as innovative approaches to irradiation process control and dosimetry.

Indeed, new methods of process control and product release are currently being evaluated. The use of Monte Carlo simulations for operational and performance qualification of an electron beam or X-ray process is becoming increasingly realistic and help for implementing this accelerator-based irradiation technique.

A photon is a photon, … and interaction of electrons with matter eventually lead to electrons being set in motion… but…
What about transference of Dmax,acc?
What about locations of minimum and maximum dose zones in a product?
How can a DUR be improved?
Which dosimetry tools should be selected with regard to the radiation technology?
Can calibrations be transferred from one technology to another?

These pertinent questions are addressed during training sessions and put into practice thanks to our unique ability to conduct hands-on sessions.

During the presentation, Aerial will showcase the resources and tools available at the feerix® platform for the benefit of trainees.

After 4 years of feedback, feerix®, as part of Aerial's technical resource center model, has demonstrated its ability to support companies and public bodies in meeting the future challenges of the irradiation industry.

IAEA-CN-332/839

Development and Construction of a Mobile Electron Beam Accelerator to Treat and Recycle Industrial Effluents

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In the world, there is a growing increase in the demand for water for human consumption, as well as the prioritization of the use of available water resources for public supply. Industries have been concentrating efforts on decontamination programs of industrial effluents. However, the existing wastewater treatment plants may have a low efficiency for removal of refractory pollutants, mainly organochloride compounds. The main gaps are associated with the following problems: a) removal of odorific substances, such as geosmine (GEO) and methylisoborneol (MIB), in drinking water to treat these chemical compounds responsible for taste and odor problems; b) removal and degradation of toxic and refractory pollutants (organic compounds) from sewage and industrial wastewater; c) sewage and sludge disinfection; d) wastewater from a municipal treatment plant for evaluation of the electron-beam technology in different steps of the plant; e) evaluation of the dewatering sludge; and f) toxicity removal by decomposition of surfactants and organic compounds in sewage and industrial wastewater treated by electron-beam process.

The treatment of wastewater and industrial effluents by electron beam irradiation is a promising technique, however, not very widespread in Brazilian territory.

The design and construction of a mobile unit by the Nuclear and Energy Research Institute (IPEN/CNEN), containing an electron beam accelerator is innovative to demonstrate the effects and positive results of this technology. The mobile unit has as one of its main advantages the possibility of treating effluents in the place where the source is located, eliminating costs and bureaucratic problems associated with the transportation of waste, besides publicizing the technology in several places in the country. To implement the project, IPEN/CNEN has been consolidating partnerships with national and international companies.

The resources for the development of the unit have been supplied by the Brazilian Innovation Agency (FINEP) and International Atomic Energy Agency, financing the “IAEA TC Project BRA1035 - Mobile electron beam accelerator to treat and recycle industrial effluents”. The Institute has associated with a specialized company (Truckvan Industry) in an innovation project for the unit design and development. Several meetings have been realized with the company and the International Atomic Energy Agency experts, aiming the compatibility of the design and the exchange of information necessary for the project development.

The project outputs are defined as: a) mobile irradiation unit with electron beam accelerator (EBA), operational and technologically established for treating industrial pollutants; b) capabilities on tests and demonstration of the mobile built; c) know-how in the design, manufacture and installation of the radiological shielding for the EBA irradiation device; and d) treatment methodologies for different pollutants developed and demonstrated using radiation processing technology to end users.

The idealized project divides the cart in the following modules: a) control room and laboratory for technical and scientific dissemination of the technology; b) industrial electron beam accelerator, hydraulic units, ventilation system, cooler and bunker with irradiation device; and c) transformer and power source supply. A 3D model study of the control room and laboratory space was done to facilitate understanding the internal distribution of the laboratory analysis equipment (Gas Chromatography Mass Spectrometry, Total Organic Carbon and UV-Visible Spectroscopy).

The irradiation system with electron accelerators allows treating different types of effluents. Depending on the effluent, the amount of ionizing radiation energy required for treatment may vary, as well as the amount of treated effluent per day. For the construction of the mobile unit, the estimated cost is about US$ 1.5 Million. The type of treated effluent, the treatment cost per m3/day and other information regarding the cost of maintenance and operation of the mobile unit are obtained from the Business Plan of the Mobile Unit.

As the installation of electron beam accelerator (700 keV, 28 mA, 20 kW and 640 mm window), irradiation device, radiological shielding, control panel and other associated systems, analytical instruments and components were completed, the mobile unit is now positioned at Technology Readiness Level (TRL) 7, in which the scale ranges from TRL 1 (lowest) and TRL 9 (highest). In other words, the working model or prototype was demonstrated in a space environment.

A new partnership agreement between IPEN/CNEN and Truckvan Industry is about to be established for the completion, demonstration and operation of the Mobile Irradiation Unit in several industries throughout Brazil. In this regard, technology will be fully positioned at TRL 9. In addition, IPEN/CNEN is also establishing a licensing agreement with Truckvan Industry to receive royalties from the upcoming exploration of this innovation in the market.

IAEA-CN-332/330

New Progress and Development Trend of China's Radiation Science and Technology Industry

K. Shen (China Isotope and Radiation Association (CIRA), China National Nuclear Corporation (CNNC)), L. Guo (China Isotope and Radiation Association (CIRA)) – China

China's radiation science and technology industry has demonstrated tremendous development potential, economic benefits, and immeasurable social benefits since the "13th Five-Year Plan" period. Now during the "14th Five-Year Plan" period, the related science and technology industry continues to improve.

There were 11 research reactors in operation nationwide in 2023. We have formed a certain scale of production capacity in accelerator manufacturing and radioactive isotope preparation. Radiation processing has been widely used in many fields such as radiation modified advanced materials, medical sterilization and storage &fresh food. The domestic social security industry is entering a new model of intelligent security check. There also has been rapid growth and significant acceleration in nuclear medicine. As a crucial component of precision diagnosis and treatment, radiopharmaceuticals now receive significant attention in the country. The government has already provided a roadmap to drive the development of medical isotopes and radiopharmaceuticals industry forward.

In the future, we will adhere to innovation-driven development, promote radiation science and technology industrial upgrading, to build a healthy safe and beautiful China.

IAEA-CN-332/841

The IAEA's Role in Advancing Radiation Science and Technology

C. Horak (Radiochemistry and Radiation Technology Section, NAPC, IAEA)

The International Atomic Energy Agency (IAEA) plays a crucial role in promoting the safe and effective use of radiation science and technology to address pressing global challenges. Among its various initiatives, the development and application of gamma and electron beam (E-beam) technologies stand out as transformative forces in fields such as healthcare, industrial processing, and environmental management. These abstract highlights the IAEA’s efforts to advance these technologies and showcases the upcoming E-beam system to be installed at the IAEA Seibersdorf Laboratories, along with innovative strategies for making this technology more accessible to Member States.

Furthermore, the E-beam system will facilitate rapid adoption through cutting-edge research and development, knowledge sharing, capacity building, and collaborative projects. Additionally, the development of e-learning courses, guidelines, and relevant scientific publications will further enhance understanding of the potential benefits and challenges associated with radiation technology. This collaborative approach not only strengthens the scientific knowledge of Member States but also promotes their technological capabilities and supports sustainable development.

IAEA-CN-332/820

Contribution of Radiation Technologies to Sustainable Development Goals, particularly Ensuring Food Security and Food Safety through the Adoption of eBeam/X-ray Technologies

O. Acuna Blanco (Texas A&M University) – USA

Access to nuclear technologies is critical for countries around the world. Besides the use of nuclear technologies for medicine, sterilization of single use medical devices, food pasteurization and phytosanitary treatments constitute the other major application of nuclear technologies. Cobalt-60 is the legacy of industrial sterilization technology all around the world. Due to the increasing costs of cobalt-60, the projected short supply of the isotope, the tightening restrictions on transboundary shipment of cobalt-60, and the security risks radioactive cobalt-60 can pose, there is a growing interest in a deeper understanding and commercial adoption of accelerator technologies such as eBeam and X-ray in member states. The expansion of the utilization of these technologies around the world will significantly contribute to key sustainable development goals, such as food security & food safety, human health and environmental remediation. In this presentation, we will delve into valuable insights gained from activities conducted by the Texas A&M National Center for Electron Beam Research, a Collaborating Center of the IAEA on the promotion of these technologies for Food, Health and Environmental Applications. The discussion will focus on our cooperation with countries around the world for the adoption of these technologies and their contributions to their economic prosperity.

IAEA-CN-332/567

Scanning Solutions for Pipelines and Trees Using Gamma Rays

A. Saadaoui, A. Jainija (CNESTEN) – Morocco

Pipelines, considered the nerve center of the industry, are subject to several problems during the industrial production process such as corrosion and internal deposits.

These internal deposits and corrosion, in turn, ultimately lead to unnecessary downtime and reduced efficiency and in the worst case, damage to pipelines and associated process equipment.

In this work, we will present a solution and cases studied for scanning pipelines using Gamma rays which can also be applied to study tree trunks in order to evaluate their internal health conditions in terms of the existence of holes or the development of diseases manifested by unexpected internal densities.

IAEA-CN-332/732

Education in Radiation Technology: Current Status and Possible E-learning Future Prospects

H. Abdelrehim (Atomic Energy Authority of Egypt) – Egypt

The development and growth have been witnessed by radiation treatments as one of the uses of the atom in peaceful applications in industry, medicine and the environment during the past two decades required real practical training after graduation which in fact. has not kept pace with this progress, whether in terms of multidisciplinary curricula and practical work or in terms of technological progress in particular. Education in the field of radiation technology is a major priority in the context of the rapid development of the uses of radiation technology, including advanced knowledge of radiation biology, radiation physics, radiation chemistry and the science of the effect of radiation on materials. In this context, the lack of training in the field of the effect of ionizing radiation on materials and its distinctive uses in aspects of life in the curricula of various faculties of science, engineering, industry and the environment may not lead to the transfer of this unique technology to the minds of students, but also in their choice of specialization after completing their university studies. There is a clear gap between actual and required knowledge in the field of using the atom in various peaceful applications, and this requires urgent treatment. We believe that distance education can quickly contribute to bridging this gap, as e-learning programs can help radiotherapy professionals or provide basic units with information about radioactive and nuclear materials, processes and equipment, the unique uses of radiation in industry, medicine and the environment, and raise awareness of its importance and role in the national economy and sustainable development. The success of e-learning depends not only on the functions provided by these new technologies, but also on the content provided. Creating content is a time-consuming task that requires teachers to prepare materials with the consideration that they will be accessed online. It is essential for teachers to prepare material that is appropriate for theory and application to obtain the desired e-learning outcomes. In addition, current technologies allow the creation of educational materials that combine images, videos, texts and sounds, through which students can access these materials interactively by providing feedback according to their actions.

IAEA-CN-332/448

Using Ionizing Radiation to Treat Cultural Heritage Artefacts for their Conservation

L. Cortella (ARC-Nucléart CEA) – France

The remedial conservation of cultural heritage aims to arrest current damaging processes, and if necessary to reinforce the structure of weakened artefact. It calls upon a very wide range of techniques, moving from an artisanal approach to a scientific and technical approach several decades ago.

Radiation processing, by stopping bio-degradation or achieving consolidation of the most fragile objects using radio-curable resins falls precisely within the scope of remedial conservation. However, nuclear technology is not part of the traditional skills of conservators and many fears remain among both conservators and curators when it comes to carrying out these actions that they cannot accomplish by themselves.

The integration of heritage professionals in the teams carrying out irradiation treatments contributes greatly to make these techniques known and accepted, but this is rarely possible. Some teams also forged strong links with institutions specializing in heritage and now routinely carry out treatments.
Scientific publication about the behavior of materials under irradiation are fundamental but not sufficient to dissipate natural fears before exposing heritage objects to high doses of radiation. Participation in conferences and workshops for restorers has to be encouraged. Examples of success stories are our best ambassadors..

IAEA-CN-332/377

Enhancing Regional Capabilities through NDT-CE Training: Insights from the IAEA-RCA Project in Asia and the Pacific

I. Mukriz Zainal Abidin (Malaysian Nuclear Agency) – Malaysia, G. Maghella Seminario (International Atomic Energy Agency) – Austria

In the Asia and Pacific region, natural disasters such as earthquakes and flooding have become more frequent over the last decade. In 2014, over half of the world's 226 natural disasters occurred in this region, which experienced severe storms, cross-border floods, and landslides, accounting for 85 percent of all disasters. The aftermath of these events caused significant damage to civil structures, severely hindering the use, operation, and delivery of essential services. Such disruptions undermine the ability of governments to provide critical public services and negatively impact economic activities. Non-destructive testing in civil engineering (NDT-CE) methods, including radiography and other complementary modalities, have proven to be efficient in assessing the integrity of critical buildings and structures. Due to the increasing frequency of natural disasters in Asia and the Pacific region, the need to enhance the capabilities of Government Parties (GPs) in NDT-CE for inspecting civil structures has become evident. This paper presents the role of the International Atomic Energy Agency (IAEA) through the Regional Cooperative Agreement (RCA) projects in assisting the GPs of Asia and the Pacific region to establish capacities in NDT-CE. It focuses on efforts to promote the establishment of national NDT-CE infrastructures through a strategic training approach, with the objective of improving regional capabilities to respond to natural disasters and facilitate the recovery of critical civil structures. The challenges and common issues faced by the GPs in achieving the expected outcomes are also highlighted and discussed. While acknowledging the contributions of experts from other regions, the success of these projects is significantly attributed to the strong regional network and cooperation between GPs, driven by the IAEA and RCA, which provided the necessary impetus for effective project implementation.

IAEA-CN-332/836

Radiation Technology for Cleaner Environment

B. Han (Bright Future Technology Inc) – Republic of Korea

Environmental pollutants have rapidly increased in both number and quantity due to urbanization, industrial growth, and population expansion. Unlike natural contamination, which arises from natural processes, artificial contamination has become a major global issue. The introduction of toxic compounds into the air, water, and soil poses a serious risk to human health and harms ecosystems, the environment, and the planet's climate.

Effective environmental control is economically more viable than the irreversible damage to the planet's life support systems, which incurs far greater environmental costs. Achieving these goals requires unique approaches and methods. Radiation technologies have emerged as powerful tools in industry, agriculture, and scientific research. Various radiation processing technologies aimed at ensuring the safety of gaseous and liquid effluents discharged into the environment have been developed in recent years. Pilot and industrial-scale installations have demonstrated that radiation-based technologies for flue gas treatment (SOX and NOX removal), wastewater, and sludge can help mitigate environmental degradation. Countries worldwide, including developing nations, have shown great interest in using radiation technology to process effluent, particularly to remediate polluted waters and wastewater.

Furthermore, radiation technology proves useful in addressing emerging pollutants found in groundwater, such as fertilizers, pesticides, and pharmaceutical residues, which can lead to groundwater pollution and subsequent contamination of water resources. Radiation technology has also shown promising results in recycling waste plastics, transforming them into raw materials for new plastics, building materials, or useful fuels. Particulates and gases, or acidic gases that cause greenhouse gas emissions, are the main culprits in air pollution, driven by power plants, industry, and transportation. Technologies that use radiation to transform greenhouse gases into other useful forms or effectively separate and store them are also being studied.

A significant advantage of radiation technology is that reactive species are generated in-situ during the radiolysis process, eliminating the need for additional chemicals. Moreover, these reactions can be conducted at relatively low temperatures, resulting in lower energy costs, minimal thermal damage to the system, and its products.

IAEA-CN-332/358

Electron Beam Technology for the High Concentrated UDMH Solution Treatment

S. He, J. Wang (Tsinghua University) – China

Unsymmetrical dimethylhydrazine (UDMH) is an excellent propellant which is often used in the aerospace industry. However, due to its high toxicity, UDMH may pose a huge safety risk to the surrounding environment and field workers. In this study, a combination processes of electron beam (EB) irradiation and electrochemical oxidation of UDMH was developed. The influence factors such as pH, concentration of UDMH and absorbed doses on the effects of UDMH degradation and chemical oxygen demand (COD) removal were investigated. The present results showed EB process could effectively degrade UDMH and COD in the wastewater and the removal efficiencies of both UDMH and COD increased with the increase in EB absorbed dose. When the initial concentration of UDMH was 40300 mg/L and the absorbed dose achieved 1200 kGy, the removal efficiencies of UDMH and COD were 99.35% and 75.47%, respectively. In addition, for UDMH wastewater with an initial concentration of 12247 mg/L, UDMH could be completely removed and COD could be reduced to less than 50 mg/L by 400 kGy irradiation coupled with electrochemical oxidation for 7 h. This study provides an alternative process, especially for emergency treatment of high concentration UDMH wastewater.

IAEA-CN-332/549

•OH Induced Degradation of Trimethoprim in Aqueous Solutions

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Background of the study: The adverse effects of pharmaceuticals, e.g., that of the Trimethoprim antibiotic (TMP), in our ecosystem are well documented, particularly due to their role in the development of antibiotic resistance. Advanced Oxidation Processes (AOPs), in which radical reactions play the key role in the degradation, are effective supplementary techniques for elimination of pharmaceuticals in water. Pulse radiolysis is an often applied method for studying the elementary steps of free radical reactions. Under ionizing radiolysis induced water purification conditions hydroxyl radicals (•OH) initiate the reactions. The degradation mechanism can be deduced from the nature and kinetics of the transient intermediates formed.

Methodology: Our transient kinetic measurements were carried out using 4 MeV accelerated electrons with electron pulse length of 800 ns and utilizing kinetic spectrophotometric detection with 1 cm path length cell. The reactions between •OH and TMP were studied in details taking into account the effect of pH. •OH reactions were investigated in N2O saturated solutions. Kinetic measurements were conducted based on the decreasing concentrations of the substrates being studied.

Results: •OH reactions of TMP were investigated at pH ~ 4.9, 7.0 and 9.5 by pulse radiolysis. Our measurements, in agreement with literature results, indicate that the primary interaction between •OH and TMP is radical addition to the double bonds in the rings. At the smallest pH, •OH predominantly attacks the 1,2,3-trimethoxybenzene (TMBz) segment, resulting in an adduct intermediate with an absorbance maximum in the 340-355 nm range. However, we detected also reaction with the 2,4-diaminopyrimidine (DAP) part. •OH being an electrophile reagent is expected to react more rapidly with the neutral DAP moiety (at high pH) of TMP than with the positively charged one (at lower pH). In the interaction between •OH and TMP H-atom abstraction from the –CH2– bridge can occur with low contribution. The second-order rate constant of the •OH + TMP reaction was determined using the concentration dependence of pseudo-first-order rate constants (k•OH □TMP□) of absorbance build-up at the wavelengths of maxima. The k•OH values at pH 4.9, 7.0 and 9.5 were found to be 5.2 □ 109, 5.5 □ 109 and 8.0 □ 109 mol□1 dm3 s□1, respectively. The pH dependence reflects the electrophilic nature of the radical addition reaction.

Conclusion: Advanced Oxidation Processes can effectively remove antimicrobial drugs, potentially reducing their environmental impact and the risk of antibiotic resistance. This study focused on the detailed analysis of reactive intermediates of radiation-induced degradation of Trimethoprim, a commonly used antibiotic. Ionizing radiation, which involves •OH radicals, effectively degrades TMP in water. At higher pH, when the molecule is neutral, •OH radicals target both the TMBz unit and the DAP part, at lower pH the target is the TMBz unit. The abstraction of H-atoms from the –CH2– bridge may occur at a low yield.

IAEA-CN-332/203

Antibiotics Degradation and Toxicity Removl by Electron Beam Irradiation

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Radiation technology is one of the possibilities for cleaning wastewater once radiation can drastically reduce microorganisms while starting the decomposition of organic molecules using relatively low dose (0.5 – 5.0 kGy). Ecotoxicology and other biological assays have extensively been applied for demonstrating the benefits for cleaning wastewater technologies: to prioritize the needs of industrial sectors; to help risk analysis; cytotoxicity and mutagenicity determinations, etc. Pesticides and pharmaceuticals are the prevalent emerging pollutants in water samples in Brazil (de Souza et al, 2021). Electron beam treatment of antibiotics resulted in high degradation efficacy: amoxicillin (> 97%), ciprofloxacin (> 95%), and sulfadiazine (> 99%); radiation doses 0.75, 1.0 and 0.50, respectively. Comparing acute effects to D. similis, ciprofloxacin was more toxic from the three treated pharmaceuticals after irradiation, and these similar procedures have also been applied for mixture of pharmaceuticals. EB irradiation may be considered for the treatment of pharmaceuticals in a combined processing of wastewater, an alternative and advanced oxidative process.

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IAEA-CN-332/043

Radiation Induced Treatment of Leachate Nanofiltration Concentrate

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Leachate nanofiltration (NF) concentrates are considered non-biodegradable wastewater due to high COD (1100-6800 mg/L) and low BOD5 (3-290 mg/L) concentrations. Leachate membrane concentrates also contain high concentrations of inorganic nitrogen species such as total nitrogen (TN), ammonia nitrogen (NH3-N) and nitrate. Since leachate membrane concentrates contain very complex and very different pollutants, a high-capacity and flexible treatment process is needed for their management.

Radiation technology offers advantages as a green technology in solving the environmental problems like non-waste generating treatment process, economically competitiveness, high efficiency. In addition, radiation technology is preferred in wastewater treatment studies as it is the only process among advanced oxidation methods that has both reducing and oxidizing properties.

In this study, NF concentrate and chemically precipitated of raw leachate were irradiated with 60Co, an ionizing radiation source. First, chemical precipitation was applied to the leachate NF concentrate of 2763 mg/L COD and 220 mg/L BOD5 with FeCl3 at pH 5. Second, different doses (0, 10, 20, 30 kGy) of 60Co gamma ionizing radiation were applied to both the raw leachate NF concentrate and chemically precipitated raw leachate. Then, pH, conductivity, color, COD, BOD5 and some organic pollutants were followed in the samples before and after irradiation. It was determined that there was no change in pH in both the raw and the chemically precipitated concentrate, but there was a slight increase in conductivity. It was also noted that there was a decrease in color due to the increasing irradiation dose in the raw leachate NF concentrated sample, and that the dose was not effective in color removal in the sample treated with chemical precipitation with FeCl3. In addition, a decrease in organic pollutant content concentrations was detected in proportion to the dose in both chemical precipitation applied and the raw leachate NF concentrate. A significant increase was detected when the treatment efficiencies of organic pollutants in the sample subjected to chemical precipitation compared with the treatment efficiencies in the sample in raw leachate NF concentrate. Average treatment efficiency raised from %46 to %68 at 10 kGy, %55 to %80 at 20 kGy and %60 to %87 at 30 kGy. It shows that ionizing radiation assisted with FeCl3 increases the treatment efficiency of the leachate NF concentrate.

IAEA-CN-332/833

Radiation Technology for Health, Environment and Sustainable Development - Good Practices in Asia

Y. Liu (China Isotope & Radiation Corporation (CIRC)) , W. Yang (CIRA) – China

Radiation application technology, which employs scientific methodologies to effectively control interactions between radiation and matter for understanding and transforming the world, has gained widespread recognition and application in modern industrial production and daily life. As a leading state owned enterprise in China's nuclear technology application sector, China Isotope & Radiation Corporation (CIRC) has dedicated itself to the research, development, and promotion of radiation technologies. Its research encompasses multiple domains, including the preparation of radioactive sources and radiation-emitting devices, design and construction of irradiation facilities, non-destructive testing and analysis, and material irradiation modification.

In the field of irradiation facility design, CIRC has independently developed gamma irradiation systems characterized by superior dose homogeneity, high energy utilization efficiency, and flexible operation. These systems have been successfully deployed and operationalized in numerous countries. Regarding radioactive sources, the company has pioneered a diversified portfolio, including non-destructive testing sources, medical therapeutic sources, industrial irradiation sources, and instrumentation sources, which have been extensively applied in healthcare, scientific research, and industrial sectors.

In material irradiation modification, sustained research efforts have enabled CIRC to commercialize a series of advanced products, such as irradiated tubing, irradiated liquor, and high-performance carbon fiber composites. Furthermore, collaborative endeavors with research institutions have yielded significant progress in the development of accelerator-driven neutron sources.

This report provides a comprehensive overview of CIRC's recent research advancements in these critical areas and outlines strategic perspectives for future development.

IAEA-CN-332/048

Radiation Assisted Decontamination of Antibiotic-Resistant Microorganisms in Hospital Wastewater Effluent

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Hospital wastewater contains antibiotics, antibiotic-resistant bacteria, and antibiotic resistance genes, posing a significant pollution threat to the environment if not properly treated before being discharged into water treatment facilities, rivers, lakes, or seas. The spread of antibiotic-resistant bacteria has become a significant worldwide issue recently.

This study seeks to utilize irradiation methods for treating wastewater to reduce environmental pollution and minimize the threats posed by antibiotic-resistant bacteria (ARB) and pathogenic bacteria to both the environment and human health. This research aims to enhance the efficiency of wastewater treatment systems by implementing on-site applications, not limited to wastewater treatment plants (WWTPs) but also including medical institutions. This research using irradiation treatment will help reduce the release of antibiotic-resistant and pathogenic bacteria into rivers, thus protecting the health of aquatic ecosystems. Initially, we conducted analyses on Total Aerobic Mesophilic Bacteria, Enterococcus, Pseudomonads, Coliform, E. coli, Staphylococcus aureus, and Salmonella spp. to ascertain the microbial load in the hospital wastewater. Following the incubation period, we isolated and analyzed the suspicious colonies from each group of bacteria. We then irradiated wastewater samples with gamma irradiators at doses of 0, 1, 2, 3, 4, and 5 kGy to isolate radio resistant bacteria. To identify suspicious colonies, Gram staining, catalase, and oxidase tests were performed. The radio resistant strains were identified as Enterococcus faecium using MALDI-TOF MS rapid identification. Following the identification of resistant bacteria, to evaluate the impact of different dose rates (1078 Gy/h and 257 Gy/h) from a gamma source, uncontaminated and Enterococcus faecium-contaminated samples were subjected to radiation doses ranging from 0 to 3.5 kGy in order to detect the reduction in both total aerobic mesophilic bacteria and radio resistant bacteria. The results of microbial load analyses showed that the number of Total Mesophilic Aerobic Bacteria, Enterococcus, Pseudomonas, Coliform, and E. Coli were 6.08 log CFU/mL, 3.57 log CFU/mL, 4.0 log CFU/mL, 5.04 log MPN/mL, and 2.87 log MPN/mL, respectively. Nevertheless, the sample did not include any Salmonella spp. or Staphylococcus aureus. Additionally the bacterial colonies collected from wastewater analyses were identified as Enterobacter aerogenes, E.coli, Citrobacter freundii, Klebsiella pneumoniae, and Klebsiella oxytoca, which belong to the Enterobacteriaceae family. Besides Enterobacteriaceae members, Pseudomonas spp. and Enterococcus spp. were also identified according to Bergey's Manual of Determinative Bacteriology. Furthermore, the radio resistant bacteria were confirmed to be Enterococcus faecium by MALDI-TOF MS rapid identification system.

The findings from analyses on the determination of D10 values revealed that the D10 values for total aerobic mesophilic bacteria were found to be 0.95 kGy for the high dose rate and 1.26 kGy for the low dose rate. The D10 values for Enterococcus faecium were determined to be 1.13 kGy for the high dose rate and 1.67 kGy for the low dose rate.

These results highlight the potential of irradiation process in wastewater treatment to combat the spread of antibiotic-resistant bacteria, thereby mitigating environmental pollution and safeguarding public health.

IAEA-CN-332/823

Degradation of Micropollutants in Wastewater by Hybrid Treatment with Low-energy Electrons and Ozone

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The growing use of pharmaceuticals and their chemical persistence lead to increasing concentrations of micropollutants in the aqueous environment because traditional wastewater facilities are often unable to effectively remove these emerging pollutants. Therefore, Fraunhofer FEP is developing a hybrid process that combines treatment of the wastewater with low-energy electrons and ozone.

The hybrid treatment module was designed as a compact and easy-to-integrate device, enabling local processing of wastewater at point sources of contaminations, such as hospitals. The aim is to transform a broad range of micropollutants into substances, which can successfully be removed in downstream biological stages of conventional wastewater purification plants.

In the present work, five selected pharmaceuticals were dissolved in synthetic wastewater, treated and then subjected to analysis by High-performance liquid chromatography. Significant degradation of greater than 80 % was achieved at absorbed doses below 2.5 kGy for each substance. This demonstrates the hybrid treatment’s advantage compared to other advanced methods, such as activated carbon filtration or UV irradiation. The biodegradability of the reaction products was studied in a laboratory-scale wastewater purification unit, utilizing activated sludge from a municipal wastewater facility, in order to assess the fate of these substances in established wastewater purification processes.

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The Terrestrial Environmental Radiochemistry Laboratory

J. Burnett (International Atomic Energy Agency) – Austria

The key task of the International Atomic Energy Agency (IAEA) Terrestrial Environmental Radiochemistry (TERC) Laboratory is to provide expertise, training and support dealing with radioactive, industrial and other pollution. It assists Member States in responding to the consequences of accidental or intentional releases to the environment through a combination of capacity building activities and the analytical capabilities of the TERC Laboratory. The capacity building activities include providing training and expertise, through training workshops, fellowships and comprehensive technical guides and instructions. These areas are wide ranging, from environmental sampling to radiochemical separations and measurement, to environmental impact assessments and remediation strategies. They also include the provision of the Worldwide Proficiency Test Exercise, with over 500 participants from 100 Member States, and aids in developing and maintaining capability for measuring radionuclides in a variety of sample types. The TERC Laboratory is also ISO17034 accredited for producing certified reference materials (CRMs) for quality assurance purposes, and each years supplies approximately 2000 CRMs to Member States globally. The laboratory has extensive analytical capabilities including the capability to perform radiochemical separations and measurement through alpha-, beta- and gamma-spectrometry and inductively coupled plasma mass-spectrometry (ICP-MS). These capabilities are utilised for the characterisation of proficiency test exercise and reference material samples, and in support of monitoring campaigns to assess the impact of environmental pollution.

IAEA-CN-332/832

Role of the IAEA Marine Environment Laboratories in Marine Environmental Monitoring and Protection

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The International Atomic Energy Agency (IAEA) plays a pivotal role in Ocean health monitoring and protection through its Marine Environment Laboratories (MEL). These unique laboratories within the UN system are dedicated to assessing and mitigating the impacts of pollutants in marine ecosystems. Through cutting-edge research and advanced analytical techniques, the IAEA MEL provides critical data and insights that inform global policies and practices for marine conservation. Key activities at the laboratories include monitoring pollutants in seawater, sediments, and marine biota, developing methodologies for the detection and analysis of marine pollutants, conducting experimental studies to assess the impact of pollutants using radiotracers or isotopes, and producing tailored reference materials for analytical purposes. The laboratories also engage in technology transfer and capacity-building initiatives, offering training and support to IAEA Member States to enhance their capabilities in marine environmental protection. By fostering international collaboration and providing scientific expertise, the IAEA MEL contribute significantly to the sustainable management and protection of the world's oceans. Additionally, the IAEA MEL integrate radiation science and technology into their routine operations to support marine conservation and sustainable development goals.

IAEA-CN-332/510

Versatile Solutions for Phytosanitary Irradiation and Multi-Purpose Applications

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Phytosanitary irradiation of fresh produce has been a critical aspect for ensuring the safety and quality of agricultural products for over two decades in various countries worldwide. While the global volumes of phytosanitary irradiation may currently be lower in comparison to alternative technologies such as methyl-bromide fumigation, cold treatment or hot dip treatment, there is an unmistakable and rapid surge in both the number of approved products and the volumes being processed, particularly in several regions across the globe.

Operating a center for low-dose products, such as fruits, while also considering the treatment of high-dose products, such as medical devices, presents an intriguing challenge. This approach allows for the flexibility needed to respond to the growing demand for phytosanitary treatments, even though the volumes of fruits may currently be moderate. Diversifying production by accommodating both low and high-dose products helps optimize facility usage and adapt to the increasing demand, ensuring a more efficient production scheme. This approach showcases the innovative strategies required to meet evolving industry needs. It's worth noting that X-Ray technology provides a significant advantage, as it can efficiently treat all product categories with superior dose uniformity (DUR) and processing speed while maintaining products on pallets, in contrast to the Duo E-beam method, which necessitates revalidation and depalletization.

The successful execution of phytosanitary irradiation using X-Ray systems poses unique technical and logistical challenges. These challenges are primarily attributed to the diverse nature of the products involved, the necessity for precise dosing, and the inherent characteristics of fresh produce, such as cold chain and rapid turn-around which are unique to these types of products.
Recognizing the pressing need to address these challenges and enhance the efficacy of phytosanitary irradiation for fresh produce, an innovative X-Ray processing system has been meticulously crafted. This system is specifically designed to overcome the unique obstacles associated with the process while maintaining the reliability and precision that is needed.

The main goal of this presentation is to provide valuable insights into the technical challenges of phytosanitary irradiation of fresh produce. Then to show how the innovative X-Ray processing systems can address them. Additionally, it explores how this novel approach can meet industry demands and accomplish with global standards for phytosanitary treatment while shedding light on the unique features and seamless integration of the X-Ray technology into real-world scenarios.

IAEA-CN-332/002

Dual Effect of pH and X-ray Irradiation on Properties of Gelatin/ Trans-Cinnamaldehyde-Based Composite Films for Sustainable Packaging

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Most of solid wastes (38 wt%) come from plastic packaging. Consequently, the environmental impact of non-biodegradable plastic polymers is a serious and major concern. To reduce pollution caused by traditional plastic films, biodegradable films which are made from renewable resources have shown a promising potential. Among the bio sourced polymer-based films, protein-based films can offer good mechanical and gas barrier properties. Indeed, the specific structure of proteins and their ability to form strong intermolecular covalent, ionic and hydrogen bonds allow to easily create linkages and then cohesive networks.

Gelatin is a protein considered as a by-product of the food industry and has a great potential for edible/biodegradable film applications The main objectives of this study were to assess the effects of pH and irradiation doses on crosslinking, mechanical properties, water vapor permeability, and water solubility of the gelatin-based film and their antibacterial properties after incorporation of trans-cinnamaldehyde (TCA).

The gelatin-based water insoluble and antimicrobial film was developed at different pH (4, 6, 8, and 10) and crosslinked by incorporating TCA and low energy X-ray irradiation of different doses (0, 5, 10 and 15 kGy). The TCA mixed compatibly with the gelatin (Gel) matrix and exposure to X-ray irradiation form dense, flexible, and strong films. The film at pH 6, incorporated with 5 wt% TCA and irradiated with 10 kGy X-ray displayed the highest degree of crosslinking (93.4 ± 3.4 %), and showed high antimicrobial activity against Escherichia coli, Salmonella Typhimurium, and Brochotrix thermosphacta. A low water vapor permeability (4.1 g.mm/m2.day.kPa), water solubility (0.5 %), and oxygen transmission rate (33.5 cc/m2.day) was also observed at this optimal condition. The crosslinked Gel films at pH 6 and irradiation dose of 10 kGy exhibited the highest tensile strength (12.5 MPa), excellent UV-barrier ability (> 99.9%), strong oxygen barrier (12.5 cc/m2.day), and exhibited strong antibacterial activity with inhibitory capacity of >50% against E. coli, S. Typhimurium, and B. thermosphacta.

In conclusion, the Gel/TCA films crosslinked with X-ray irradiation developed have muti functional properties and has a strong potential in food packaging application to increase the shelf life of food and reduce the food waste problem.

IAEA-CN-332/113

Risks of External Cereal Supply in Tunisia: EPR Technics for Irradiated Iimport Cereal Detection

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The risks associated with external cereal supply in Tunisia necessitate robust detection and monitoring systems. Electron Paramagnetic Resonance (EPR)techniques offer a reliable method for detecting irradiated cereals, ensuring that imports comply with safety standards and maintaining public health. By adopting advanced detection technologies like EPR, Tunisia can mitigate the risks associated with imported cereals and enhance food safety protocols.

This study measured over two-month period free radicals created in local and imported cereals:wheat, barley, oats and maize subjected to various radiation doses by applying theEPR detection of unpaired electrons in samples, which can be indicative of irradiation.Cereal sampleswere irradiated usingCNSTN'sGamma Facility for a dose range from 0 to 25 kGy and with Dose rate of 14.89 Gy/min.The measurements were performed at room temperature with a Bruker-Magnettech ESR5000 spectrometer equipped with a standard rectangular X-band TE microwave cavity. The EPR signal intensity dependences on the absorbed dose were obtained also the temporal kinetics of the entire spectrum and separated peaks has been studied. The exposed cerealsto ionizing radiation exhibit specific EPR signals that enable precise identification of irradiated samples, highlighting the effectiveness of EPR as a detection method.

Keywords:Imported Cereals, Food Security, Irradiation, EPR.

IAEA-CN-332/517

Calibration, Intercomparison and Simulations: Key Factors in Dosimetry for Better Phytosanitary Treatment

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Phytosanitary treatment using radiation is a current trend in the fruit export-import trade. Radiation dosimetry is a key factor in determining the success of phytosanitary treatment. This study will explain three key stages in assessing radiation quality in phytosanitary treatment.

Calibration and validation are needed to ensure the acceptable dose is correct. This study proves that if the calibration is done correctly, it will produce accurate validation data. Validation is carried out as intercomparison at target doses (in Gy) is 102, 397, and 1000. Prediction of results can also be obtained through Monte Carlo simulation. Where the geometry and simulation process are made close to actual conditions.

The results were obtained that the intercomparison dose read by the accredited laboratory was (dose in Gy) was 97, 381, and 958. Statistically, the standard error is less than 5% compare with dose settings, so the intercomparison results are still within the acceptable range. Similar results were obtained from the Monte Carlo simulation method. Where the agreement between the actual and simulated doses is less than 4%. So from this study, it was obtained that simulation is used as a treatment planning system to ensure that the qualification and dose mapping process is carried out efficiently in terms of cost and accuracy of results. These three stages are techniques for phytosanitary processes to obtain radiation doses that are more precise, reproducible, and predictive.

IAEA-CN-332/297

The Rise of Solid-State Power - a Game Changer in the Accelerator World

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Today's high-energy radiofrequency (RF) accelerators typically rely on vacuum tubes such as triodes, tetrodes and klystrons to drive their final power amplification stage. These vacuum tubes are robust and cost efficient at high power; however, they can represent a significant cost for the operators of these accelerators as they need to be replaced regularly and come at a high premium. Furthermore, these tubes can fail, and typically account for the most common cause of downtime, sometimes resulting in highly intensive diagnostic and repairing efforts, and thus high Mean Time To Repair (MTTR). The maintenance of tube-based amplifiers also requires specific knowledge, fine tuning and trained personnel. The high voltage at which the tubes are operating poses a safety concern and further need for specialized personnel.

Until recently, there were no affordable and practical alternatives to these vacuum tubes. However, promising new developments in the field of solid-state amplifiers (SSA) may very well cause a paradigm shift in the field of RF power for accelerators. These new SSA are based on a plug-and-play modular design, where no component is a single point of failure, making them much more reliable. They do not require any manual tuning and operate at low voltage, diminishing the need for highly trained personnel and facilitating the maintenance. They do not contain any short-lived consumable parts, reducing maintenance load and operational costs. Furthermore, they boast superior electrical efficiency which makes them more sustainable and reduces electricity costs.

In this study, we will present the results of the actual implementation of solid-state technology on an E-beam Rhodotron accelerator. The system allows to generate up to 240 kW of RF power, coupled to the Rhodotron cavity to allow accelerating up to 160 kW of electron beam at 10 MeV. The Rhodotron will be installed in factory and thoroughly tested on RF load at maximum power for several months. Numbers from these tests will be presented, comparing the electrical efficiency measured in practice and the real system uptime to those measured on a Rhodotron equipped with conventional vacuum tube technology. A cost analysis will be presented, showing that solid-state amplifiers are already cost competitive with tube-based amplifiers.

IAEA-CN-332/051

High-Energy Industrial Electron Accelerators ILUTtype

A. Bryazgin (Budker Institute of Nuclear Physics. BINP) – Russia

Budker Institute of Nuclear Physics is constantly developing new industrial accelerators. This report is describing to a series of accelerators of the ILU type. These accelerators are successfully operating in the market for sterilization of disposable medical devices. Entering the promising food processing market requires increasing the power of accelerators and their efficiency to operate in the bremsstrahlung mode. A line of 3 accelerators with energies up to 5 MeV, up to 7.5 MeV and up to 10 MeV with an electron beam power of up to 100 kW has been developed. These models now are manufactured for industrial enterprises in Vietnam and Uzbekistan. New physical solutions for accelerators and features of the layout and conveyor systems for irradiation both in boxes and on pallets are described.

IAEA-CN-332/821

Gamma Sterilization: Sustainable Technology for the Long Term

R. Wiens (Nordion) – Canada

Gamma sterilization has been the predominant radiation sterilization modality for decades, and accounts for more than 40% of all single use medical device sterilized in the U.S. Gamma relies on the ongoing supply of Cobalt-60, a radioisotope produced in nuclear reactors. As sustainability becomes an increased focus of manufacturers everywhere, gamma's clear advantages in terms of environmental impact adds to stability and simplicity as another reason to select this sterilization method.

In this session, you will learn how Cobalt-60 is produced, get updates on the global supply chain and initiatives under way to increase production, and gain insight into the aspects of the technology that make it sustainable for the long term.

IAEA-CN-332/831

Gamma Irradiation in South Africa, Past, Present and Future developments

C. Balt (High Energy Processing Cape (PTY) LTD) – South Africa

Food irradiation in South Africa has a rich history, dating back to pioneering research in the 1960s. The country's irradiation program gained momentum in the 1970s, driven by the Atomic Energy Board and international collaborations, such as the International Food Irradiation Project (IFIP). Research demonstrated the safety and efficacy of irradiation for various food products, leading to regulatory approvals and commercial applications. Despite early successes, including consumer acceptance and industry adoption, international trade restrictions—such as the EU's rejection of irradiated fruit—hindered commercial expansion.

Nevertheless, food irradiation continued to evolve, particularly in spice pasteurisation and phytosanitary applications for both imported and exported fresh products. The South African government played a critical role in supporting irradiation for phytosanitary control, notably mandating irradiation for imported honey (to prevent the spread of AFB), garlic and ginger (prevent sprouting and planting thereby protecting agriculture) and phytosanitary irradiation of fruit (preventing the spread of insects). More recently, renewed interest in phytosanitary irradiation for fruit exports, particularly table grapes, has revived efforts to establish a dedicated irradiation facility. A feasibility study explored options for EBeam, X-ray, and gamma irradiation to meet industry needs.

While the spice industry remains a stronghold of food irradiation, fresh produce applications are poised to reinvigorate the sector, with advancements in phytosanitary treatments and infrastructure development driving future growth.

IAEA-CN-332/166

Optimized Design and Integrated Supply of Product Handling Systems for Irradiation Facilities

W. Peng (ThreeRays (Beijing) Technology Co., Ltd) – China

Irradiation facilities which using gamma, EB and X-ray technologies are pivotal in industries such as healthcare for sterilizing medical equipment, in the food industry for extending product shelf life, and in material science for cross-linking polymers. The efficiency and safety of these facilities are heavily reliant on the performance of product handling systems which mainly including conveyor system and processing control software. This paper introduces the optimized design and integrated supply of products handling system mainly focused in the radiation sterilization applications.

The paper will highlight key aspects of the conveyor system's design, emphasizing the importance of adaptability to various product types, precision in dose delivery, and the assurance of a sterile environment. The integration of advanced control software is paramount, facilitating automated operations, real-time monitoring, and data analytics to enhance process control and system responsiveness.Safety considerations are underscored, with a focus on radiation shielding, communication and emergency protocols, and compliance with international radiation safety standards. The role of a robust supply chain in delivering high-quality components and maintaining system performance is also discussed.

Furthermore, the paper will touch upon the implementation challenges, including project planning, risk assessment, and the financial implications of initial investment versus long-term benefits. The paper will also explore future trends, such as the artificial intelligence technology and industry 4.0 technologies for the supply and operation of irradiation facilities.

IAEA-CN-332/398

Electron Accelerators for the Future

R. Edgecock (International Irradiation Association), A. Chmielewski (Institute of Nuclear Chemistry and Technology) – Poland

The different industrial applications, like sterilization, food irradiation, polymer and semiconductor modification and cable and tyre crosslinking, based on the presently available eb accelerators are well established and competitive with conventional technologies [1]. Other still emerging fields of applications that are aimed at ensuring the safety of gaseous and liquid effluents and of solid waste discharged into the environment have been developed and some demonstrated on the industrial scale. The remarkable R&D work on wastwater purification (endocrine distruptors, antibiotics and pharmaceuticals, superbugs), sludge hygenization, marine diesel off gases and ballast water treatment has been developed in the frame of ARIES and IFAST EU, IAEA and national projects. Argonne National Laboratory listed the main obstacles to the widespread use of technology connected to accelerators [2] and identified the following connected to accelerators: (i) the absence of accelerator devices that are capable of operating at full-scale industrial levels, which tend to be at least ten times beyond the current state of the art; (ii) the necessity of developing accelerator systems that can be significantly reliable and efficient while remaining competitive with existing technological advances; (iii) the lack of pilot level applications for these new technologies to show their efficiency and efficacy. In the recent period, there has been a tendency to practically use the achievements of accelerator technology used to date only in research equipment in the field of nuclear physics for the construction of devices useful for work in conditions of industrial radiation processing. Such unique solutions include a cyclic electron accelerator in short called eFFAG (electron fixed-field alternating gradient), working with a continuous wave with electron energy, beam power and dimensions adapted to the requirements of radiation technology. Another equally innovative design is an accelerator for radiation technology using a superconducting structure accelerating electrons. These structures means less energy demand for the cooling of the structure, and the power it is almost entirely transmitted to the electron beam. Magnets and other applications based on high temperature superconductors (HTS) present a promising path towards highly efficient solutions. Current developments in other future particle accelerator technologies are providing substantial impetus in this regard and can contribute to societal benefits. Particularly notable advancements in the mass production of high-temperature superconductor materials and reductions in cost will enable large-scale applications in the future. A second topic are power converters, which are used to convert grid power to DC power for magnets and RF sources. Besides reliability, precision of current and voltage control, also the efficiency of power converters is an important aspect for optimized designs. The possibility for the use of these developments for construction of industrial electron accelerators are discussed in the paper.

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Small Scale electron Linear Accelerators for Industrial Applications

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Electron accelerators operating at 1-10 MeV energies and power levels of 1-30 kW are used for many industrial applications, medical device sterilization, non-destructive testing, cargo inspection, and others. However, many of these applications, especially novel ones, require that the accelerators' size, weight, and costs be significantly reduced to be considered a suitable radiation source. Some examples of such applications include field radiography, mobile cargo inspection, radioactive source replacement, and industrial irradiation such as food irradiation. The dramatic level of miniaturization and cost-reduction can be achieved thanks to the implementation of such innovative technologies as high-frequency magnetrons, solid-state Marx modulators, and novel fabrication technologies.

RadiaBeam is a small-business accelerator technology R&D company that designs and manufactures linear accelerators and systems for such applications, as well as electron beam sources, instrumentation, and diagnostic systems for research laboratories. Simultaneous engagement with the research and industrial markets often guides RadiaBeam towards developing custom and semi-custom irradiation systems, specifically tailored to address the needs of customers either in niche markets or engaged in experimental application studies, where off-the-shelf accelerator solutions are not readily available. In this presentation, we will review some examples of such systems developed in recent years, including self-contained irradiator systems, hand-portable accelerators, and high-power irradiators, where our case studies of the accelerator system optimization for specific applications could be of interest to the broad community.

IAEA-CN-332/326

Supplementing Gamma Radiation With E-Beam or X-Ray for Single Use Systems' Sterilization Purpose – A Material Viewpoint

L. Delaunay, S. Dorey ((Sartorius Stedim FMT S.A.S.). B. Krieguer, N. Dupuy, S. Marque (AMU) – France

In the biopharmaceutical industries, ionizing radiation treatment is used for sterilization and microbial decontamination of packaged products. Gamma irradiation is a standardized process for sterilizing health care devices due to its low toxicity. New technologies like X-rays and electron beams are emerging, allowing sterilization without significant heating and handling products in their final packaging. However, these methods can induce modifications in exposed materials, influenced by factors like chemical composition and environmental oxygen. As the focus shifts towards sustainable technologies, it is essential to reassess the preparedness of radiation technology industry programs to prepare for future challenges. This data gap poses a challenge for biomanufacturers transitioning from gamma-ray to X-ray or electron-beam sterilization.

Research focuses on radiation-matter interactions to ensure the performance and safety of materials post-irradiation. Physicochemical and mechanical testing on irradiated products, including polymer components, is underway. Investigations on polymers used in manufacturing storage bags for buffer and drug solutions are being conducted. This research, in parallel with physical evaluations by Team Nablo, examines the chemical modifications using various techniques (pH analyses, Fourier transformation infrared spectroscopy, RAMAN spectroscopy, ESR, HPLC, etc.) to understand their impact on interactions with biopharmaceutical fluids. Communicating these findings can support biomanufacturers in performing risk assessments during the transition to alternative irradiation technologies.

IAEA-CN-332/083

Accelerator Based Neutron Source VITA for Radiation Technology in Physics, Material Science and Medicine

S. Taskaev (Budker Institute of Nuclear Physics) – Russia

The Budker Institute of Nuclear Physics has developed a neutron source VITA, consisting of an electrostatic tandem accelerator of charged particles of an original design (vacuum insulated tandem accelerator) to produce a beam of protons or deuterons, a thin lithium target for generating neutrons and a system for generating a neutron beam. The facility produces powerful neutron fluxes in a wide energy range: from cold to fast.

The neutron source VITA at the BINP is used for the development of boron neutron capture therapy (BNCT), including the development of methods and instruments of dosimetry, testing of new boron delivery drugs, and treatment of domestic animals with spontaneous tumors. The source is actively used for radiation testing of promising materials with thermal and fast neutrons.

Thanks to the neutron source VITA-II□ made for a clinic in Xiamen (China), China became the second country in the world to begin treating patients with BNCT. The neutron source VITA-II□ was made for the National Medical Research Center of Oncology in Moscow to begin clinical trials of the BNCT technique in Russia from 2025. The neutron source VITA-III□ is currently being developed for the Federal Medical Biological Center in Moscow.

IAEA-CN-332/472

Application Scenarios for the Self-Shielding Electron Accelerator and the Prospect of EB Irradiation Curing

Y. Zhang (Wuxi El Pont Radiation Technology Co., Ltd. China) – China

El Pont's electron accelerator sales performance has exceeded 500 units, and users include more than 10 countries such as the United States, Mexico, Turkey, India, Vietnam, Thailand, etc., with full coverage of product series from 0.2 MeV to 10 MeV. In the past decade, with everyone's demand for energy conservation and VOC emission reduction, the application scenarios of low-energy electron accelerators have become more and more extensive.

At present, El Pont's self-shielded low energy accelerators below 1MeV are mainly used in the following industries: 1. Sheet and foam materials; 2. Wires and cables, especially automotive wiring harnesses; 3. Battery diaphragm, mainly used in the energy storage battery industry; 4. Tire pre-vulcanization; 5. Film industry, including EVA film for photovoltaic panels, POF shrink-film and PVDC food packaging film; 6. Surface curing of decoration panels; 7. The surface curing of coil and extrusion coatings, etc.

Among them, those two applications of surface curing have been the main R&D focus of El Pont in low-energy machine in recent years. El Pont has developed the world's first all-EB line for decorative panels. The products are manufactured with EB coatings from Sherwin-Williams, the world's leading paint company, to create an unrivaled product. The speed of the production line reaches 30M/min (2.5 times the production efficiency of thermal curing approach), the production process has zero VOC emissions, and the decorative boards processed through full EB curing have excellent performance in resistant to yellowing (QUV Tested for 168 hours, $\Delta E \leq 1$), odorless (level 0.5), zero formaldehyde release, excellent silky touch properties as well as many other performance indicators; the production of decorative panel by using this technology is high in efficiency and low in unit cost, the appearance, physical and chemical properties, and environmental performance of E-beam cured coatings are far ahead of existing decorative panels on the market. This product is currently attracting a lot of interest in the market. By the end of 2024, two more EB decorative panels will be produced and put into production, and El Pont will have three commercial production lines for EB decorative panels.
In December 2023, El Pont signed a strategic cooperation agreement with AkzoNobel, which is also a leading paint company, to jointly develop EB technology for coil coatings. So far, this collaboration has been experimented with several times and has made great progress. Although it is still some time before it is officially put into production, it has already aroused the interest of many giants in the steel industry.

In summary, we believe that the development and promotion of low-energy curing using electron beam technology will make a great contribution to global carbon neutrality and bring huge economic benefits to society.

IAEA-CN-332/073

Gammacell-220 Isodose Curves after Reloading with 60Co Sources

S. Pawlak (Comision Nacional de Energia Atomica - CNEA)) – Argentina

The main purpose of this work is plotted the isodose curves of the irradiator after reloading with 7500 Ci of 60Co sources by Dioxitek Company in year 2022.

IAEA-CN-332/337

Micrometer Dosimetry for LEEB Irradiation

U. Gryczka, Sylwester Bulka (Institute of Nuclear Chemistry and Technology – Poland), A. Nasreddine, F. Kuntz (Aerial CRT – France), R. Schwarz (Pacific Northwest National Laboratory – USA)

Dose measurement is an important and critical aspect of every irradiation process. Novel applications of low energy electron beam, such as food irradiation for microbial decontamination, require revision of existing tools and standards to clearly define their applicability and limitations depending on the irradiation conditions and type of irradiated samples.

The presented study aimed to determine the following parameters of the low energy electron beam irradiating process: dose deposited in the micrometer region under the surface, total dose deposited in the region of interest and depth dose distribution in dosimeter and in a treated object. In the study, the B3 dosimetry films with RISOScan software and AerEDE/EPR alanine system were used. For irradiation with low energy electron beam, accelerator ILU 6 (INCT) and Comet lamp at Aerial were used. The dose measurements determined the penetration ability of electrons in conditions of experiments and were used to estimate the depth dose distribution in treated objects which were black and white peppercorns.

Due to the limitations of existing physical dosimetry systems Monte Carlo simulation tools can be helpful in the determination of depth dose distribution and more importantly, dose in the first microns of the product. In this study, PUFFIn (PNNL, USA) simulation software was used to simulate experimental conditions and characterize the dose profile in dosimeters and peppercorn samples, focusing on the micrometer region under the surface.

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IAEA-CN-332/566

Process Control at Low Energy E-beam Sterilization

A. Miller, C. Ankjærgaard (DTU Nutech, Technical University of Denmark) – Denmark

Tetra Pak® produces lines for filling liquid (water, milk, fruit juices) into containers. The containers are folded in the filling machine from rolls of specially prepared packaging material.

To ensure an adequate degree of sterility of the packaging material, it is irradiated using low-energy electrons in an in-line process. The selected energy at 80 keV is great enough to ensure a needed dose on the surface, and small enough to avoid deterioration of the packaging material.

Characterization of the in-line e-beam facility and measurement of dose to the product are done with measurement traceability ensured through Risø HDRL using the Dμ-method with thin-film Risø B3 dosimeters.

A tool – the DCT - was developed to verify that initial process characterization is maintained by measurement of electron current delivered from the lamps (e-beam accelerator). The DCT signal is calibrated in terms of surface dose Dμ and represents therefore virtual dose with traceability to national standards.

The claim for traceable dose measurements is valid for controlled machine parameters (mainly energy and speed) within specified limits. Deviations from the limits shut down the facility.

Effects of influence parameters on the DCT signal was measured and correction factors were determined to allow the DCT to be used under varying environmental conditions.

IAEA-CN-332/600

Study of the Impact of the Absorbed Dose Rate on the Response of Alanine Dosimeters

A. Nasreddine, F. Kuntz, H. Bouaicha (Aerial) – France

Alanine/EPR dosimetry system is well known for being robust, precise and having low measurement uncertainty for absorbed dose to water measurements, all, whilst covering a broad dose range (few Grays up to more than 100 kGy). In addition, the alanine/EPR dosimetry system is widely used by National Metrology Institutions as well as SSDLs as a transfer standard dosimetry system for calibration of other systems.

For alanine, literature shows that the dosimeter's response can suffer from a combined dose/dose rate influence, for dose levels higher than 5 kGy, at dose rates smaller than 2 Gy/s [1]. This could pose a problem during the creation of reference alanine dosimeters by metrology labs, where often 60Co sources are used and such sources could have dose rates inferior to 2 Gy/s. From the user's side, alanine dosimeters could have been calibrated at high dose rates but irradiated at low dose rates in attenuated radiation fields (gamma or low to medium power X-rays), where dose rates could get far below the 2 Gy/s limit.

In this study, an investigation is carried out to characterize the alanine response change with respect to absorbed dose, at different dose rates, as well as for different types of X-ray beams: continuous beam generated by a kV X-ray generator, and a pulsed MV X-ray beam generated by a Rhodotron®.

Preliminary results, obtained using a continuous X-ray beam, tend to confirm the described phenomenon for absorbed doses greater than 5 kGy, at a dose rate lower than 2 Gy/s. Work is ongoing to study the impact of the absorbed dose rate on alanine's response, in the case of a pulsed X-ray beam.

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IAEA-CN-332/655

Dosimetry Intercomparison Exercise for Gamma and E-beam Using Alanine Pellet Dosimeter

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Radiation processing technologies play an important role in material processing, as well as the sterilization and decontamination of various products across numerous IAEA TC Regions. IAEA is conducting IAEA technical cooperation project RAS1028 to improve the level of competitiveness and customer satisfaction of radiation processing facilities of RCA GPs. As part of RAS1028, the Korean Association for Radiation Applications (KARA) is conducting 'The Dosimetry Intercomparison Exercise' for Gamma (12) and EB (7) irradiation facilities in Bangladesh, India, Indonesia, Republic of Korea, Malaysia, Myanmar, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam (alphabetical order) using Alanine/ESR dosimetry methods with alanine dosimetry readouts. KARA has distributed alanine dosimeters and a holder (phantom) to participating facilities by mail and the facilities have irradiated the alanine dosimeters in 5 different doses (5 kGy, 10 kGy, 15 kGy, 30 kGy and unknown dose). The distributed phantom consists of two types: a rectangular(for fixed irradiation) and cylindrical(for rotating irradiation). To readout collceted alanine osimeters, dose response curves for photon and e-beam were measured using certificated alanine pellets for reference dosimetry by Aerial CRT. It was confirmed that the R-square values of the dose response curves were 99.99%. The results reported by participating countries were overall satisfactory for dose of 5, 10, 15, 30 kGy of gamma and e-beam, but some countries also confirmed cases of over estimated by more than 10%. These cases were believed to have been caused by differences in radiation irradiation protocols for each facility. After this intercomparison exercise, particiapting countries are working to improve their QA/QC procedure and quality management(QM) system, and KARA will continue to support it.

IAEA-CN-332/588

Enhancing Mechanical Properties of Recycled Plastics Through Electron Beam Treatment

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The Philippines has been reported to be one of the leading contributors to plastic litter in the oceans. To address this issue, we propose using radiation technology to improve the properties of materials made from recycled plastics, thereby promoting their increased utilization. The radiation-induced modification of high-density polyethylene (HDPE) and polyethylene (PP) pellets, made from recycled plastic wastes, were performed using a 2.0 MeV electron beam. The flexural strength and melt flow index of extruded plastic pellets from irradiated and non-irradiated plastics were measured. Different characterization tests were conducted to determine radiation effects. The results demonstrated a positive correlation between PP content in the blend and the flexural strength. Irradiation of the blends at the optimal composition resulted in samples with higher flexural strength. Furthermore, it was shown that irradiation of the HDPE component may have caused the observed mechanical property enhancement. MFI measurements showed no significant difference between irradiated and non-irradiated blends. Gel fraction data indicated no crosslinking in HDPE following irradiation, but a slight increase in TGA values was observed, suggesting possible chain-branching. These findings show the potential of using irradiation to increase the mechanical strength of samples from recycled HDPE and PP pellets without significantly impacting processability.

IAEA-CN-332/460

Radiation-Induced Enhancements in Multilayer Plastics Recycling and Compostable Polymers: Environmental Impacts and Benefits

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The integration of radiation sciences and technology into environmental monitoring and protection represents a transformative approach to addressing contemporary ecological challenges. This study examines the emerging roles of radiation technology in mitigating the environmental impact of multilayer plastic packaging and compostable polymers, emphasizing sustainable production and consumption within a circular economic framework. Employing Life Cycle Assessment (LCA) methodologies, we evaluate the carbon footprint and environmental performance of these materials in the situation of Indonesia.

Radiation technology provides innovative pathways for recycling and degrading plastic waste, significantly enhancing waste management and pollution reduction efforts. Our research underscores the potential of radiation-induced modifications to improve the recyclability of multilayer plastics and the biodegradability of compostable polymers. These advancements align with circular economic principles, facilitating more sustainable production and consumption patterns.

In the context of multilayer plastic packaging, radiation technology offers a unique solution to one of the most pressing issues in waste management. Multilayer plastics, commonly used for their superior barrier properties, are notoriously difficult to recycle due to the combination of different polymer layers. Radiation-induced cross-linking and degradation can potentially simplify the recycling process, breaking down complex polymer structures into simpler forms that are easier to process and reuse. This not only reduces the volume of plastic waste but also minimizes the need for virgin plastic production, thereby lowering the overall carbon footprint.

Similarly, for compostable polymers, radiation technology can enhance biodegradability by altering the polymer structure to make it more susceptible to microbial attack. This modification can significantly accelerate the composting process, ensuring that compostable plastics break down more efficiently in natural environments or industrial composting facilities. As a result, the environmental burden associated with plastic waste is further alleviated, contributing to a reduction in pollution and greenhouse gas emissions.

The findings reveal that radiation technology can considerably diminish the environmental impacts associated with plastic packaging, fostering a resilient and sustainable environmental management system. This study also discusses the implications for policy-making and industrial practices in Indonesia, offering strategic insights for integrating advanced radiation technologies into national environmental protection frameworks.

IAEA-CN-332/593

Life Cycle Assessment for Thermoplastic Elastomers Based on Electron Beam-Assisted Recycling of Polyolefin and Rubber Waste

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Increasing production rates of plastic and rubber products combined with a lack of effective recycling methods have led to an exponential growth of waste in landfills and incineration. For plastic waste, mechanical recycling and sorting into different polymers are still challenging. Mostly physical sorting methods are applied, which cannot be used successfully for mixed polyolefin waste, due to their similar physical properties. A promising way is the application of electron treatment to sort recycled polyolefins.

Crosslinking of rubbers prevents recycling via melt processing. One way to recycle cross-linked rubber is the mechanical recycling into ground tyre rubber particles (GTRP). Together with thermoplastic polymers like polyolefins, this elastic filler can be used to produce thermoplastic elastomers by melt mixing.

In this study, a life cycle assessment was performed to compare the environmental impacts of mechanical recycling of rubber and mixed polyolefin waste as well as the conventional production of virgin rubber and polyolefin. Real industry data was combined with environmental database information. The results of this study will contribute to the understanding of current and future recycling processes and will help guide future research towards innovative solutions of the global plastic waste problem.

IAEA-CN-332/390

Impact of Ionizing Radiation on Recycled Polymer-Based Composite Materials

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Structural materials could be a valuable option for integrating plastic waste into the circular economy system because they allow the combination of recycled plastics, mineral and natural fibers, and others.

In this research, recycled plastics like polypropylene (PP) and high-density polyethylene (HDPE) were exposed to gamma radiation and electron beam irradiation to induce oxidation. The irradiated PP and HDPE were then incorporated as a compatibilizer in a composite material made up of recycled polymers (PP+HDPE) and calcium carbonate. Different composite formulations were tested to optimize Young's Modulus and flexural strength. Characterized of the composites involve FTIR and DCS, and SEM was used to assess the dispersion of calcium carbonate in the PP-HDPE matrix.

These findings indicate that incorporating irradiated PP or HDPE in a small concentration significantly enhances flexural strength, especially when electron accelerators are employed for irradiation. This approach demonstrates the efficacy of ionizing radiation in modifying recycled polymers, highlighting its potential in the recycling and transformation of plastic waste.

IAEA-CN-332/285

A New Kind of Concrete Using Irradiated Plastic Waste: A Solution for Reducing Greenhouse Gas Emissions

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Research has delved into the utilization of recycled plastics in concrete as a strategy to enhance the mechanical properties of concrete, offering a dual benefit of repurposing waste plastic and mitigating carbon emissions by partially replacing cement. Despite these efforts, there is a challenge in developing a cement formulation that accommodates plastic additions while maintaining high compressive strength. This study investigates the efficacy of incorporating electron beam-irradiated plastic as an additive in cement paste samples (comprising Portland cement, additives, and water) to enhance its proprieties in term of tensile and compressive strength. To determine the optimal conditions, polyethylene terephthalate (PET) was subjected to electron beam irradiation at three different doses (0, 10, 50, and 100 kGy). The study investigated the effects of replacing 10% of the cement volume with PET waste. Various tests, including workability, compaction factor, compressive strength, split tensile strength, and water absorption, were conducted to assess the properties of the resulting concrete. Our findings underscore the need to account for radiation effects when assessing concrete performance, especially when integrating irradiated plastic materials. The study revealed that, when compared to standard concrete, there were no significant changes in the workability and air content of the various concrete mixes tested. However, the tensile strength showed a consistent increase in all samples that included PET. Notably, a reduction in water absorption was observed in PET-containing samples. While there was a decrease in compressive strength, it remained within the acceptable range for structural concrete with 40 MPa, suggesting favorable outcomes in the overall performance of the concrete. These insights are valuable for comprehending the behavior of irradiated plastic concrete and can inform decision-making in construction and material selection.

Key words: Ionizing radiation, polymers, concrete, plastic waste (PET), compressive strength.

IAEA-CN-332/172

Design Study of a High-Current q/A=1/2 K100 Compact Cyclotron for the Production of Radiotracers for Industry

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We have designed a high-current q/A=1/2 K100 cyclotron to produce radiotracers. The ions for acceleration are H2+, D+, He+ with a maximum energy of 25 MeV/u. The maximum proton current expected is over 2 mA if considering the same space charge effects (perveance) at injection on commercial H- cyclotrons providing ~1 mA [1]. The beam extraction is most critical issue for high-current cyclotrons. Extraction efficiency should be well over 99 % at a beam power of 50 kW to avoid severe radio activation. A single-turn extraction for realistic beam size is required using electrostatic deflector by RF acceleration and orbital precession induced by 1st harmonic field [2]. The final radial gain with four RF dees at 100 kV in four sectors is ~10 mm by acceleration and enlarged by precession. In addition, we explored a self-extraction method by grooving a pole tip to rapidly reduce the sector magnetic field (Fig. 1). Beam optics study revealed the beam can be extracted along the groove (Figs. 2, 3). A further study will include adequate radial focusing during extraction. In addition, charge-stripping extraction was studied for H2+ to enable energy variability (Fig. 4). A facility layout is then envisioned to accommodate different types of beam extraction. The design-study results will be presented.

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IAEA-CN-332/825

Emerging Applications of EB/Xray/Gamma in Asia

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Radiation technologies are advancing in many fields including polymers enhancement, environmental protection, food preservation, medical diagnostic and treatment all over the world in the recent years. In particular, many countries in Asia are developing more promising applications of ionizing radiation in many fields. In the Republic of Korea for example, radiation technology has been used in preservation by disinfection treatment of water-logged cultural heritage (CH) in flood disasters by gamma rays. China on the other hand is leading the world in radiation applications in environmental protection. Recently, the world’s largest EB treatment of industrial wastewater from textile industry utilizing 7 EB accelerators with energy up to 2 MeV and capacity of 30000 m3/day was commissioned in Jiangmen city. In Saudi Arabia, electron beam treatment of flue gas technology (EBFGT) was used to treat flue gas from oil refinery using a Mobile EB accelerator with 0.7 MeV : 20 kW for treatment of 2000 Nm3/hour (15 kGy) of flue gas in Rabigh Oil Refinery. In Vietnam, application of Low Energy X-ray Irradiation (LEEX) for preservation of CH, like Nguyen Dynasty woodblock is gaining momentum. An absorbed dose of 10 kGy is sufficient to eliminate the most resistant fungi. Similarly in Thailand, preservation of Thai CH artefacts using radiation technology is commercially explored by radiation induced in consolidationn woods at an absorbed dose of 25 kGy using gamma rays.

IAEA-CN-332/574

Establishment of a Production Facility for Radiation-Crosslinked Hydrogel Dressings

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High energy irradiation, in particular electron beams, have found extensive applications in industry, medicine, and environmental protection as well. A notable application of this technology is the destructive polymerization irradiation method, which leads to crosslinked hydrogel formation by covalent bonding, thereby enhancing the mechanical and elastic properties of origin polymer materials.

The use of radiation technologies significantly contributes to industrial advancement in polymer modification processes. In 2022, the Institute of Nuclear Physics Ministry of Energy of the Republic of Kazakhstan initiated a project aimed at establishing a production facility for polymer-mineral composite hydrogels for medical and cosmetic uses. The project consists several key stages:

1) industrial implementation of electron-beam cross-linking technology for producing hydrogels;
2) creation of a cleanroom complex for production;
3) installation and commissioning of production equipment;
4) certification of the quality management system (QMS) acording to the requirement ISO 13485 standard;
5) and, finally, subsequent commercialization of the products.

The paper describes the experience of implementing the E-Beam irradiation technology to produce hydrogels for cosmetic and medical purposes using ILU-10 and ELV-4 electron accelerators.

This project was carried out within the framework of the grant financing of commercialization of the results of scientific-technical activities, financed by Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

IAEA-CN-332/537

Radiation Processing and Salt Concentration: Emerging Approach for Modifying Staphylococcus aureus Resistance

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Background of the Study:

Staphylococcus aureus is a significant pathogenic bacterium with major implications for food safety. It is a Gram-positive bacterium that can be easily destroyed by heat treatments such as cooking or pasteurization. However, if food is cross-contaminated, S. aureus can secrete heat-stable toxins. The World Health Organization (WHO) identified antimicrobial resistance (AMR) as one of the top 10 global public health threats in 2019, with methicillin-resistant S. aureus (MRSA) being a major cause of bloodstream infections. In 2020, 43 outbreaks of S. aureus toxins were reported in the EU, affecting 402 individuals. S. aureus demonstrates extensive adaptability, including antibiotic resistance through the acquisition of resistance genes and the ability to withstand high salinity stress.

Methodology:

This study examined the response of MRSA and methicillin-sensitive S. aureus (MSSA) to antibiotics following exposure to environmental stressors such as high salinity and sublethal doses of gamma irradiation. Two strains of S. aureus (one MRSA and one MSSA) were tested for antibiotic susceptibility using the agar disk diffusion method with ten antibiotics. The MRSA strain was exposed to 6% NaCl concentration and 0.6 kGy dose of gamma irradiation, both individually and in combination. Comparisons were made with a control sample that was neither salted nor irradiated. Changes in bacterial survival and antibiotic resistance were measured, and the presence of the mecA gene (responsible for beta-lactam antibiotic resistance) was detected using PCR in both intra- and extracellular DNA.

Results:

The study established that the applied stress factors altered behaviour of S. aureus of bacteria towards antibiotics. Some antibiotics showed increased susceptibility, while others showed increased resistance. Notably, increasing NaCl concentrations (6%, 10%, 12%) progressively reduced antibiotic resistance to meropenem, and susceptibility increased significantly when combined with a sublethal dose of 0.6 kGy gamma irradiation. PCR results confirmed the presence of the mecA gene across all treatments, indicating no genetic change. There was a significant decrease in bacterial count numbers, particularly with irradiation.

Conclusion:

High salinity and low doses of gamma irradiation decreased MRSA's resistance to meropenem. Despite the presence of the mecA gene, the findings suggest that resistance loss might be due to inhibited gene expression or altered membrane permeability. These results indicate that the combined stressors could enhance the uptake of antibiotics, potentially offering a strategy to combat antibiotic-resistant S. aureus.

IAEA-CN-332/340

High Dose Rate Irradiations at the 60Co Gamma Irradiation Facility – Experimental and Monte Carlo Simulation Results

M. Majer, L. Pasariček, Z. Knezevic (Rudjer Boskovic Institute) – Croatia

The 60Co gamma irradiation facility, located at the Ruđer Bošković Institute, is the only of its kind in Croatia. A special and unique feature of the facility is the possibility to use radiation for both, radiation processing and research. The samples/products to be irradiated can be place around the irradiator (medium and low dose rate area) or inside the irradiator (high dose rate area i.e. > 1 Gy/s). Small samples that need to be exposed to large doses (kGy MGy) in a reasonable time such as urgent sterilization and radiation hardnes testing for radiation detector components and materials are comonly irradiated inside the irradiator (i.e. in the high dose rate area).

Irradiation chamber with irradiator was moddeled using two Monte Carlo (MC) codes: PHITS and Geant4. MC model and dose mapping simulations were validated with measurements made with ionisation chamber (IC) [1]. Chemical dosimeters based on chlorbenzen in ethanol (ECB dosimeters) are used for routine dosimetry in everyday practise but also for dose mapping inside the irradiator (in addition to MC simulation) becouse IC can not be used inside the irradiator [2]. The huge advantage of MC simulatons is to provide 3D dose distribution within the irradiated sample and also at places where dosimeters can not be placed.

In this presentation results/examples and chalenges related to the experimental and MC study for irradiations inside the irradiator (high dose rate area) will be presented.

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STREAM C

Control Methods and Industrial Diagnostic using Radiation Technologies

IAEA-CN-332/644

Advancements in Dual Source Gamma-ray Computed Tomography for Enhanced Multiphase Flow System Analysis

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Dual Source Gamma-ray Computed Tomography (DSCT) is a sophisticated technique utilized to obtain cross-sectional phase distribution measurements in multiphase flow systems such as gas-liquid, gas-solid, and gas-liquid-solid mixtures. This technique has proven invaluable for visualizing and analyzing different multiphase flow systems, enhancing understanding and optimization of different multiphase flow systems. DSCT employs gamma radiation from Co-60 and Cs-137 sources, each selected for their unique properties: Cs-137 offers a long half-life and minimal photon scatter, while Co-60 provides small scatter interference, both contributing to clear, accurate imaging. The DSCT setup involves a platform equipped with collimated detectors and opposing sources that rotate 360 degrees around the column to be scanned, providing 197 views per scan and 21 projections per view. This setup allows for capturing detailed 2D and 3D images of the flow systems. The gamma ray sources, with initial activities of 200 mCi for Cs-137 and 300 mCi for Co-60, emit fan-shaped beams that are collimated to 3 mm thickness and a 40-degree angle. Opposite each source, an array of 15 NaI scintillation detectors, equipped with 2 mm slit width lead collimators, captures the unattenuated gamma rays passing through the column. The detectors convert the absorbed radiation into light photons, which are then processed to generate electrical signals for imaging. To ensure accurate phase distribution measurements, the DSCT system undergoes multiple scanning steps, including CT scans under various conditions: with the column filled with solids (packed bed), empty (air-filled), and during actual test conditions (gas-solid spouted bed operation). Data from these scans are averaged and processed using the Alternating Minimization method for image reconstruction. This method discretizes the scanned cross-section into a matrix of pixels, with each pixel representing approximately 2 mm or 1 mm in size, depending on the column diameter. Validation of the DSCT technique is performed using standard specimens, or "phantoms," consisting of concentric Plexiglas cylinders with known dimensions and filled with water. The reconstructed images show linear attenuation values and dimensions that closely match the actual values, demonstrating the technique's accuracy within 1%. Additionally, repeated scans under similar conditions confirm the reproducibility of the DSCT results. The application of DSCT in multiphase flow research provides critical insights into the spatial and temporal distribution of phases, aiding in the optimization and safety of industrial processes. This technique's non-invasive nature and high-resolution imaging capabilities make it a pivotal tool in the field of radiation science and technology, with significant implications for process improvement across various industries. The presentation will cover detailed findings on the development and optimization of DSCT imaging protocols, along with case studies on various multiphase systems. It will also include a comparison of DSCT results with Computational Fluid Dynamics (CFD) simulations to highlight the technique's accuracy and effectiveness. Additionally, the presentation will explore future directions and potential advancements of this innovative technology in industrial applications.

IAEA-CN-332/568

A Study of Laminographic Scanning for Process Distillation Column using Pixel-Sum Simulation and Filtered Back Projection Algorithm of Image Reconstruction

D. Saengchantr (Chulalongkorn University) – Thailand

The term “Laminographic Scanning” was introduced in RAS1030 Expert Group Meeting in 2022. It is one of gamma ray scanning methods that can be regarded as “Vertical Cross-section Image Reconstruction”. The difference between conventional gamma ray scanning and laminographic scanning is that, for conventional method, the scanning results are reported in plotting of gamma intensity vs elevation. For laminographic scanning, the results are reported in reconstructed images derived from scanning data. The operation time is the backdrop of laminographic scanning since the position of either source or detector should be repeated as the elevation step of equipment. This study presents a method of simulation using pixel-sum method. The grayscale (8 bits) picture is created for different density values varied from 0 to 255 level. Each level can be mapped to the matter properties, for example 255 grayscale value is referred to very high absorption whereas 0 grayscale value may refer to no absorption. The scanning data is treated as scanning data and using the filtered back projection algorithm to reconstruct image. The results showed that, image filtered back projection algorithm is applicable to reconstruct the image from pixel-summation data. The conclusion from this study shall be used in Laminographic Scanning in the field work.

IAEA-CN-332/399

Development of a Gamma-Ray Multiphase Flow Monitoring System utilizing Machine Learning

A. Taheri, J. Karimi-Sabet, M. Reshtebar (Nuclear Science and Technology Institute, Tehran, Iran) – Iran

In this work, we aimed to design a fixed and cost-efficient gamma-ray scanning system that utilizes artificial intelligence (AI), enabling us to determine the type and specifications of the multiphase flow regimes.

IAEA-CN-332/184

Multiphase Hold-up of Packed Bed Reactor Using Gamma Densitometry

M. Abdul Rahman, H. Ithnin, L. Dahing, Sh. Ebrahim, M. Izwan ishak (Malaysian Nuclear Agency) – Malaysia, H. Al Bazzaz – Kuwait

Multiphase flow is common in chemical reactors, quantifying the hold-up of each phase is critical for efficient reactor design and performance evaluation. Packed bed reactors, which contain catalyst particles, are widely used in the chemical and petrochemical industries. This study investigates the use of gamma densitometry to determine the hold-up of gas and liquid phases in a packed-bed reactor. Gamma densitometry, which uses Barium-133 as the radioactive source (with an activity of 1.58 mCi), quantifies hold-up by utilizing the different gamma ray attenuation properties of each phase. A gamma ray source and detector were placed in two axial locations of a packed bed reactor that had a diameter of 3 cm, a thermo-well diameter of 0.5 cm, and a length of 2.5 m. The study looked at the effects of different gas and liquid flow rates on hold-up. The results showed that higher gas flow rates increased gas hold-up, while higher shear rates reduced liquid hold-up by stripping the liquid from the catalyst surface. These findings show that gamma densitometry can accurately determine multiphase hold-up in packed beds, providing a non-invasive alternative to pressure drop and sampling techniques. The study provides valuable insights into packed bed hydrodynamics and supports reactor modeling and design. Future studies should use gamma densitometry to investigate the effects of particle shape, size distribution, and packing geometry on hold-up.

IAEA-CN-332/439

Scale-up, Scale-down: How Tracings are Important Tools to Help to Design Full-scale Reactors and Representative Pilot Plants

O. Potier, D. Vauris, F. Miguel, N. Adouani (LRGP CNRS - Université de Lorraine), C. Merlin (LCPME CNRS - Université de Lorraine) – France

The environmental and economic crisis around the world underlines the need for new approaches in Chemical Engineering science and technology, notably with smaller and more efficient processes which follow Green Engineering principles. Chemical Engineering has a long history of successful response-driven design and innovation. This presentation aims to show how tracing experiments can be a useful tool to better understand, model and design innovative processes.

It is well known that hydrodynamics of reactors has a strong influence on performances of these reactors (conversion, pollutant removal efficiency, selectivity, etc.). It is one of the important purposes of the scientific discipline called Chemical Reaction Engineering (also known as Reaction Engineering, since it can be also applied to other reaction types, biological for instances). To be able to achieve deep research or design studies it is often useful to work at the scale of the pilot-plants, because it is easy to control a lot of parameters that are not accessible at full-scale. But to do it, it is important to be able to build such pilot plants with suitable and precise hydrodynamic behaviors.

Hydrodynamics depends on fluid properties, and energy brought to the system, but also on the shape, the proportions and the size of the reactors. For scientific studies on pilot plants this angle is particularly tricky since the downsizing of given full-scale reactors (scale-down) can lead to significative errors (the problem is the same for applying to full-scale plant results obtained on pilot plants; scale-up). Indeed, reducing the size of a reactor while maintaining the same proportion of the different dimensions leads to a hydrodynamic behavior too different of the original full-scale reactor. Then, in this situation, the new pilot-plant is not representative of the studied full-scale plant. When building a reactor pilot plant, to obtain the suitable hydrodynamics, it is important to carefully determine the shape and proportions of the reactor pilot plant; these parameters will be generally very different of the one of the full-scale.

The purpose of this talk is to present a method to calculate the dimensions of pilot reactors, really representative of full-scale plant reactors, using modelling, computational fluid dynamics (CFD), numerical tracing and numerical residence time Distribution (RTD), and secondly real tracings (RTD) to control their hydrodynamics. Afterwards an example presenting breakthrough results about wastewater treatment will be developed. It notably deals with micropollutants removal and antibiotic resistance development limitation. Wastewater treatment plants occupy a key position between anthropic activities and the environment in such way that it progressively became the final control point before releasing contaminants of emerging concern in the downstream environment. These include micropollutants but also biological pollutions such as antibiotic resistances (of pathogenic bacteria). The project goal is to use innovative design approaches to develop new treatment processes based on the control of the reactor hydrodynamics to improve their performances regarding the degradation of micropollutants and the control of antibiotic resistance release. This example shows how tracing studies about hydrodynamics can be very useful for health and environmental protection.

IAEA-CN-332/352

Emerging Technologies for Non-Destructive Testing and Monitoring of Concrete Structures in Nuclear Facilities

E. Niederleithinger (Bundesanstalt für Materialforschung und-prüfung (BAM)) – Germany

For a long time, practical application of non-destructive testing in civil engineering has been limited on simple (but useful) methods such as rebound hammers, ultrasonic pulse velocity measurements, rebar detectors or potential mapping. Since the late 1990ies new methods and devices have been developed for geometry and damage detection, including radar and ultrasonic echo array techniques which brought progress in condition assessment of buildings and infrastructure assets.

However, there are still gaps, especially for massive concrete structures used in nuclear facilities, including lack of penetration depth, resolution, or translation of NDT parameters to engineering properties.

Recent research tries to fill these gaps. Currently, new ultrasonic devices with greater penetration depth and better resolution depth are developed, including imaging methods revealing greater details of the interior of concrete constructions. Ultrasonic technologies are also extended to nonlinear methods providing baseline free damage assessment and monitoring capabilities. Another example of a technique with a huge potential for concrete constructions is muon tomography, where first field experiments are underway. A review of the potential and limitations of these methods will be given in the presentation.

IAEA-CN-332/610

NDT-CE in Heavy Industrial Facilities

S. Laprida (AAENDE - CEND) / SL INGENIERÍA SA – Argentina

In almost all industrial plants there are facilities that are not directly associated with the production of the goods for which the plant is intended, but which are essential for its operation. This is the case with Water-Cooling Towers (WCT). Although there are many types of WCT and different materials are used to build them, in the case of large volumes of water to be cooled, concrete WCTs are widely used. In an important industrial plant, located in Argentina, the authors of this work were asked to carry out the necessary studies to evaluate the remaining useful life of 3 WCTs built in concrete and up to 50 years old; foreseeing that their eventual replacement was a medium to long term project. To respond to this query, a set of Non-Destructive Tests in Civil Engineering (NDT-CE) was designed and executed; complemented with laboratory analysis. This set includes mechanical and chemical tests typical in concrete constructions. Ultrasonic, radiation, electrical and magnetic techniques were also employed. External environmental aspects were also considered, such as chlorides of marine origin, summer and winter temperatures and humidity. The internal environment was also considered, due to the constant presence of treated water. As a result of this work, based on the NDT-CE results, a differential diagnosis for the external and internal parts of the WCT was made, and a plan to retrieve and monitor the WCT to extend its useful life by no less than two or three decades was proposed to the industrial plants owners.

IAEA-CN-332/685

An Insight into Fire Behaviour of Concrete via Neutron Radiography

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Concrete is known to exhibit good fire endurance, thanks to its incombustible nature and poor thermal conductivity, which allow the cover to protect the steel reinforcement and the core of cross-sections in structural members. However, this behaviour can be jeopardized by explosive spalling, namely the sudden expulsion of flakes from the exposed surface, leading to quick cover erosion. One key factor in this phenomenon is the water content of pores, since its quick vaporization may boost the instability of cracks and the acceleration of the fractured splinters. Monitoring pore saturation in heated concrete, either during the smooth drying of the cover or while a crack opens is then essential in unravelling the intricate mechanism behind explosive spalling.

In this perspective, an effective tool is Neutron radiography, due to the high beam attenuation entailed by the hydrogen nuclei in water molecules. Different test setups have been devised by the authors to observe the gradual loss of water in hot concrete specimens, the possible disturbance induced by embedded pressure probes, the cracks ensuing from stress intensification and differential shrinkage, and the sharp moisture gradients developing once pressure is suddenly released at a sealed interface.

In the proposed paper, an overview of these results will be provided, showing the high potential of Radiation Technology in Civil Engineering applications.

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Non-Destructive Evaluation and Characterization of the Loma de la Lata Embankment Dam Using Cosmic-Ray Muography

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Cosmic-ray muography is a non-invasive imaging technique that leverages the directional flux of atmospheric muons to produce density-contrast images of the object under study. This technique is conceptually similar to X-ray imaging, but the source in this case is the local atmospheric muon spectrum. The penetration capability of muons, combined with appropriate data acquisition methods, can be utilized as complementary techniques to inspect for potential fractures or structural changes related to damage or performance issues in natural or artificial dams.

In this study, we focus on an embankment dam with an impermeable core and concrete transitions, located on the Neuquén River in Argentina, which has sustained a certain degree of damage. We present and compare findings from Monte Carlo simulations and semi-analytical methods to evaluate the feasibility of muography in identifying fractures and structural damage in the dam. The simulations and assessments were conducted considering the ITeDA muon telescope, which comprises three modular panels based on plastic scintillators and SiPM readouts. Our analysis also incorporates previous studies and data related to the dam's structure.

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Low Frequency Ultrasonic Coded Waveform Technique for the Inspection of Highly Attenuation Concrete Samples

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Low frequency piezocomposite transducers have been used in combination with pulse compression methods to penetrate 35 cm into concrete-type materials. A chirp coded waveform signal with a frequency range 100 – 200 kHz and of 10 ms duration was used to excite a pair of 54 mm diameter piezocomposite transducers in patch-catch mode. The centre frequency of the transducers was 170 kHz. Using this arrangement, good signals could be obtained, but there was a problem with variability due to the high degree of scattering – even small changes in transducer location changed the measurement. An additional signal processing method was introduced, whereby the total energy reaching the receiver was calculated as a function of time from the cross-correlation outputs. Results have shown that the developed pulse compression system at low frequencies is capable of testing highly attenuation materials such as thick concrete. Pulse compression techniques without further processing could be used to give a fairly consistent estimate of sample thickness at depths. The new reflected energy technique gives a promising indication of the likely position within a sample of a major defects, such as a change in thickness or a major through-thickness fracture.

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Tomographic Imaging of Industrial Water Pipelines: An Application for Detecting Detached Coatings

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Background of the Study:

Industrial pipelines are crucial for transporting water and other fluids in mining and industrial operations. Ensuring the integrity of these pipelines is essential to prevent operational disruptions and maintain safety. Detached coatings within pipelines can lead to significant damage and inefficiencies. While a few tomographic systems tailored for pipeline inspection have been reported, there are very limited examples of industrial field tests, and almost none in mining. This study aims to develop a transportable gamma ray-tomographic scanner for non-intrusive pipeline inspections, specifically targeting the detection of detached coatings without interrupting operations.

Methodology:

The developed scanner comprises mechanical parts, a computerized controller, a 15 mCi Co-60 gamma-radiation source, a NaI (Tl) scintillation detector, and data acquisition hardware. The system scans objects through translation and rotation movements. Image reconstruction is carried out using the Maximum Likelihood Estimation Method (ML-EM), and detached coatings are identified using the Canny edge detection method. Laboratory experiments were conducted to assess the scanner's resolution and accuracy, followed by field tests under industrial water flow conditions (0.1 m^3/h).

Results:

The gamma-ray tomographic scanner demonstrated a resolution of approximately two millimeters, producing clear images in both laboratory and field settings. Field tests confirmed the scanner's capability to detect detached coatings within pipelines under operational conditions, proving its practical application in real-world scenarios. The tomographic images obtained on-site provided compelling evidence of detached coatings, highlighting the necessity for timely pipeline maintenance.

Conclusion:

The portable gamma-ray tomographic scanner represents a significant advancement in pipeline inspection technologies. Its ability to conduct non-intrusive inspections without disrupting operations offers substantial benefits for the mining and industrial sectors. By enabling early detection of detached coatings, this technology enhances operational efficiency and mitigates the risk of undetected pipeline damage. The study emphasizes the importance of investing in innovative tools to ensure the longevity and integrity of critical infrastructure.

Keywords: Portable system, Gamma-ray computed tomography, Pipeline inspection

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Utilizing SRGAN for Enhanced Structural Evaluation of Reinforced Concrete via Gamma Computed Tomography

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Abstract

This study introduces a first-generation Gamma Computed Tomography (fgen-GCT) method for non-destructive evaluation of reinforced concrete structures. Laboratory experiments and field applications demonstrate its effectiveness in imaging internal structural elements like reinforcement bars and conduits. Using a Super-Resolution Generative Adversarial Network (SRGAN) to enhance image resolution from lower-resolution scans, the study reduces acquisition time and radiation exposure. Results indicate that fgen-GCT significantly improves structural assessment accuracy, benefiting infrastructure inspection and maintenance.

Introduction

Monitoring the integrity of reinforced concrete structures is crucial for the safety of infrastructure like bridges, dams, and power plants. Regular inspections ensure timely repairs and confirm the quality of new concrete. Traditional non-destructive evaluation methods include ultrasonic pulse velocity, rebound hammer, electromagnetic rebar testing, and core sampling, each with its limitations. This study introduces a novel fgen-GCT technique for assessing reinforced concrete structures, aiming to offer more accurate measurements of reinforcement bars and improve field assessments by identifying flaws and degradation.

Methodology

Three cylindrical concrete columns (185 mm diameter) with varying reinforcement configurations were prepared, mixed, poured, vibrated, and cured for 28 days. Using a gamma CT system (Gamma CT 60), optimal voltage, pulse height spectrum analysis, and filtering were determined. The SRGAN model was trained to enhance image resolution from 64x64 to 128x128 using over 25,000 paired images, convolutional neural networks, and data augmentation, taking 12 days on a workstation. The SRGAN-enhanced images allowed for accurate extraction of features, ensuring high-quality images with fewer scans and minimized radiation exposure.

Results and Discussion

Filter selection and projection numbers were evaluated for optimal image reconstruction. The cosine filter provided the best results, reducing blur and revealing small features like 1 mm thick electrical wires. Higher resolutions, such as 128x128 scans, offered the best image quality, capturing detailed internal structures and reinforcing bars. While higher resolutions required longer acquisition times, they provided crucial insights into the columns' structural integrity. The SRGAN model, trained to upscale 64x64 images to 128x128, preserved original image details and improved visualization of concrete features, as shown in Figure 1. Measurement errors ranged from 2% to 5%, demonstrating the method's potential to enhance image quality from lower-resolution scans. This not only makes it a valuable tool for precise structural assessments but also significantly reduces radiation exposure risks, thereby enhancing safety in the field.

IAEA-CN-332/086

Double Activation for Producing Radioactive Tracers in Friction Parts for Thin Layer Activation (TLA) in Wear Measurement

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Thin Layer Activation (TLA) [1,2] is a versatile tool for quick, economical, and accurate measurement of wear, corrosion, or erosion. The principle of the TLA is producing radioactive tracer isotopes in the surface of the friction parts. In order to produce radioactive tracers in material or machine parts to be investigated, one can irradiate them with neutrons and /or charged particles to induce nuclear reactions on the elements of the part. By using neutrons, the whole volume will be activated, so this method is rarely used. By charged particle activation only a selected spot or surface will be activated in a depth of several hundred nanometers to several hundred micrometers, depending on the selected nuclear reactions and the irradiation parameters. The energy of the bombarding particles must be chosen in such a way that the depth distribution of the induced radioactive isotopes should be homogeneous (best) or linear within a depth range. If the friction parts are of different composition or both contain iron, it is possible to activate them for different radioisotopes and during the wear measurement distinguish between the source of the removed wear derbies.

In the case of iron-containing materials, there are two proper nuclear reactions on iron-containing substrates, which produce proper radioactive tracers. One of them is proton induced, natFe(p,x)56Co, the other one is natFe(d,x)57Co at 13.2 and 7.2 MeV bombarding energies, respectively. At these energies, the depth distribution of the above isotopes will be constant (homogeneous) down to given depths. When one expects a much lower wear rate linear distribution can also be produced at lower bombarding energies. By modern materials and coatings, it occurs that one of the friction parts does not contain iron and even metal, e.g. DLC coatings. In this case, the nuclear reaction on carbon natC(3He,x)7Be can be used to produce beryllium radioisotope, which has proper half-life and gamma energy for radioactive tracing and wear measurement.

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[2] P. Brisset, F. Ditrói, D. Eberle, M. Jech, A. Kleinrahm, C. Lenauer, T. Sauvage, J. Thereska, Radiotracer Technologies for Wear, Erosion and Corrosion Measurement, INTERNATIONAL ATOMIC ENERGY AGENCY, Vienna, 2020, ISBN: 978–92–0–101620 –1

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Unconventional TLA for Tribological Examinations

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Material degradation and loss due to corrosion, wear, and erosion is a serious issue worldwide that primarily limits the useful life of equipment, engineering materials, constructions, hydraulic transportation systems, etc. Undesired material degradation followed by emission of degradation products as contaminants to the geosphere and biosphere may also cause severe ecological problems. Study and prevention of such processes is imperative. Nuclear methods play an important role in this respect.

The main method is based on so-called localized radiotracers imbedded or caged into the material under examination. Upon material loss the radiotracer will be lost in the same proportion. On-line or off-line measurements of the nuclear radiation (mainly gamma radiation) during equipment operation is a direct measure of the degree of material loss.

The most well-known method for imbedding (or implanting a radionuclide into the surface of a metallic component is to induce nuclear reactions by particle irradiation (protons, deutrons, alpha particles) of moderate energies (for instance 10-35 MeV) into the material itself. A radioactive layer will be generated from the surface at a distance (µm to mm) into the material. An alternative to charged particle irradiation is to irradiate the wearing component by neutrons in a nuclear reactor. In this case the induced radioactivity will be homogeneously distributed throughout the whole metallic volume, and only relatively small components can be examined in this way.

This presentation will focus on alternative non-conventional methods of carrying out “TLA”-examination, mainly with a nuclear reactor and thermal neutrons as radiation source. Keywords are: 1. Host metals and alloying elements that can be reasonably radioactivated setting limitations on half-lives and gamma energies, 2. metallic components that cannot be reasonably radioactivated, 3. cerames, plastic or organic polymer materials and graphite-carbon materials studied by reaction product implantation (direct reaction recoils or fission fragment recoils), 4. purification of reaction products by electromagnetic isotope separation (EMIS) before implantation, 5. post-acceleration to higher energies of EMIS-purified radionuclides for deeper implantations, 6. application of nanoparticle slurries in surface polymer coatings where the nanoparticle themselves are radio-activable, 7. preparation of radionuclides as nano-particles before mixing into the surface-protecting polymer matrix and more. Material loss depths ranging from nanometers to tens of micrometers may be studies with these latter methods. Some of these methods are still awaiting full development.

IAEA-CN-332/268

Evaluation of Organic Inhibitors for Corrosion Control of Copper Alloy Using Thin Layer Activation Method

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Small organic molecules having suitable functional groups can have the potential to be used as inhibitors for corrosion control in metals / alloys. Thin layer activation analysis (TLA) is a highly sensitive nuclear method for monitoring corrosion in a number of metals and alloys. In the present study three different organic molecules, such as, ascorbic acid, citric acid and oxalic acid are used for controlling corrosion in bronze (a copper alloy) in acidic medium using TLA method. Bronze test coupons of size 10 mm x 10 mm x 2 mm were irradiated with 11 MeV proton beam using BARC-TIFR Pelletron accelerator, Mumbai with a beam current of 200 nA for 4 hours each. 65Zn radioisotopes (t1/2: 244 d, E□: 1.11 MeV (branching ratio 50 %)) were produced on the bronze surface through 65Cu(p,n)65Zn nuclear reaction. A test solution was prepared by mixing 0.3g/L Na2SO4, 0.3 g/L NaHCO3, 0.3 g/L NaNO3 and the pH of the solution was adjusted to 2.6 by addition of diluted H2SO4. The corrosion experiments were performed by immersing the irradiated coupon into the test solution without the inhibitor and with different concentrations of individual inhibitors. The activity loss from the surface of coupon as a consequence of corrosion was monitored using a gamma spectrometer. The activity loss was converted into thickness loss with the help of a calibration curve and the rate of corrosion was estimated from the slope of thickness loss versus time curve. The results showed that ascorbic acid has higher corrosion efficiency than other two inhibitors. The corrosion rate in absence and in presence of ascorbic acid (300 □M) was estimated to be 3102 nm/day and 316 nm/ day, respectively.

IAEA-CN-332/211

New Water Tracer for Improved Monitoring of Phase Separation and Residence Time Distribution in Industrial Process Equipment During Operation

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A new water tracer has been developed which will improve phase separation and residence time distribution (RTD) measurements in multi-phase separators and other process equipment during operation. The technique utilizes a 68Ge (T1/2 = 271 d)/68Ga (T1/2 = 68 min) radionuclide generator. This enables repetitive injections of tracer and measurements of phase separation and/or RTD with just a few hours in between injections. The positron-emitting 68Ga-nuclide (Eh□ = 511 keV and E□ = 1077 keV) offers non-intrusive measurements as it can be detected on the outside of even non-transparent pipelines and housing. The half-life of the mother radionuclide 68Ge allows this devise to be used for at least 2-3 years before replacement is needed. The tri-valent 68Ga3+ should not be used as such in most flow systems but should form a strongly bound hydrophilic complex with some ligand. The compound formed and studied here is a complex between 68Ga3+ and 1,4,7-triazacyclononane-N,N',N''-triacetic acid (NOTA). This complex has shown remarkable qualities as a tracer for water and brine. At and around neutral pH the complex is entirely hydrophilic, forms easily and fast, has high stability and does not absorb to sand, mineral scales or other materials which are present inside a multiphase separator. The technique is robust and delivers reliable and repetitive results. This radiotracer may replace longer-lived tracers traditionally used like 82Br- (T1/2 = 35.3 h) and 131I- (T1/2 = 8.02 d). Thus, it represents a safety improvement as the potential radiation load to the workers is reduced considerably. Since 1 GBq of 68Ga will be sufficient for one measurement cyclus in most equipment, and due to the fact that it elutes carrier-free from the generator, it has no negative environmental impact as the radionuclide turns into 0.4 ng stable zinc after decay.

IAEA-CN-332/139

Micro-lLakage Detection on a Steam Generator

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The Nuclear Safety Authority required of PHENIX reactor to take measures in the event of appearance of a micro-leakage in a steam generator.

The Steam Generator (Sodium / water) consists of 3 stages: ECO/EVA, super heater (surchauffeur), reheater (resurchauffeur).

Each stage includes 12 exchanging modules water-sodium. The possible micro-leakage is announced by a system of hydrogen detection (DH) in a total way by stage of the Steam Generator.

The aim of the study is to evaluate the feasibility of a method to localize the leaking module among the 12 per radioactive tracing. The project leakage is 1 mg/s corresponding to a leakage rate of 10-8. The equivalent diameter of the breach is then of about 35 µm.

A particular methodology based on radiotracer has been developed to reach this objective.

IAEA-CN-332/229

Efficient Processing Algorithms of Radiotracer Signals for Optimizing Flow Rate Measurements Based on Residence Time Distribution

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Radiotracer investigations were conducted to trace primary flow in a pipeline system, designed to provide sufficient residence time for the primary fluid, allowing short-lived radioisotopes to decay to safer levels before exiting. The main objectives were to measure breakthrough and residence times and examine flow dynamics. Residence Time Distributions(RTDs) were measured using technetium-99m as a radiotracer with activities ranging from 5 to 10 mCi, injected into the pipeline flow. Scintillation detectors, equipped with Data Acquisition Systems(DAS), captured detailed temporal dynamics of tracer dispersion. RTD analysis techniques revealed intricate flow patterns and residence times. An axial dispersion model with two parallel flow streams simulated the measured RTD curves, indicating coolant bypassing. The breakthrough time (BTT) and mean residence time(MRT) determined from the measured RTD were inadequate for the decay of short-lived radioisotopes to permissible levels. Flow rates were determined using several established methods, including integrating concentration-time curves with the Method of Moments and analyzing peak concentrations during tracer pulse injections. Optimizing flow rate measurements based on RTD faced challenges, especially in extracting meaningful features from noisy radiotracer signals. This noise, due to environmental factors, sensor limitations, and other interferences, obscured important features and introduced variability. Complex and dynamic behaviors within flow systems, such as turbulent flows or varying flow rates, further complicated the extraction of consistent features. Determining relevant features for accurate flow rate measurement from a potentially large set was a significant challenge. Irrelevant or redundant features could degrade classifier performance, leading to inaccurate flow rate measurements. Optimizing these features for classification algorithms was computationally intensive, requiring efficient algorithms to avoid suboptimal classifiers that affect system reliability for real-time applications. An advanced algorithm was proposed to address these issues, comprising training and testing phases. In the training phase, raw radiotracer signal data was divided into zones to facilitate localized feature extraction. The Hilbert Transform extracted instantaneous amplitude and phase information from the signal, capturing dynamic flow characteristics. Feature optimization was performed using a hybrid algorithm combining Butterfly-Particle Swarm Optimization (Butterfly-PSO/BFPSO) and Whale Optimization Algorithm(WOA). Butterfly-PSO/BFPSO leveraged the strengths of Particle Swarm Optimization and Butterfly Optimization Algorithm, while WOA performed a global search for optimal features. Classification was achieved using Gaussian Mixture Models(GMM) and Naive Bayes(NB). GMM modeled the distribution of extracted features, identifying clusters corresponding to different flow conditions, while NB classifiers handled probabilistic classification based on optimized features. In the testing phase, new radiotracer signal data was processed similarly, with optimization performed using Butterfly-PSO/BFPSO and WOA. The GMM and NB classifiers were applied to optimized features to identify and classify pulses, matched with trained features to accurately identify flow rates. Deep Learning was applied to develop algorithms for detecting flow rate malfunctions in radiotracer signal data within pipelines. A robust malfunction detection approach utilizing pretrained deep convolutional neural networks(CNN) was introduced, involving three pretrained networks: AlexNet, ResNet18, and VGG-19, employed for feature extraction. The extracted features were independently classified as indicative of normal operation or malfunction using two classifiers: artificial neural network (ANN) and multiclass support vector machine (MSVM).

IAEA-CN-332/103

The Natural Radionuclide 7Be as a Tracer in the Study of Hydrodynamics of Artificial Wetlands

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Background:
Constructed wetlands (CWs) are recognized as effective tools for treating wastewater and improving water quality. They offer a natural, environmentally friendly approach to addressing challenges such as water scarcity and pollution. Understanding the principles of CWs operation is crucial for compliance with regulations and promoting sustainable water management practices. Additionally, the simulation of CWs hydrodynamics plays a critical role in conceptualizing these systems and optimizing their performance. Various processes can be studied using this natural radionuclide as a tracer.7Be, a natural radionuclide of cosmogenetic origin with a half-life of 53.3 days, is widely used as a tracer in various environmental studies.

Methodology:
The present research aims to determine CWs hydrodynamic systems using the natural radionuclide 7Be as a tracer. In the present work simulation scenarios are applied in theoretical CWs to determine optimal decontamination conditions, particularly after rainfall events. The analysis concerns the presence of the natural radionuclide 7Be, as a tracer, within the wetland after rainfall events. 7Be, a natural radionuclide of cosmogenetic origin with a half-life of 53.3 days, is widely used as a tracer in various environmental studies. By monitoring, for example, its decomposition within a medium/sample, it is possible to identify the movement and behavior of substances or particles present in this medium. Sediment samples collected from the boundaries of the wetland area are analyzed to determine isotope concentrations. Various simulation codes, including MODFLOW and its versions, are tested to assess their suitability for studying CW hydrodynamics. The radioactive tracer method is utilized for validation and optimization of CW performance.

Results:
The study identifies the potential of CWs as eco-friendly wastewater treatment solutions and emphasizes the importance of understanding their hydrodynamics for effective operation. Initial tests with simulation codes reveal promising results, with the NWT version of MODFLOW showing particular promise for CW optimization. The use of radioactive tracers presents a challenging yet valuable approach for testing CW efficiency.

Conclusions:
Constructed wetlands offer a nature-based solution to water treatment and pollution control, with significant potential for sustainable development. The research highlights the importance of simulation in understanding CW hydrodynamics and optimizing their performance. Further investigation, particularly using radioactive tracers, is recommended to enhance the efficiency and effectiveness of CWs in wastewater treatment.

IAEA-CN-332/387

Tracing Coastal Sediment Dynamics Using Natural Radionuclides: Case Studies from Gran Canaria Beaches

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Coastal areas, particularly beaches, are dynamic environments that play a crucial role in ecological balance, economic activities, and human recreation. Understanding the processes that govern sediment movement and deposition in these areas is essential for the sustainable management of natural coastal areas and the conservation. One of the advanced approaches in studying coastal sediment dynamics involves using radionuclides as tracers. The use of artificial radionuclides or sediments from other locations (black sand) with high content of natural nuclides can pose problems with the environmental regulations of the sedimentary systems under study. Therefore, an effective approach is to characterize the natural radionuclides present in the sedimentary systems being studied. Analysing their distribution in beach sands can offer valuable insights into sediment transport, erosion, and deposition processes.

In this study, the spatial distribution of different natural radionuclides was analysed for in El Confital Bay and Las Canteras beach (Gran Canaria, Spain). For this, the activity concentration values of 226Ra, 228Ra and 40K were determined by gamma spectrometry for 39 submarine samples collected in 2022.

The sampling process involved collecting intertidal sand at low tide from a 1 m^2 area at each point. The samples were taken from the top 0-5 cm of sand, ensuring that the surface sediments were examined. Once collected, the samples were transported to the laboratory where they were dried at 80°C for 24 hours. Following, the samples were sieved through a 1 mm mesh to ensure homogeneity and then stored in PVC containers to allow for secular equilibrium between 226Ra and 222Rn. Gamma spectrometry was employed to measure the concentrations of radionuclides. The detector used was a high-purity germanium detector, which provided precise measurements of 226Ra, 232Th, and 40K. The data obtained from these measurements were then subjected to statistical analyses. Cluster analysis (CA) and principal component analysis (PCA) were used to identify and interpret the spatial distribution patterns of the radionuclides. Additionally, the ratio of 226Ra to 228Ra was calculated to distinguish between periods of erosion and accretion, providing insights into the temporal variability of sedimentary processes. In addition to the radionuclide measurement and previously, continuous monitoring of environmental parameters such as grain size, pH, conductivity, and temperature was made. These parameters were measured to establish correlations with radionuclide data, providing a deeper understanding of the factors influencing sediment dynamics. Also, a mineralogical analyse was made.

The results showed that 226Ra, 228Ra and 40K trace the sediment erosion, transport and accumulation that can be found in diverse parts of the bay (Figure). The highest concentration values of these radionuclides track sediment transport from the western coast to the deeper parts of the bay. In the submerged part of Las Canteras Beach (shallower zone), the concentration values of 226Ra, 228Ra, and 40K identified the same erosion/accumulation patterns as described for the intertidal zone. Furthermore, the mineralogical analysis results indicated that 40K is an effective tracer for sediment transport and accumulation, attributed to its presence in K-bearing minerals..

IAEA-CN-332/041

Investigation of the Relationship between Grain Size and the Concentrations Natural Radionuclides in Sediment

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BACKGROUND

The transportation of sediment particles in aquatic environments is influenced by their grain size. It is essential to understand the correlation between natural radioactivity and particle size in sediment in order to effectively monitor sediment processes in aquatic settings. Through investigation of radionuclide distribution in various sediment types, scientists have the capacity to track sediment movement and develop effective erosion and deposition management techniques.

The concentrations of natural radionuclides may be associated with the distribution of grain sizes in particular sediment and can serve as a unique radio fingerprint for that sediment. The grain size of sediment is primarily determined by the geological composition of the source material and the erosion processes that led to the formation of the sediment. The size of sediment grains is directly related to the surface area and porosity of the particles. The aim of this study is to provide a mathematical representation of the connection between the levels of natural radioactivity and the distribution of grain sizes in sediment. This relationship will then be used as a means of tracing or identifying certain characteristics or movements within the sediment.

METHODOLOGY

Various sediment samples were gathered from different aquatic systems, including river basins and coastal regions. The samples were sorted into several grain size categories by the process of sieving. These categories include gravel (>2 mm), very coarse sand (>1 mm), coarse sand (>500 µm), medium sand (>250 µm), fine sand (>125 µm), very fine sand (>63 µm), and silt and mud (>0 µm). A grain size distribution was subsequently generated for each sample. A laboratory gamma spectroscopy method was used to determine the nuclide concentrations of potassium, uranium, and thorium. The grain size distribution of the radioactive concentrations in each sample was then correlated with the geological end members present in the sample.

RESULTS

Distinct grain size distributions were identified for each sample. All the distributions followed either a normal or lognormal pattern, with each sample having its own distinct mean and standard deviation. The nuclide concentrations in relation to the size of the sample grains exhibited consistent patterns, with smallest and largest grains having the highest concentrations of nuclides. Nevertheless, each sample exhibited distinctiveness within this similarity. The final mathematical model linked nuclide concentrations, particle size distribution, and geological end members. This model produced unique radio fingerprints which were used to identify sediment samples.

CONCLUSION

This study links natural radioactivity with sediment grain size in water. By analyzing radionuclide distributions in different-sized sediment samples, unique radio fingerprints for each sediment type were created. Using gamma spectroscopy, consistent nuclide concentration patterns were found across grain sizes, leading to a model for identifying sediment samples based on these fingerprints.

IAEA- CN-332/310

Integration of Radiometric Fingerprinting and Grain Size Distribution Analysis for Enhanced Understanding of Sediment Dynamics

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Background of the study

Understanding sedimentary dynamics in aquatic environments is critical for sustainable civil engineering management of beaches, harbours, rivers, and dams, which are integral to the protection of human infrastructure. Radiometric gamma surveys of natural occurring nuclidesin sediments provides rapid and useful data regarding sediment transport. Traditionally sediment transport studies was done by using artificial radioactive tracers. We propose to use variations in the concentrations of natural occurring radionuclides to investigate sediment transport processes. To facilitate the interpretation maps of radionuclide concentrations to sediment properties, a radio-sedimentological framework was constructed.

Methodology

This study present a model that merges radiometric fingerprinting with grain size distribution analysis to create a robust model for assessing sediment provenance and composition. This model is based on an end member analysis of sediment to groups of sediment with similar mineralogical and grain size properties. Each end member has a unique grain-size distribution (grain-size end member), with a constant mean and each end member is unique in its concentration of radionuclides (radiometric end member). This model then converts in-field measured radionuclides concentrations to sediment grain size and end member maps.

Results

The combination of radiometric fingerprinting with grain size distribution analysis was used to interpret field measurements of an underwater gamma-ray spectrometer (the “Medusa” sensor). These field measurements of a coastal zone in the Netherlands were converted to a map showing the median grain size of the sediment. This information is the reflection of sediment transport processes and helped to understand the sedimentary processes in the shoreface of this intertidal beach.

Conclusion

The integration of radiometric fingerprinting and grain size distribution analysis provides a comprehensive tool to understand the variation in the composition of sediments. This innovative methodology offers a robust framework for the precise assessment of sediment composition and provenance, enhancing sediment management practices for coastal infrastructures. The findings underscore the potential of natural radionuclides as future tracers in evaluating sediment transport, both underwater and on beaches.

IAEA-CN-332/181

The Use of Natural Isotopes as Tracers for Sediment Transport

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For a long time, sediment tracing has been a reliable method for investigating routes, destinations, and deposition forms. Nuclear techniques in hydrogeological investigations typically use radioactive isotopes as artificial tracers. Despite the security measures surrounding these applications, it is crucial to seek efficient alternatives within the nuclear framework that utilize natural radiation as sediment tracers. In this context, the research project "Development of Radiometric Methods and Modelling for Sediment Transport Measurement in Coastal Systems and Rivers," coordinated by the International Atomic Energy Agency (IAEA), proposes an approach based on natural radiation. Based on these premises, researchers from the Nuclear Technology Development Center (CDTN) in Brazil aimed to investigate sediment transport in two municipalities in the state of Minas Gerais. Natural radiation levels were surveyed using gamma spectrometry scans during dry and post-monsoon periods in various locations within Caldas and Januária. In Januária, ground caldasite ore was used to trace sediment movement in a wetland area. In Caldas, scanning occurred at a decommissioned uranium mine. It was concluded that caldasite ore could not be tracked in the proposed period. Conversely, the scan at the decommissioned mine indicated contamination of the dam due to sediment runoff from a tailings deposit.

IAEA-CN-332/404

Development of a Radioactivity Mapping tool to Study Sediment Dynamics at the Shoreline Enabling Nuclear Techniques

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In recent years, many research groups worldwide focus on the study of the environmental impact of climate change in the coastal zone using different methodologies. In this study we present a tool for rapid beach-sand mapping using geo-referenced modules and an underwater radioactivity sensor. The system provides activity concentrations maps of naturally occurring radionuclides for estimating the sediment dynamics in the studied area. The study of temporal data is essential for understanding the impact of climate change. The R programming language was implemented for data statistical analysis and visualization.

The developed methodology was applied in two coastline locations of the Northern Aegean Sea, Stratoni and Ierissos. Our results indicate the activity concentration for 238U progenies (214Bi), 232Th progenies (208Tl and 228Ac) and 40K to vary up to (33 ± 4) Bq kg-1, (19 ± 3) Bq kg-1, and (420 ± 30) Bq kg-1, respectively. The activity concentration of 137Cs in Stratoni and Ierissos beach sands were (8.1 ± 2.2) and (3.9 ± 1.2) Bq kg-1, respectively. Additional trace elements concentration measurements were performed on the laboratory on collected samples prior the in-situ survey. The results showed high values ranging between (800 ± 40) μg g-1 and (12 ± 1) μg g-1 for As, (1200 ± 60) μg g-1 and (33.3 ± 0.3) μg g-1 for Pb, (100 ± 6) μg g-1 and (6.0± 0.3) μg g-1 for Cu and (2000 ± 60) μg g-1 and (8.0 ± 0.4) μg g-1 for Zn.

The geo-referenced in-situ detection system KATERINA II is a low resolution gamma-ray spectrometer and was upgraded to provide rapidly activity concentration maps. The system consists of a NaI crystal and appropriate electronics for saving the sequential buffering data in special memories. The system offers activity concentrations of all detected gamma-ray emitters in absolute units. The system efficiency calibration is performed via Monte Carlo simulations. The surveys of the spectrometer were performed by mounting the in-situ system for acquiring first the gamma ray spectra and then to perform the quantitative analysis. The radiometric maps on beach sands were produced after the experimental work. The geo-referenced system was also applied in areas in Attica (Greece) where the shoreline is affected from various anthropogenic activities in order to assess the level of erosion or accretion in the beach sand areas.

The spatial distribution of the total counting rate and the activity concentration of naturally occurring radionuclides may support other research groups to identify rapidly the erosion or accretion processed in the shorelines of interest.

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Assessing Sediment Transport Processes Using Multivariate Analysis of Natural Radionuclides in Aquatic Environments

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Background

Sediment transport is an important phenomenon in the management of ports, coastal engineering, and pollution in aquatic systems. The use of artificial tracers such as 46Sc for sediment transport has been established. However, this method poses a burden on the environment and public safety. Therefore, the use of natural radionuclides is safe for assessing sediment dynamics. The activity concentrations of natural radionuclides in sediments provide detailed information about the characteristics of sediments in marine and aquatic environments. This can be achieved using statistical tools that elucidate sediment characteristics based on the activity concentrations of primordial natural radionuclides. The aim of this study was to apply multivariate analysis, principal component analysis (PCA), and ternary plots to investigate the sediment provenance in the Berg River on the West Coast of South Africa. These techniques form the basis for the application of natural radionuclides as sediment tracers.

Methodology

The study was conducted at the Berg River at the West Coast of South Africa. The Delta Underwater Gamma Ray System (DUGS) was used to survey the river channel. Four transect lines were measured along the main channels, and one transect was measured along the Port Owen Peninsula. Activity concentrations were then extracted from the spectra using modified full spectrum analysis (FSA). PCA and ternary diagrams were then obtained using R statistical software to gain greater insight into the sediment data from the study area.

Results and Discussion

PCA was used to examine the contribution of radionuclides to the sediment distribution in different river sections. The first two components, PC1 and PC2, explained 79.45% of the total variability in the activity concentration. PC1 displayed the highest variability (46.08%) compared with PC2 (33.37%). In addition, a strong association (99.19%) between 232Th and 238U in the sediment matrix was observed as they clustered with PC1. Conversely, 40 K exhibited the highest variability in PC2 (98.06%), indicating a separation from 232Th and 238U. This can be attributed to feldspar, which was enriched with 40K. The surrounding areas are characterized by light minerals, such as quartz and feldspar. The close association of 238U and 232Th with correlation coefficient of 0.83 and -0.82, respectively, suggests a shared source rock origin, with statistical significance ($p < 0.05$). However, 238U correlated positively with PC1 and negatively with 232Th. This potentially indicates that 238U has higher mobility owing to its water solubility and subsequent reabsorption into the mud.

Ternary plots depict the relative proportions of radionuclide concentrations, further elucidating sediment provenance. The results showed significantly higher 40K activity concentrations than those of 238U and 232Th, which is consistent with the PCA observation that 40K contributed the highest variability.

Conclusion

The PCA and ternary results revealed elevated activity concentrations on both the left and right sides of the riverbed compared with the middle section, indicating sediment deposition on the riverbanks. These multivariate analyses concluded that mud was the dominant sediment type in the riverbeds. Therefore, multivariate analysis is an important tool for studying sediment transport, using natural radionuclides as sediment tracers.

IAEA-CN-332/141

Radioactive Tracers for Diagnosing Industrial and Environmental Processes

J. Thereska – International Society for Tracer and Radiation Applications (ISTRA)

Radioactive tracers (or radiotracers) have been applying since many decades to investigate fluid flow dynamics in industry and environment. Radiotracers are very competitive for obtaining hydrodynamic parameters inside reactors, vessels and ponds in industry and environment. Radioactive tracers are mostly used for online non-invasive diagnosis; they are very sensitive and resistant in harsh conditions. Radionuclide availability has been increasing worldwide due to radionuclide generators and medium size cyclotrons.

Relevant target areas for radiotracer applications are defined; the petroleum and petrochemical industries, mineral processing and waste-water treatment sectors are identified as the most appropriate target beneficiaries of radiotracer applications: these industries are widespread internationally and are of considerable economic and environmental importance.

Radiotracer case studies are presented using methods of:
- Residence time distribution
- Flow rate measurement
- Leak testing in pressured vessels, heat exchangers and buried pipelines.

IAEA-CN-332/006

Investigation of Process Flow inside Demineralizer Column of PUSPATI TRIGA Reactor (RTP) Using Radiotracer Technique

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Radiotracer approach was introduced in order to map out the demineralization process and diagnose the process anomalies inside the demineralizer column located at PUSPATI TRIGA Reactor (RTP), Malaysian Nuclear Agency. The column acts as a fixed bed column whereby the upper part of the column is filled with water whereas the lower part is occupied by with Amberlite IRN 150 resin respectively. The work was carried out during reactor maintenance week when Reactor was experiencing shut down. Some modifications were made in this work to ensure radiotracer material did not compromise with the reactor operation. For that matter, the column inlet flow rate was assigned to 5gpm instead of 10gpm whereby the outlet was isolated from being recycled to reactor pool. Instead of using water from reactor pool as the input, tap water was used as continuous input to the column and the outlet was not recycled to reactor but discharged to reactor pit. Room temperature was adopted whereby Tinlet is 27oC instead of 49oC. However, monitoring of dose rate was still made to the discharged water before channeling to radioactive aquifer. The detected dose rate was 3µSv/h during the running of experiment and contained in the reactor pit. About 3.72mci/4ml 68Ga-NOTA-NHS was prepared to be injected inside the demineralizer. 68Ga was eluted from commercial 68Ge and chelated with NOTA-NHS as chelating agent with 1M Sodium Acetate anhydrous (NaOAc) as buffer in order for 68Ga to be water tracing material. 12 sodium iodide (NaI) detectors were arranged accordingly around the column. Detector which was assigned at the outlet of column was analyzed for residence time distribution (RTD) measurement. Detector 1 and 1 were installed at the upper part (water area) whereas the remaining detectors were installed at the lower part (resin space) around the column. Four detectors were assigned for Resin Upper Level (RUL) from D3-D6 whereas for Resin Lower Level (RLL) another four detectors denoted as D7-D10 were installed respectively. D11 was assigned for isolated discharged to reactor whereas D12 was meant for outlet at pit. RTD was carried out to D12 and MRT was measured to determine the time the particles reside in the reactor. In conclusion, water-68Ga radiotracer was distributed well at the lower part of resin and perfect mixers in series with exchange model and perfect mixers in parallel provide comparable results with the experiment

Keywords: Demineralizer, radiotracer, Ga-68-NOTA-NHS, RTD, Amberlite IRN 150 resin

IAEA-CN-332/257

Analysis of Residence Time Distribution (RTD) of a Wastewater Treatment Unit at an Oil Refinery Using Radioactive Tracer Technique

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Waste water from municipal and industrial activities are mainly collected in wastewater treatment plants (WWTPs), which are mainly composed of various units for processing before discharge into the environment. The wastewater discharged from the operational activities of the Tema Oil Refinery in Ghana contained crude oil content higher than the EPA limits.

To help meet the strict effluent quality standards of the Environmental Protection Agency (EPA), the experiment was undertaken to help diagnose the operational problems of the Dissolved Air Floatation (DAF) tank. The tank is made up of three equal chambers connected in series, the pH-adjuster unit first, followed by the coagulation unit, then finally into the flocculation unit. These units are responsible for the oil/water separation, before the wastewater goes into the biodigesters.

To investigate the mixing efficiency between the wastewater and the chemicals introduced into the three units of the DAF tank, a 20mCi radioactive tracer, technetium-99m with a half-life of 6 hours, was introduced at the inlet of the tank. Sodium Iodide Scintillation detectors NaI(TI) were placed at the outlet of each of the units to record their residence time distributions (RTD) respectively.

From the results obtained, it emerged that the units have mixing efficiencies of 0.8, 0.77 and 0.65 respectively. These corresponded with dead volumes of 15%, 16.7% and 18% respectively. Based on the results, it was recommended that the flow rate of the wastewater through the DAF tank be reduced from 20m3/hr to 15m3/hr, to increase the contact time between the wastewater and the treatment chemicals for higher process efficiency and better effluent quality.

IAEA-CN-332/240

Measuring Mean Residence Time Using Responses Curves to Dirac and Non-Dirac Radiotracer Injection Pulses in a Phosphoric Acid Production Line

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The use of radioactive tracer to obtain the residence time distribution (RTD) of a vessel in an industrial production unit is very beneficial to understand the fluid dynamics inside the prospected reservoir. The most critical parameter deduced from the RTD is the Mean Residence Time (MRT) of the product inside the vessel. RTD is generally obtained by processing the response curve at the outlet of the vessel to an injection of the radioactive tracer, in the form of a dirac pulse, at the inlet of the reservoir. However in some industries, such as phosphoric acid production lines, the number of vessels in series and their huge volumes would make it difficult to inject a relative high quantity of the radioactive tracer at the entrance of each vessel in order to obtain the RTD of each element of the production line. So, in the present paper, we consider the possibility of using the response curve obtained at the outlet of a vessel, separated by one or two reservoirs from the radioactive tracer injection point, to determine with acceptable uncertainty the MRT of the vessel. In such a case the injection of the radioactive tracer cannot be considered as a Dirac one. In order to assess such approach, in the present work, we compare experimental results of MRT in a crystallizer obtained with a Dirac injection of I-131 radioactive tracer at the inlet of the crystallizer, to the MRT deduced from the response curve, obtained at the outlet of the crystallizer with the injection of radioactive tracer at the entrance of two digesters placed upstream from the crystallizer.

IAEA-CN-332/626

Detection and Evaluation of Scale Deposits in Geothermal Pipes Using Gamma Pipe Scan: Case Study

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A geothermal plant in southamerica exhibited symptoms of obstruction in its pipelines. Initially, the staff attempted to locate these restrictions using gamma radiography. However, considering that the plant could not halt its operations and the pipes needed to remain filled with fluid, this technique proved ineffective. After several attempts, they ultimately called us for a solution. The technique involved moving a gamma radiation source and a detector on opposite sides of the pipe in a cross-section manner, recording the penetrating radiation.

This study presents the results of a cross-sectional Gamma Pipe Scan inspection conducted at 16 points along process lines. The inspection assessed the presence of obstructions in pipes ranging from 200 mm to 600 mm in diameter. A 6.2 mCi Co-60 source was used, taking into account the schedule of each pipe for wall thickness attenuation. Quartz density (2.65 g/cc) served as the basis for calculating the thickness of the scale deposits.

The findings revealed potential scale deposits in several lines, with Items 1 and 13 being particularly notable. Item 1, a 450 mm brine supply line, showed significant scaling in its central section. Item 13, a 600 mm condensed brine line, exhibited substantial deposits in its upper and lateral sections. Both cases indicated potential cross-sectional area losses in the pipes. Other points of interest were identified, such as Item 2, which showed moderate scaling and high-density deposits at the bottom, and Items 9 and 12, which had high-density deposits in their lower sections.

The Gamma Pipe Scan method enabled a rapid assessment of the pipes at ground level, using ionizing radiation to evaluate density differences. The resulting density profile was used to assess the distribution of materials within the pipes.

Keywords: Gamma Pipe Scan, gamma radiation, Co-60, Scale deposits, density distribution, wall thickness attenuation, obstruction detection, obstruction assessment, geotermal process.

IAEA-CN-332/389

Evaluation of the Mechanical Structure of an Air Liquefaction Distillation Column Using Gamma Column Scanning Technique

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A 50 mCi cobalt 60 sealed radioactive source was used to evaluate the mechanical structure of a distillation column used in air liquefaction. Two scan lines, one diagonal and one transverse were used to assess the columns. The radioactive source was moved on one side of the scanned column with a NaI(Tl) detected moving in synch with the source but on an opposite side of the column. A linear density profile relating to the internal structure of the scanned column was obtained. High density sections of the column resulted in heavy attenuation of the gamma radiation whilst low density sections resulted in low attenuation. The distillation column scanned is made up of a top column and a bottom column separated by a condenser. The scan profiles obtained seem to indicate that all the trays in both columns were in their correct positions and were separated by either 15 cm or 20 cm, alternatively in both columns. The top column was suspected to have some liquid in the top section as heavy attenuation was observed in this section. The bottom column also had sections with some liquid as there were observations of some heavy attenuation. The diagonal scan line passed through a heat exchanger which was in the closed "Cold Box" whilst the transverse scan managed to detect the trays in the bottom column.

IAEA-CN-332/149

Capsule Networks for Naphtha Splitter Column Malfunctions Classification based Gamma Scanning Techniques

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In this work a software for naphtha splitter column malfunctions classification will be presented. The software has been tested using different cases studies for gamma scanning of different distillation columns scanned using Gamma rays. Sodium iodide scintillation detectors are used to measure the penetrating gamma ray and data acquisition system (DAS) was used for collecting, saving and displaying the measured signals. The signals obtained from different scanning have been analyzed for troubleshooting the tested distillation columns. In the developed Software, the captured signal divided into frames; each frame contains one column tray signal only to be able to classify the type of column malfunctions, and also to determine the position of the malfunction tray to facilitate the maintenance process. Then the spectrums of these frames are used as features that fed the capsule networks to extract the discriminating features from the processed signal. The output of the software is tray number, tray position and types of malfunction. The results show that the proposed approaches can be used efficiently at high noise levels.

IAEA-CN-332/009

Verification on Underground Pipe Leakage for Fire Hydrant System Using Industrial Radiotracer Tc-99m

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The use of radiotracer techniques is well-established as an assisting tool for troubleshooting and process optimization in various industries rely heavily on water distribution system. Industrial radiotracers have proven to be highly useful for examining and verifying the condition status of fire hydrant systems.

A fire hydrant system is a crucial component of fire protection in buildings. This system supplies pressurized water from the municipal water supply into the distribution fire water sprinkler system for suppressing fires. In certain regions, water supply lines within the building are linked via underground pipes. Once the underground pipe leakages happen, the only way to investigate the problems are from the observation of known water pressure meter. A jockey pump is a small pump connected to a fire sprinkler system to maintain pressure in the sprinkler pipes. The jockey pump is activated when a pressure drops in the fire hydrant system is occurred. If the fire sprinkler system is not activated its mean the water leakages is happening.

This study introduced an important opportunity to confirmed a water pipe leakage due to the rise in water bills and a significant increase in water consumption but the water leakage is not visible. It is also important to identified the section of the underground pipe leakage, even though the specific area is unknown. Because the jockey pump adjusts the water pressure decrease to keep the sprinkler system operating occasionally, this investigation also aimed to determine whether there are any water leakages on any floor of the structure.

A radiotracer experiments was carried out to measure the radiation signals using 5-unit Sodium Iodide (NaI) scintillation detectors located at 5 different points nearby the inlet and outlet of the fire hydrant system. In this work, aqueous form radioisotopes which emit γ-ray with energy 140 keV have been chosen as radioactive tracer which is Tc-99m produced from Mo-99/Tc-99m radioisotope generator. Approximately 500 MBq (13.5 mCi) of the radiotracer activity was estimated to be injected into the feed line with 50 bar pressure.

Based on the results of the radiotracer investigations there is movement of radiotracer resulting the displacement of water in flow stream. The last detector position shown no radiation signal response to conclude that there is no water displacement inside the building. This present study proved that the underground pipe is leaked and jockey pump is in good condition since there is no radiation exposure at ground level was found after the random surface monitoring been carried out.

IAEA-CN-332/249

Effect of Experimental Parameters on the Uncertainty of Residence Time Distribution Analysis Using Radiotracers

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Residence time distribution (RTD) of fluid is measured using radiotracers to diagnose and troubleshoot industrial processing systems. The most important quantitative result of RTD analysis is mean residence time (MRT), which is used in various system diagnoses including flow rate calculation. The uncertainty of a MRT should be reported together with the MRT as it is vital information especially when the result is used for making decisions or fiscal metering.

Recently, a new approach for evaluating the uncertainty in an MRT was established based on the ISO GUM 1995. The equations for the uncertainty propagations were derived and all the calculations could be demonstrated on a spreadsheet.

The uncertainty of MRT can be affected by various experimental parameters, such as

- activity of radiotracer injected,

- number of data points,

- background radiation level,

- half-life of the radionuclide, and

- dead-time of the radiation counter.

The effects of the parameters on the uncertainty of MRT were evaluated using an impulse response curve simulated using Perfect mixers in series model and the spreadsheet mentioned above. The results of this study provide useful information in planning radiotracer RTD experiments as well as in analyzing the experimental results.

IAEA-CN-332/245

Numerical Study of the Scour Erosion Around a Square-shaped Pile at Different Positions in a Narrow or Wide Channels

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In this study, a numerical investigation is conducted to study the scour erosion dynamics around vertical square and diamond-shaped piles in clear-water and live-bed conditions. The focus is particularly on cases involving narrow channels, aiming to examine the differences compared to more extensively studied scenarios, such as wide channels with circular piles.

This work employs a Large Eddy Simulation (LES) model to simulate the turbulent flows around the structures under waves and currents. The hydrodynamic model is based on the Navier-Stokes equations in σ-coordinate, and the bed evolution is simulated by solving the Exner-Polya equation. The governing equations are solved using a second-order unstructured finite-volume method. The model is initially validated through a comparison with experimental data and numerical results found in the literature.

Subsequently, it is applied to conduct a comprehensive study, enhancing our understanding of the various conditions influencing the scour process. The results indicate that the shape of the piles has different effects on the scour depth under clear-water and live-bed conditions. In live-bed conditions, the simulations reveal a deeper scour around the square-shaped pile compared to the diamond-shaped pile at the equilibrium stage.

Conversely, an opposite behavior is observed in clear-water conditions, with a deeper scour around the diamond pile. Moreover, this behavior is consistent across both narrow and wide channels. It is discovered that, in clear-water conditions, the evolution of the scour in a narrow channel reaches equilibrium faster than in a wide channel, leading to a deeper equilibrium scour hole in the wide channel scenario.

IAEA-CN-332/039

NDT Monitoring: Acoustic Emission & Machine Learning for Crack Detection in Concrete Structures

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In the field of civil engineering, there is a growing interest in developing non-destructive evaluation (NDE/NDT) methodologies proficient in monitoring the health conditions of concrete elements and structures.

Acoustic Emission (AE) is an NDE/NDT method that involves the detection, processing and analysis of ultrasonic waves originating from localized sources within a material or structure when subjected to varying stress levels. This technique facilitates structural monitoring in a passive and non-invasive manner. However, a significant limitation of this approach is the voluminous quantity of signals generated, which poses substantial challenges due to the extensive data processing requirements. Recent progress in machine learning computational strategies has introduced a novel perspective to the application of AE technology.

In the present study, the evolution of the failure process of concrete beams subjected to bending in a controlled laboratory environment until their maximum load capacity is examined. Throughout these tests, AE waves emitted from the samples were continuously recorded by several sensors mounted on their surface. The failure behavior of the beams and the AE parameters for assessing damage levels were analyzed. Furthermore, a machine learning model has been trained to identify specific patterns and characteristics in the AE signals. This analysis demonstrated a robust correlation between AE parameters and the initiation and progression of cracking, highlighting the capability of AE in monitoring concrete elements during load testing and detecting localized damages.

IAEA-CN-332/259

Hydraulic Structure Health Monitoring Before and After Rehabilitation with Nondestructive Testing using Artificial Intelligence Technique

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This study delineates a comprehensive methodology for the identification of structural issues in hydraulic barrages by employing non-destructive testing (NDT). It is imperative to prioritize the evaluation of the structural integrity of such infrastructure due to its critical importance, both prior to and following any maintenance projects. A sophisticated method for assessing the structural integrity of barrages without causing any damage to the structure is provided by NDT. This enables the timely and precise identification of potential issues. Our methodology improves the processing of NDT data by utilizing cutting-edge AI tools, with a primary focus on signals generated by vibration effects in impulse dynamical testing. These evaluations are conducted in a systematic manner on barrage structures both before and after restoration. They generate unique sets of NDT signals that precisely reflect the structural condition under dynamic pressures. To process and evaluate NDT signals, the study first uses a deep learning network built to reliably detect and classify them. A convolutional neural network (CNN) extracts important data properties. Feature extraction is crucial to future analytical efficiency. Two steps of machine learning algorithms—SVM and ANN—process the obtained attributes. These phases improve classification accuracy. Signal analysis is further enhanced by the implementation of Scale Invariant Feature Transform (SIFT) and boundary energy extraction algorithms. These procedures are specifically engineered to detect the intricate nuanced aspects of the NDT signals that suggest the structure's condition. In order to effectively manage the multidimensionality and intricacy of the data, we implement the Binary Grey Wolf (BGW) optimization technique, which reduces the number of features. This, in turn, optimizes the utilization of CPU resources and reduces processing time. We employ a variety of classifiers, including the Gaussian mixture model (GMM), to classify these optimized features. Our comparison analysis demonstrates that deep learning models have an identification accuracy of 99%; however, they necessitate a significant amount of processing resources and time. Conversely, the integration of BGW optimization and GMM classification not only accomplishes comparable accuracy but also substantially reduces processing time, rendering it a viable option for real-time applications. This investigation emphasizes the structural health of hydraulic barrages can be precisely and effectively monitored through AI-enhanced NDT. The integration of AI algorithms with conventional NDT techniques establishes a robust diagnostic framework that can significantly improve the maintenance plans for critical infrastructure. This study provides the way for additional research in the future to explore the potential applications of these AI-driven NDT approaches to a broader array of civil structures. The expansion of the scope to include NDT image processing using AI will be the primary focus of future advancements. The goal is to develop a comprehensive monitoring system that is capable of continuously detecting, predicting, and analyzing defects. The safety and functionality of civil infrastructure will be guaranteed by this system.

IAEA-CN-332/586

Structural Study using NDTs for a Military and Temporary Bridge Built in 40s and Actually in Use. Feixa Llarga's Bridge in Barcelona

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Feixa Llarga's bridge was built in 40s at the end of the Spanish Civil war. The bridge was designed and built by the Military engineer's department with a temporary meaning. The problem the bridge was trying to solve is the connection of the Barcelona's Port crossing the train line and connecting with the enter of the city by road.

80 years later the different political, economic, and social changes didn't affect the useful of the bridge and the temporary structure continued doing its function. Now the train line is the highspeed connection of Barcelona and the traffic of trucks is high and heavy because is one of the most importance entrances in the Port.

The bridge is composed by a steel welded structure. Actually, the structure presents high level of deterioration in the material and in the welds because different factors like corrosion effect (close the sea, corrosion ambient) and fatigue efforts (high traffic of heavy trucks). Our purpose was to make a structural study without affectation in the traffic. Using different NDTs we could evaluate and estimate different values of the structure for the engineers responsible of the reinforcement project. In a second phase we participate in the reinforcement jobs using NDTs in all the process.

Our campaign was developed in the first phase of investigation in 2019 and the second phase in the reinforcement jobs in 2022. The most important difficulty was to develop our jobs without stop the traffic and looking for typical defects of corrosion and fatigue. We were using different NDT techniques like: Visual Testing, Magnetic Testing, Ultrasonic Testing Phased Array, Ultrasonic Thickness Measurements, Adherence test and Magnetic Thickness measurement.

IAEA-CN-332/687

An Intelligent Translator for NDT Application in Reinforced Concrete Structures

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Select the non-destructive test for specific reinforced concrete elements and properties is a challenge activity for civil engineers. Between a quite large number of parameters and states as density, elastic modulus, strength, reinforcement location (size and distance from the surface) voids, cracking and delamination, the engineer must decide on the application of particular type of testing and its possible results. The main obstacle is that key structural information is surrounded by uncertainty and imprecision, so for the election of an NDT is not straightforward choice: the designer/modeler/constructor employ a reasoning process for handling these inexact, uncertain, and fuzzy concepts in an appropriate manner and relating them to numerical NDT results. In this research fuzzy logic and expert systems are used for providing a framework to model uncertainty, the human way of thinking, reasoning, and the perception process.

The NDT intelligent translator is a tool developed as a fuzzy expert system (Figure 1) (Mamdani type rules) where the antecedent (the IF) is based on parameters and their relation into structural behavior (divided in several stages: construction works, pouring and cure of concrete, service and possible refurbishment or straightening- after disasters). The output (the THEN) is a recommendation of a particular non-destructive testing equipment (between ultrasonic, stress wave, nuclear, thermal, magnetic, and electrical tests) explained based on its operating requirements.

IAEA-CN-332/438

Building a Network of NDT-CE Personnel to Counteract Disaster Effects on Both Civil and Cultural Heritage Structures

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The effects of natural and non-natural disasters have a significant impact on the population, especially in terms of housing and transport needs. The most pressing request after a disastrous event such as an earthquake is to quickly and efficiently verify the usability of damaged buildings and the functionality of the nodes of the infrastructural networks. Of course, during the emergency period, the infrastructural networks perform the essential function allowing the management of rescues and the subsequent reconstruction.

Non-Destructive Testings (NDTs) are fundamental for the purpose of quickly and safely determine the characteristics of the materials used and above the structural level of damage. For this reason, IAEA has been working for some years to spread the use of NDT techniques by providing technically advanced instrumentation and organizing dissemination, training, and certification activities. The long-term goal is to create well-identified centers of competence at the regional scale that can guarantee uniform levels of performance and above all rapid operativity in the event of disasters.

The development of these skills can also have a significant technical impact on the global safety as Non-Destructive Testings are also fundamental for developing prevention activities and for allowing maintenance and quality control in the Civil Engineering sector.

IAEA-CN-332/411

Numerical Residence Time Distribution: Comparison of Computational Fluid Dynamics and Smoothed Particles Hydrodynamics Frameworks

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Resource recovery from wastewater using photosynthetic consortiums is gaining increased interest. These systems display low energy consumption due to photosynthesis, which provides the oxygen required for bacterial oxidation of pollutants. The produced biomass can be utilized in various applications such as fertilizers, biofuels, and methane generation. In wastewater treatment, raceway ponds are the most common reactor configurations. Hydrodynamics and mixing in these ponds play a major role in ensuring recurring light exposure of algal cells, reducing cell sedimentation, and enabling uniform distribution of nutrients and carbon dioxide. These features should be provided with minimal energy consumption to circulate the flow and without damaging the mechanical structure of the biomass.

Understanding and optimizing this complex hydrodynamics can involve different experimental and numerical methods. This study presents the development, application, and comparison of several models to accurately describe the flow behavior in raceway ponds: Computational Fluid Dynamics (CFD) using grid-based methods and Smoothed Particle Hydrodynamics (SPH), a grid-less method.

The lab-scale raceway pond has a central length of 386 cm, including two curves and two 20 cm wide straight channels. The straight channel is divided by a central wall, and two deflectors are provided midway on either side of the two curves. A six-blade paddlewheel, 73 cm in diameter, is installed inside one of the straight channels. Grid-based CFD simulations have been carried out using the Ansys FLUENT commercial as well as OpenFOAM packages, while SPH simulations were conducted using the DualSPHysics v5.2 code based on the weakly compressible formulation of SPH.

Numerical tracer experiments were used to determine the global hydrodynamic properties of the reactor: mixing time, dispersion quantified by the Peclet/Bodenstein number. For this, a passive scalar transport equation was implemented in both CFD and SPH codes. Both frameworks were then compared in terms of tracer transport prediction (numerical dispersion, contribution of eddy diffusivity). To the best of authors knowledge, this has never been carried out in SPH.

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Hydrodynamic and Biological Modelling of Constructed Wetland through CFD Simulations

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Background:

Constructed Wetlands (CD) are an economic and efficient alternative for wastewater treatment, usable for sewage, storm water runoff and landfill leachate. CW use flora and fauna to treat contaminants in water with almost no energy cost. However, they can be difficult to design and optimise. This work constitutes the first stage of the project from the IAEA "Development of Radiometric Methods to Measure and Study Hydrodynamics of Constructed Wetlands" which is focused on improving the design and operation of CW.

Methodology:

This first stage aims to develop Computational Fluid Dynamic (CFD) simulations that can model the hydrodynamic and biological behaviour of CW. CFD will allow to test different geometries to investigate the flow characteristics and optimize the final design. The complete modelling will account for the porosity of the material (enabling to define different regions to mimic the stratum of CW). It will also include models for the permeability such as the model of Brooks and Corey, all in a single CFD solver code ready to be used by any researcher, worker or academy. To replicate the biological reactions that take place to treat wastewater, the CWM1 model will be included, with the possibility to add models for the clogging of porous caused by vegetation growing and for the interaction of the flora with the water dissolved components.

The complete model will provide tools to test different CW geometries, analysing the hydrodynamics and allowing to run Residence Time Distribution (RTD) tests to detect dead volumes, recirculating zones or shortcuts. Also, the biological behaviour will be modelled, allowing to assess the performance of the design in terms of water treatment. Experimental validation can be done by analysing compound concentrations in scale models or real CWs, and also by means of radioactive tracers in a future work.

Results:

Since the work has recently begun, only preliminary results have been obtained. The mentioned solver is under development, but it is expected to be finished by the end of the year and have complete results in time for the conference. As an example of future work, two CW designs have been simulated, performing an RTD to evaluate the characteristics of the flow. In Figure 1, the velocity field is shown as well as the RTD curves comparing both cases. As expected, the deflecting baffles create a recirculating zone that translates into a second peek in the RTD curve. This example illustrates the ability of CFD test different designs and evaluate its performance in a virtual environment.

Conclusion:

To sum up, this work will develop a model that integrates complex phenomena related to geophysical properties such as material porosity and biochemical reactions to simulate CW with the maximum reliability to become an open-source tool that will help in the future design of CW.

Figure 1: Simple geometry (A) compared with a modified case (B) and the RTD curves comparison between cases (C).

Keywords: Constructed wetlands, Computational Fluid Dynamics, RTD

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Review of Residence Time Distribution Simulation Parameters of Stirred Tanks

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Residence Time Distribution (RTD) methodology is used to obtain the hydrodynamic parameters of stirred vessels. These parameters are of significant interest to plant engineers because they determine the performance of process vessels. The important parameters of interest are the mean residence time (MRT), the pattern of flow by design, and the extent of mixing. In most cases, the parameters are determined from properly conducted experiments using suitable radioactive tracers. Researchers have used the experimental method extensively to characterize the flow behavior of stirred vessels. However, the downside of this method is the absence of explicit pictures of the flow parameters especially the flow structure and areas of improper mixing in the vessels. In this study, the flow structure, the extent of mixing and the MRT of an industrial stirred tank were simulated using Computational Fluid Dynamic (CFD) codes. Multiphase and turbulent flow models were used to generate the flow fields, and the Lagrangian particle tracking method was used to determine the MRT. Simulation results were in good agreement with previously determined experimental results. Findings from this study could be beneficial at the design stage of stirred tanks and the validation of design data after process intensification or revamping of operational vessels.

Key Words: residence time distribution; mean residence time; computational fluid dynamics; radioactive tracer, multiphase, and turbulent flow models; Lagrangian particle tracking method

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CFD Modeling of Residence Time Distribution (RTD) Using Radioisotope and Chemical Tracer

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This study presents and compares two tracer techniques used in nuclear applications for modeling residence time distribution (RTD). The first technique employs a radioactive tracer, 99mTc (gamma energy = 140 keV, radioactivity = 40 μCi, half-life = 6 h), introduced as a δ-Dirac pulse into a T-shaped pipe perpendicular to the feed flow using a calibrated glass syringe. The transit time of the radiotracer is measured with collimated scintillation NaI(Tl) detectors. Tracer concentrations are recorded at the inlet and outlet until radiation levels return to background, and the data is analyzed with standard RTD analysis software.

The second technique uses a chemical tracer, sodium chloride (common salt), to model variations in boron concentration or coolant temperature. This tracer is injected as a δ-Dirac pulse into the main coolant stream upstream of the reactor inlet nozzle. The distribution of the chemical tracer is measured using Wire Mesh Sensors (WMS), which sample the electrical conductivity across the flow cross-section.

Although the CFD model developed in ANSYS CFX for predicting spatial-temporal distribution profiles does not distinguish between chemical and radioactive tracers, it incorporates the tracer into the transport equation as a user-defined function (UDF). Validation of the model is achieved by comparing simulated tracer distributions with experimental data from both WMS and NaI(Tl) scintillation detectors. Results show that the CFD simulations align well with the trends observed in the experimental data, demonstrating the model's effectiveness in predicting RTD behavior.

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Innovative Design of Gamma-Ray Densitometry (GRD) Technique for Multiphase Flow Systems

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The Saudi petrochemical industry, a global leader, is pivotal to the nation's Vision 2030 initiative, which aims to reduce reliance on fossil fuels, create jobs, cut carbon emissions, and diversify the economy. The selection and performance of multiphase reactors are critical in this industry, influencing the design and efficiency of separation, mixing, and blending units, as well as minimizing environmental impact. Across the nuclear and petrochemical industries, as well as in research and development, radioisotope-based measurement techniques are widely used for monitoring, inspection, process troubleshooting, optimization, and control. These techniques are favored for their reliability, accuracy, cost-effectiveness, and safety, as they do not involve hazardous materials. Among these techniques, Gamma-Ray Densitometry (GRD) is particularly effective in analyzing multiphase flow systems, which often feature complex interactions among various phases. GRD provides a non-destructive method for measuring fluid density in a system, making it a safe and precise tool for detailed mapping of multiphase flows. It can be used to determine phase holdup profiles, flow regimes, and fluid levels in different systems. This study presents the development of an innovative GRD design using GEANT4-based Monte Carlo simulations. The simulations evaluated various GRD parameters, including radioisotope source activities, source shape, source window, and detector collimation device. The simulation results were validated with experimental data from a gas-liquid bubble column. Additionally, a new GRD platform design was created to address alignment issues between the source and detector collimation device. The presentation will provide a comprehensive overview of the GEANT4 simulation results and the mechanical design of the new GRD technique.

IAEA-CN-332/362

Non-Destructive Testing Applied to the Safeguarding and Conservation of Wooden Roofs of Italian Historic Architecture

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Wooden roofs play a crucial role in understanding and preserving historical architecture. They offer interesting insights from both architectural and structural viewpoints, as well as in terms of material culture.

In order to plan a conservation intervention that respects the existing structure, it is essential to analyze the construction techniques, material characteristics, and their degradation, as well as identify previous interventions. This information can be obtained in an effective way by applying non-destructive investigation techniques. A specifically designed methodology was applied to some relevant historical buildings located on the shores of the Lake of Como in Italy. This method has demonstrated significant efficacy in assessing the current conditions of the elements and in designing subsequent consolidation interventions in compliance with the proper conservation principles.

The initial phase of comprehension entails visual analysis to evaluate the condition of wooden structures and identifying areas susceptible to deterioration, including visually inaccessible zones such as supports, that require additional instrumental investigation. Targeted investigations have to be then carried out using a specific penetrometeric device, which measures the drill resistance of the wood. Additionally, wood moisture levels are recorded, and micro-corings can be sampled for macro/microscopic analysis aimed to identify wood species. Non-accessible areas can also be analyzed through additional non-destructive techniques such as endoscopic inspections.

IAEA-CN-332/670

Development of Fluoroscopic Dual-Energy CT as a Non-Destructive Tool Identify Indicators for Fossilized Bone

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Dual-Energy Computed Tomography (DECT) uses two different X-ray energy levels to scan an object, allowing for the differentiation of materials based on their varying absorption at different energy levels. However, the utilization of an in-house low-cost x-ray fluoroscopic detector in a DECT system to assist in the investigation of archaeological fossilized bone has not yet been explored. This study examines the development of fluoroscopic dual-energy computed tomography (DECT) as a non-destructive technique to identify indicators for fossilized molar bones. Traditional methods of analyzing fossilized bones often involve destructive sampling, which risks damaging valuable specimens. DECT, utilizing two different X-ray energy levels, enables detailed material differentiation and structural analysis without compromising the integrity of the fossils. Our research demonstrates that fluoroscopic DECT can effectively distinguish between fossilized molar bones and surrounding matrices, providing precise measurements of mineral composition and density variations. The technique also allows for the visualization of internal structures and microcracks, offering insights into the preservation state and fossilization processes. By applying fluoroscopic DECT to molar fossils from various geological strata, we have identified specific indicators that can aid in the accurate classification and study of these specimens. This non-destructive approach presents significant advantages for paleontological research, ensuring the preservation of fossils while delivering comprehensive analytical data using a low-cost DECT system.

IAEA-CN-332/628

NDT Testing and Ground/Foundation Investigations for Design the Reinforcement Works of an Historical Building in L'Aquila (Italy)

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The April 6th 2009, Mw=6,3 L'Aquila earthquake (Central Italy) caused 309 victims and produced a heavy damage in the centre of the city. Historical heritage and several old masonry buildings were heavily damaged by earthquake.

The paper presents:

- the structural and mechanical characteristics of Palazzo Margherita masonry building (in the centre of L'Aquila) by using NDT testing techniques for structure surveys;
- soil investigations at the site of the building: stratigraphies and profiles of shear velocity down to a depth of 40 m;
- inclined boreholes to explore the botton depth of brickwork foundations.

The evaluation of the parameters necessary to verify static conditions of the structure and to design reinforcement works required the following principal tests:

- core small diameter boreholes taking samples in the most representative points of the structure;
- sonic and diagonal tension tests on masonry sections, obtained at the various levels of the structure.

The coring operations allowed samples to be extract the material on which analysed in laboratory the chemical-pysical and mechanical characteristics of bricks, stones and mortars. Masonry sections tests were carried out by comparing as-built panels and others strengthened with mortar injections and composite fabric.

The document presents the results of tests carried out on foundations and vertical elevation structures to determine the consistency state for soil behaviour modelling and assess the effectiveness of proposed structural measures in relation to current regulations.

IAEA-CN-332/228

HBIM Applied for Historical Building Using NDT and 3D Modeling Techniques

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This paper presents the principles of Heritage Building Information Management (HBIM) for the Mansion of Costache Conachi, a place of achievement of Romanians ideals has started with the Little Union, through the deep changes it has determined and the symbolic value it holds. HBIM practices have emerged as innovative solutions in the preservation and restoration of cultural heritage buildings, integrating Non-Destructive Testing (NDT) methodologies with 3D modeling techniques. At the core of this practice lies the NDT technologies, such as ground-penetrating radar, 3D laser scanning provide valuable insights into the internal composition, material properties, and potential defects of the structure. By the end of the design process, industrial radiography techniques will be applied to this objective. An integrated process model will be developed, encompassing all factors across the entire lifecycle stages, to provide with digitized datasets to ensure effective maintenance protocols. The HBIM practice represents a paradigm shift in the field of cultural heritage conservation, offering a holistic approach that harmonizes traditional preservation methods with cutting-edge technologies. By integrating NDT with 3D modelling, can be ensured the long-term sustainability of cultural heritage. The history of interventions on cultural heritage buildings requires a comprehensive understanding of past restoration efforts.

IAEA-CN-332/631

Advanced Non-Destructive Diagnostic Approaches for the Conservation of Sursock Palace Post-August 4th Explosion-Lebanon

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Sursock Palace, an iconic symbol of Lebanon's architectural heritage from the late 19th century, was built using traditional materials and techniques. The palace sustained severe damage during the August 4th explosion, prompting urgent conservation measures.

In 2021, a workshop held with the International Atomic Energy Agency (IAEA) concentrated on employing non-destructive techniques to evaluate and document the palace's structural integrity and historical elements. This paper presents a diagnostic plan formulated from the IAEA training insights. The plan incorporates advanced non-destructive methods, including ground-penetrating radar, thermography, and laser scanning, to meticulously document the damage, assess the material integrity, and pinpoint areas requiring immediate preservation efforts. By proposing this diagnostic approach, the study contributes to the ongoing efforts to protect Sursock Palace's heritage. It underscores the importance of international collaboration and the use of innovative methodologies in the conservation and restoration of cultural landmarks impacted by unexpected disasters.

This abstract outlines the necessity of immediate conservation for the palace, details the advanced techniques proposed for assessment, and highlights the significance of the international collaboration facilitated by the IAEA. Integrating these non-destructive methods aims to ensure the preservation of Sursock Palace, showcasing a model approach for safeguarding cultural heritage sites affected by catastrophic events.

POSTER PRESENTATIONS

IAEA-CN-332/022

An Experience of Electron Beam (EB) Irradiated Gemstones in Thailand

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In Thailand, a study on gemstone irradiation using electron beam (EB) have been conducted at Irradiation Center, Thailand Institute of Nuclear Technology (Public Organization) (TINT). The different kind of semi-precious stones have been irradiated by the 20 MeV of electron accelerator. The color change of gemstones containing beryl, tourmaline and topaz was evaluated. After irradiation of the stone samples were measured by the stone color card Munsell Rock Color Chart. Topaz exhibited changes color from colorless to brown at electron fluence of 4.41x1015 electron/cm2. The color was transformed again from brown to pale blue which gems market call sky blue topaz by heating at temperature between 150 □C to 180 □C in air for 2 hours. Tourmaline showed behavior of color change slightly different with topaz. At electron fluence of 3.74x1014 electron/cm2, the pale pink tourmaline sample increased color to dark pink. The electron fluence performed on tourmaline lower than in topaz around 10 times. While the similar level of electron fluence performed on topaz at 4.96x 1015 electron/cm2, color change of beryl was transformed from colorless to yellow. The isotope of Cs-134 (2.06 year of half-life) in yellow beryl founded the main effect for a quarantine period to allow the residual radioactivity to reach a safe level of less than 74 becquerels per gram. In the other hand, the short half-life radioactive nuclides were activated in topaz and tourmaline which take a quarantine period shorter than in beryl.

IAEA-CN-332/023

Optimization of Physicochemical Properties of Carboxymethyl Chitosan/Polyvinyl Alcohol/Curcumin Edible Antimicrobial Films for Food Packaging Application

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Improvement of shelf-life and quality of fruits via edible coatings technique using bio-based materials of antimicrobial activities is important for vital health benefits and human beings. This work aimed to synthesize edible coating solution and membranes for food packaging applications based on carboxymethyl chitosan (CMCS) and polyvinyl alcohol (PVA) combined with curcumin nanoparticles (Cur-NPs) and assisted by γ-irradiation for extending the shelf life of sweet orange "Valencia" fruits at room temperature for 70 days of storage. Curcumin was synthesized after extraction from turmeric powder and converted to Cur-NPs of the average size of 108 nm to avoid the poor dispersibility and solubility disadvantages of curcumin. Cur-NPs were characterized by different advanced techniques. The prepared Cur-NPs possessed good solubility and stability in an aqueous medium without aggregation, possessed small size, and good crystallinity. CMCS/PVA/Cur-NPs coating solution was prepared by γ-irradiation at the radiation dose of 15 kGy. In addition, CMCS/PVA/Cur-NPs membranes were prepared via the casting method followed by exposure to γ-irradiation at different doses of 5-25 kGy for further investigations and possible use in packaging applications or orange fruits. The effect of dose on the properties of CMCS/PVA/Cur-NPs membranes was studied using different analyses. Orange fruits of the same size (medium) were selected and divided into three groups, each group containing three replicates (25 fruits/ replicate). The orange fruits were dipped separately in the prepared coating solutions, packed in carton packages, and stored for 70 days at room temperature (22 Cº) and 65-70% humidity. Furthermore, the fruits were packaged by CMCS/PVA/Cur-NPs membrane, sealed with Teflon tape, and stored under the same condition. At the end of the storage, the efficiency of edible coatings and packaged membranes of CMCS/PVA/Cur-NPs were assessed by decay (%), weight loss (%), pH, vitamin C content, total soluble solids (TSS), titratable acidity (TA) and TSS/TA ratio. The results showed that the treated fruits by edible coating solution possessed better quality, and kept the external and internal quality than the uncoated fruits leading to extending the shelf life of fruits without decay up to 56 days while the control exhibited 36%. Furthermore, similar results were obtained by packaging the fruits with CMCS/PVA/Cur-NPs membrane; the decay decreased from 40% to 8.5 %, and weight loss decreased to 22.8%. The CMCS/PVA/Cur-NPs had superior antimicrobial and cytocompatibility properties. From these findings, the CMCS/PVA/Cur-NPs edible coating solution and membranes could be used as a safe packaging material to maximize quality and extend the shelf life of orange fruits.

IAEA-CN-332/029

Conditioning and Storage of Category 3 to 5 Gamma/Neutron Emitter Disused Sealed Radioactive Sources (DSRS) in Cameroon: Monte Carlo Study and Experimental Validation

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Sealed radioactive sources (SRS) are used in various beneficial applications in Cameroon, including medical, industrial, and research and development. However, the safe management and regulation of disused sealed radioactive sources (DSRS) is of utmost importance to mitigate any potential risks to the environment or human health. The DSRS phase of the life cycle is the most critical, as control procedures alter when sources become disused and unprofitable for end-users. Neglecting DSRSs can result in severe accidents. To address these concerns, we propose a combination of Monte Carlo methods and standard experience to assess DSRS management before undertaking any under-job dismantling, characterization and conditioning tasks. Monte Carlo tools provide a powerful solution for radioactive waste management. We compare the experimental results after conditioning of DSRS to the predicted ones assessed via Monte Carlo methods for validation purposes. Both simulation and experimental results showed adequate and accurate performance of Monte Carlo tools for radioactive waste management. The predicted effective dose rates at contact and 1 m away from the DSRS waste drum had less than 5% uncertainty at a 95% confidence level. The conditioning process is undertaken to provide a safe and secure sustainable solution for the DSRS pending the next management step. The results of our study demonstrate the efficacy and accuracy of Monte Carlo tools in DSRS management. Proper conditioning and management of disused sealed radioactive sources are essential to ensure their safe and secure disposal and continued use for peaceful purposes. Our study provides insights into complying with SDGs No. 3 through risk reduction to unnecessary exposure, 4 through training in MC and DSRS management, 8 through fostering skills and nuclear techniques & science related employment, 9 through MC innovation in DSRS management and waste management infrastructure development, 10 through enhancing Cameroon's capacity to use nuclear tech, 12 through RWM support including the safe and secure management of DSRS, 13 through the promotion of nuclear techniques that are environmentally friendly, 16 through the deterrence of nuclear weapons spread via credible assurance that radioactive and NMs are used for peaceful application and in good hands, and 17 though partnership with members states, international organisations, research institutions, and all advocator of nuclear science and technique.

IAEA-CN-332/042

Phytosanitary Irradiation Treatment of Sitotroga Cerealella Olivier (Lepidoptera – Glechiidae) and Assessment of its Effect on Physiochemical and Microbiological Quality of Wheat Flour and Toast Bread

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Background; Cereal grains are an important staple food for most world's population. Various insect pests can infest stored grains during improper storage, causing appreciable damage. Sitotroga cerealella is one of the most common serious pests of stored grains. It starts to infest the grains of wheat preharvest in the field and during storage. Phytosanitary irradiation (PI) as an alternative technology to toxic gases is increasingly used now for controlling insect pests of agricultural commodities. The present study determined the minimum absorbed irradiation dose required to control S. cerealella, identify the most radio-tolerant stage, and validate the minimum irradiation dose required to prevent P1 generation by the large-scale confirmatory test. The effect of PI irradiation dose on wheat flour's physiochemical and microbiological quality as a host commodity and toast bread was evaluated.

Methodology; Sitotroga cerealella was reared on 500 gm wheat grain in a glass jar (1L capacity), covered with muslin clothes, and tightened with a rubber band, at a suitable condition, (26±2oC and 75 ±5% RH). The irradiation process was achieved at Co60 - Gamma Chamber (4000A). Alanine dosimeters were used for measuring the average absorbed dose and dose mapping. The eggs and larvae stage were exposed to 0- 400 Gy of gamma radiation. The chemical constituents of wheat flour were carried out according to the Association of Official Analytical Chemists. However, the toast baking was assessed according to the method of the American Association of Cereal Chemists. The microbiological analysis was determined according to the specifications of laboratory methods in food microbiology.

Results; The results indicated that the dose levels of 270 and 300 Gy prevented P1 adult emergence when one-day-old eggs were exposed to gamma irradiation in test tubes and infested wheat, respectively. However, when 21-day-old larvae inside wheat grains were irradiated, the dose level required to prevent adult emergence of P1 generation was 360 Gy. Based on that, the larval stage of S. cerealella was more radio-tolerant than the egg stage. To measure effective irradiation dose and phytosanitary efficacy, 360 Gy was required for the disinfestation of S. cerealella. To validate the efficacies of 360 Gy dose, it was applied to a large number of 15,000 late larval instars inside wheat grains. The results of large-scale tests show that no adult emerged with a confidence of 77.7 %. In addition, this irradiation dose had no significant effect on the major chemical constituents (moisture, total protein, fat, Crude fiber, and ash) of flour extracted from irradiated wheat grains. The phytosanitary irradiation dose of 360 Gy slightly reduced the log of total aerobic bacterial (TABC), Total molds and yeasts (TM&Y), coliform bacteria and E.coli counts in flour. It also had no significant effect on the physical properties (specific volume, volume, and weight) and sensory properties (appearances, color, texture, chewiness, and taste) of toast bread made from flour of irradiated wheat grains.

Conclusion; The low dose of gamma irradiation 360 Gy stopped the reproductive potential of S. cerealella and maintained the quality characteristic of wheat flour and toast bread.

IAEA-CN-332/046

Monte Carlo Based Dose Calculation of Fluidic Stream for Wastewater Treatment

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Electron beam (e-beam) accelerators are used in diverse industries to enhance the physical and chemical properties of materials and to reduce undesirable contaminants, such as pathogens or toxic by-products. In the processing, dose and dose distribution are the most critical issues. In radiation processing of fluidic streams, there is great interest in the dose deposited by ionizing radiation. This dose, correctly named energy dose is responsible for the decomposition of organic pollutants and/or disinfection of microorganisms in wastewater. In wastewater treatment process, liquid dosimeters (alanine, dichromate or methylene blue solutions) or calorimetric methods are mostly preferred. However, these are not easy applicable and do not give actual dose in the process. It is therefore, a new and solid method needs to be used.

Mathematical models can help ease the design process, for example, by calculating absorbed dose distributions in a product or a wastewater stream long before any process is applied. The use of mathematical modelling (mostly regarding Monte Carlo methods) in electron beam processing is assumed to be the future of dosimetric system to be used in industrial radiation processing or wastewater treatment. In electron beam processing, Monte Carlo transport codes are widely used because they simulate the tracks of individual particles based on detailed physics of the interaction of radiation in matter. In contrast to deterministic models, which solve the mathematical equations of radiation transport, Monte Carlo codes sample interactions as probability functions from cross-section data and physical concepts. Energy losses of particles (mainly electrons and photons) in matter from different histories are summed to estimate absorbed dose. Several Monte Carlo programs are available and used for industrial applications. However, severe examples are not available for wastewater treatment.

In this study, the effect of the electron beam on fluids using the FLUKA Monte Carlo codes is simulated. For the simulation, the 500 keV – 20 mA electron accelerator in TENMAK has been considered and the thickness of the fluid was selected as 1 mm in all simulations performed. The energy deposition, absorbed dose, and electron fluence of the electron beam on the target were calculated for electron beams with different energies between 200 and 500 keV. At the same time, by changing the speed of the fluid and the beam current, energy deposition and absorbed dose plots have been obtained for different dose rates. Another variable for the dose rate has been made by changing the distance between the electron beam window and the fluid. Absorbed doses calculated in simulations with FLUKA Monte Carlo methods have been compared with experimental results carried out in the electron beam facility and validation was provided. The results of this study will make great contribution to radiation technology applications such as wastewater treatment and liquid sample irradiation with the electron beam.

IAEA-CN-332/047

Validation Process of a Newly Established Shutter and Conveyor System Adapted to the Electron Beam Facility Initially Designed for Flue Gas Treatments

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The TENMAK-NÜKEN Electron Accelerator Facility is operated by Nuclear Energy Research Institute, which is affiliated with TENMAK. The Electron Accelerator Facility is a facility with an electron accelerator that has characteristics of 500 keV and 20 mA of the ICT type. Although it was initially designed for flue gas treatments, with its existing infrastructure, it is possible to perform various applications of Radiation Technology. With this accelerator, which has an electron beam power of 10 kW, it is possible to cross-link a 90 kg polyethylene sheet with a thickness of 0.8 mm per hour, irradiate approximately 25,200 kg of wastewater, or clean 3000 m^3/hour of flue gas.

The effective utilization of electron beam (EB) technology in both environmental and industrial sectors necessitates relevant validation to ensure reliability and compliance with international standards. This study presents the comprehensive validation process of a newly established shutter and conveyor system adapted to the electron beam facility initially designed for flue gas treatments. Though, this system had been originally manufactured as self-shielded and the minimum achievable dose was 2 kGy, now, this mobile conveyor system makes the machine capable of moving at a max speed of 10 m/s enables uniform irradiation of samples with a thickness of 1 mm (2 mm in bidirectional irradiation) at every dose value above 100 Gy thanks to the subsequently adopted shutter system. Key components of the validation included the effect of beam current, voltage, duration under beam, conveyor speed and number of tray passes, which are crucial for determining the dose delivered.

Initially, dosimetric measurements were performed using FTW-60 thin film dosimeters to determine the dose distribution and verify the calibration of the electron beam. These measurements confirmed that the electron accelerator consistently delivered doses with a significant relation of beam current, conveyor speed and the number of passes of the tray connected to the conveyor system under the irradiation window.

In conclusion, the validation of the electron beam facility highlights its effectiveness and robustness in handling liquid-solid target irradiation applications. The outcomes of this study provide a foundational framework for the operational protocols of EB facilities and contribute to the advancement of radiation processing technologies.

IAEA-CN-332/050

Mutation Breeding Studies in Turkey

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Türkiye's geography provides an ideal climate for growing a wide variety of plants. Türkiye has also an important production potential in terms of field crops (wheat, barley, chickpeas, etc.), horticultural crops (grapes, fruits, and vegetables), and ornamental plants. In this context, Türkiye keeps up a vigorous breeding program to create new cultivars and varieties that are more productive and of higher quality while having a high tolerance to diseases, pests, global warming, and soil deterioration. The significance of mutation breeding has grown, particularly since the 1985s. In this context, the Turkish Energy Nuclear and Mineral Research Agency (TENMAK) leads the adaptation and application of the mutation breeding technique to breeding studies and collaborates the Governmental Agricultural Research Institutes, relevant university departments, and private seed companies in the entire country. In economically significant species like wheat, barley, chickpeas, beans, grapes, apples, apricots, oranges, pistachios, tea, tomatoes, lettuce, green beans, and chrysanthemums, breeding for mutations and related biotechnological techniques are used to boost yield and quality as well as to provide drought tolerance.

The mutation breeding studies are carried out using gamma irradiation sources within TENMAK. Besides the gamma rays induced mutation studies, some studies are also being carried out simultaneously with chemical mutagens. Especially in the last decade, studies supported by in vitro mutations and molecular techniques have been increased. To date, it has been superior in terms of yield and quality characteristics and has features such as being early, tolerance to drought, and disease; two soybeans, two tobaccos, one chickpea, two barleys, one sesame, one potato, two cherries, four lemons, one mandarin, and four chrysanthemum varieties developed through mutation breeding and introduced into Turkish agriculture and they have added to Mutant Variety Database of IAEA. There are also several candidate varieties (chrysanthemum, chickpea etc.) whose registration trials are still ongoing. In addition to these already registered or nominated varieties, studies on tea, tomato, lettuce, pistachios, apricot, apple, green bean, barley and wheat have been conducted. Regarding field results, there are many promising cultivars within the studied species.

IAEA-CN-332/053

Gamma Radiation-Assisted Synthesis of Metal Nanoparticles in MNSR Research Reactor for Catalytic Applications

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The controlled synthesis of nanostructured materials offers the potential for developing new materials with precise mechanical, optical, magnetic, electronic, conductive, and catalytic properties. These materials have a wide range of applications, including as drug carriers in medical diagnosis and treatment. While there are various methods for producing nanostructured materials, the use of gamma radiation offers unique advantages, including minimal use of hazardous chemicals and simple production methods in an aqueous environment. In a recent research project, the possibility of synthesizing metal nanoparticles using gamma radiation in a research reactor, specifically the Isfahan MNSR reactor, was investigated. The project involved design and use of a gamma irradiation cell in the vicinity of the reactor core to synthesis of metal nanoparticles, including Ag, Pd, and Pt nanoparticles, as well as copper metal oxide (CuO), on amorphous silica and graphene oxide substrates. The gamma irradiation cell designed in such a way that absorb the neutrons, to prevent the neutron activation of samples, and let the samples just irradiated by the gamma rays emitted from the reactor core. The process involved preparing separate suspensions of amorphous silica (SiO2) or graphene oxide (GO) with the selected metal ions, followed by irradiation to ensure a minimum exposure of 25 kGy of gamma rays from the reactor core to the materials. Subsequently, the samples were removed from the reactor, washed, and dried to obtain Ag/SiO2, Pd/SiO2, Pt/SiO2, CuO/SiO2, Ag/GO, Pd/GO, Pt/GO, and CuO/GO nanocomposites. In the next step, these synthesized samples were characterized and evaluated using XRD methods, SEM, and EDXA to confirm the successful synthesis process of metal nanoparticles, their crystalline phase, and nanometer dimensions. The efficiency of some synthesized nanocomposites in catalyzing the removal of dyes such as methylene blue (MB), congo red (CR), and methyl orange (MO) in the presence of NaBH4 was also investigated. Observed results are presented and discussed in this article. Furthermore observed results in this research project highlights the potential use of gamma radiations of research reactors for the controlled synthesis of metal nanoparticles and their application in catalytic processes. The findings contribute to the development of advanced materials with diverse practical applications in various fields.

IAEA-CN-332/067

Adsorption of Strontium Ions from Aqueous Solutions using Radiation Synthesized Starch /2-Hydroxyethylmethacrylate/Bismuth Nanocomposite

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Numerous activities have resulted in the production of radioactive waste as a result of the global advancement of new nuclear technology. 90Sr is the most significant long-lived radionuclide that humans have produced in the marine environment from a radioecological perspective. It is one of the most dangerous metal ions in radioactive waste due to its high solubility, transferability, and easy accumulation in organisms. Because strontium has similar chemical properties to calcium, it can easily replace calcium in the human body, resulting in leukemia, anemia, genetic abnormalities, and other disorders. From this aspect, starch/2-hydroxyethyl methacrylate/bismuth starch/HEMA/Bi nanocomposite was synthesized via gamma irradiation to be used as an adsorbent for removal of Sr(II) from simulated low-level radioactive waste. The preparation parameters conditions were investigated to get the perfect nanocomposite consistent with the application. Many instrumental analyses were performed to characterize the nanocomposite such as FTIR, XPS, SEM, TGA, and XRD. The removal condition of Sr(II) was investigated from the operation, isotherm, kinetics, and thermodynamics views. The highest removal percent of Sr(II) takes place at pH 6 and reaches a steady state after 90 minutes. starch/HEMA/Bi is recommended for removal of Sr(II) where the removal exceeded than 90%.

IAEA-CN-332/069

A Comparative Investigation on Radiated and Non-Radiated Chitosan on Productivity, Digestibility and Defense Responses in Festuca Arundinacea

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Enhancing forage productivity and quality is crucial for sustaining livestock production and productivity. Simultaneously, there is parallel need for environment friendly alternatives for boosting forage productivity and quality. Among many molecules, chitosan has emerged out as a promising biological molecule (elicitor) with a diverse array of applications including its potential to enhance plant growth, boosting plant defense mechanisms, simulating oxidative stress and preparing plants for external challenges. In the current investigation, three different types of chitosan molecules viz., electron beam irradiated chitosan (EBIC), gamma irradiated chitosan (GIC) and normal chitosan (NC) were investigated for their potential in enhancing productivity of Tall fescue (Festuca arundinacea Schreb.) grass, which is a prominent grass species in the temperate region and has impotence in providing lush green forge for longer duration of the year. The study revealed distinguished variations in growth indicators following the application of EBIC, GIC and NC @ 25ppm, 50ppm, and 100ppm through seed treatment, foliar treatment and combination of seed and foliar treatment. The GIC application as foliar treatment @ 50 ppm significantly improved morpho-physiological traits, leading to a remarkable 2.68-fold increase in plant height and 4.49-fold increase in the number of leaves per plant. Treatment with GIC also demonstrated significant enhancement in photosynthetic pigments with 64.46% increase in total chlorophyll content and a 47.20% increases in carotenoid content along with elevated levels of defense-related enzymes involved in combating biotic and abiotic stresses and scavenging activity against reactive oxygen species (ROS). Likewise, nutritional components such as crude protein and total carbohydrates revealed substantial improvements, with GIC foliar treatment @50ppm. Conversely, EBIC and NC treatments also exhibited beneficial effects, albeit to a lesser extent compared to GIC. Additionally, reduction in anti-nutrients viz. tannins, oxalate, total phenol, lignin and cellulose content was also recorded with FT of GIC @ 50 ppm. Furthermore, all chitosan variants contributed to a reduction in cell wall constituents, with GIC foliar treatment @ 50 ppm leading to a considerable decrease of 12% in neutral detergent fibre and 25% decline in hemicellulose content. The treatment with gamma irradiated chitosan also improved dry matter digestibility (IVDMD) of the grass. These findings suggested that among different chitosan variants, the foliar application of gamma irradiated chitosan (GIC) at 50ppm is effective in enhancing productivity, digestibility and stress-responsive effects in tall fescue grass.

IAEA-CN-332/071

Similarities and Differences in the 137Cs Accumulation on Floodplains of Rivers in Zones of Radioactive Contamination: Chernobyl and Fukushima

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Presentation deals with the features of sediment-associated 137Cs accumulation and erosion on the river floodplains in the Chernobyl-affected and Fukushima-affected areas. Evaluation of 137Cs inventories changes on different floodplain levels that were studied in the Upa River basin (Tula region, Central part of European Russia) and along the valley bottom of the Abukuma River (Fukushima Prefecture, Japan). The Upa River basin is the typical river with high level of initial radionuclide contamination in the upper reach of the main river and some tributaries after explosion at Chernobyl NPS. The Abukuma River is the largest river of the Northern half of the Honshu island with medium level of the initial radionuclide contamination in the part of the basin after explosion at Fukushima Daiichi NPP. Several floodplain cross sections were studied in both river basins. The combination of the different techniques, including analysis of the 137Cs depth distribution curves, and field survey with measurement of air dose rates, was used for understanding the transformation of the floodplain contamination levels. It was found that sediment-associated 137Cs sedimentation rates are strongly dependent on the type of the river bottom for the both river basins. Also, the transfer of sediments contaminated with radionuclides and their redeposition in floodplain areas with low levels of initial contamination contributes to the expansion of territories with increased 137Cs inventories. At the same time, the sedimentation rate on the floodplains of the Upa River basin is relatively low, with the exception of the low level floodplain. But they are significantly higher on the floodplain of the Abukuma River, which is associated with high water flows in the river during the passage of typhoons. In addition, the development of erosion processes in various areas of the floodplain is a typical phenomenon for the Abukuma River. This is due to the significant power of streams passing through the floodplain during floods and the weak turf of the floodplain surface with herbaceous vegetation. The thickness of the “fresh” sediment accumulated on the floodplain in the case of ordinary flood is in the range of 1–5 cm in both regions, while up to 40–50 cm of sediment are accumulated in some floodplain sections during the extreme floods at the Abukuma River basin associated with typhoons. The high rates of sediment accumulation on the floodplains of rivers in the Fukushima contamination zone contribute to a quick decrease in the air dose rate within the river valley bottoms with high levels of initial contamination due to the accumulation of “cleaner” sediments with relatively low 137Cs concentrations. A similar decrease in the air dose rate on the floodplains of the rivers of the Upa basin occurs much more slowly, and on high level floodplains, where sedimentation rates are extremely low, it practically does not occur.

IAEA-CN-332/084

Implementation of Alanine Postal Dosimetry Audit Service for Radiotherapy

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Dosimetry audit is a key component in radiotherapy quality assurance programs as it plays an important role in identifying and resolving problems, as well as reducing uncertainty and increasing the consistency of dosimetry protocols among participating institutions. However, the access of radiotherapy centers across the world to dosimetry audit services is still insufficient. Thus, the aim of this study was to develop and implement a postal quality control system for radiotherapy based on alanine/EPR dosimeters in the state of Pernambuco, Brazil. For this purpose, a setup was developed to allow the positioning and irradiation of six dosimeter holders at the same time, enabling measurements of dose at the center of the radiation field, depth dose at 10 cm and off-axis doses. The results allowed to evaluate the flatness, symmetry and beam quality of the radiation field. To validate this system, an intercomparison was carried out with the TLD postal audit service of PQRT/INCA, Rio de Janeiro, Brazil. Both systems were irradiated in a LINAC True Beam STX with 6 MV beam, 600 MU/min and dose of 10 Gy for the DEN/UFPE system and 2 Gy for the PQRT/INCA system. The dose data obtained with these systems were compared with those from ionization chambers irradiated under the same conditions. The intercomparison results (Table 1) showed agreement between the two systems, so that the differences between the deviations relative to the ionization chamber measurements were smaller than 1.8%, which demonstrates that the proposed postal audit system is suitable for quality control purposes in radiotherapy.

IAEA-CN-332/085

Nuclear Science Museum: A Tool to Support Science Teaching

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Science education is an important way for school-age children and young people to understand their environment and develop their skills. As students perceive the world around them, they seek explanations for situations they are experiencing for the first time. This gives rise to a curiosity to understand the phenomena that surround them, but this fact is still very little explored and appreciated in nuclear education. The Nuclear Science Museum was established with the objective of facilitating the dissemination and socialization of scientific knowledge related to nuclear applications, as well as to support science teaching. This Museum has served as an educational and cultural space, contributing to the dissemination and popularization of science and technologies associated with the nuclear area in Brazilian society, particularly in the northeast region.

Interactivity is at the heart of the Nuclear Science Museum. The scientific principles embedded in the replicas of the exhibits are approached interactively, with the visitor as an active agent in the construction of learning. In line with the idea of learning by doing, various experiments and games are presented that deal with the applications of ionizing radiation, as well as experiments that clarify the concepts of external irradiation and radiation contamination. These materials act as a means of educational practice, complementing the theoretical content developed in schools and participating as agents of informal education.

IAEA-CN-332/092

The Possible Effects of Iranian Propolis on Potassium Dichromate Reabsorption with Different Tissues in Redfish (Carassius Auratus)

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Chromium is an abundant metal element in the earth's crust. Chromium plays an important role in water pollution. In the present study, the effects of propolis on the amount of chromium reabsorption in the liver, kidney, gill, and muscle of the Redfish were investigated. At first, the Redfish was fed with a treated diet with irradiated/non-irradiated alcoholic extract and irradiated/non-irradiated propolis as a highly antioxidant natural bee product for 70 days. All the treatment and the positive control groups were exposed to 9 mg/liter of chromium for 6 weeks. According to the data available in this study (Table-1), the amount of chromium reabsorption in the positive control groups is in the order of gill > liver > kidney > muscle. Treatment groups with an irradiated propolis diet have a significant difference compared to the positive control group. Treatment groups 3 and 4 have significant differences with treatment groups 1 and 2 in all organs except the liver. Also, in gill, liver, kidney, and muscles, treatment groups 3 and 4 had a lower amount of reabsorption of chromium than the positive control group, which indicates a significant difference in the level. Results obtained from this study showed that the propolis could be effective as a chemoprotectant in the management of potassium dichromate reabsorption via different organs in the Redfish tissues. Therefore, it can be concluded that irradiated alcoholic extract propolis is recommended as a suitable and cost-effective food additive to increase the level of its antioxidant properties in the fish industry.

IAEA-CN-332/094

Radiation Techniques for Converting Plastic Waste into Feedstock Oil and Functional Additives

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This research project capitalizes ionizing radiation to transform polyolefin plastic waste into valuable feedstock oil and breaking down the polymer waste into micro powder. The project activities are implemented under RAS 1031. The radiation assisted pyrolysis of plastic waste is aimed to convert waste material into valuable feedstock oils, including fuel and oil. Both gamma-ray and electron beam irradiation were used to evaluate the decomposition temperature, yield and activation energy of reaction process. The results show that irradiation enhances the pyrolysis process, with a significant reduction in solid composition from 12% to below 5%, and an increase in liquid and gaseous composition to over 90%. Additionally, radiation contributes to the lower decomposition temperature of the pyrolysis reaction process.

In the degradation of polymeric waste, the project aims to optimize the recycling process by using ionizing radiation to convert polymeric waste into micro-powder additives. The primary objectives include determining optimal processing parameters, assessing chemical, thermal, and morphological changes in irradiated polymeric waste, and exploring the effects of micro powder/polymer blends. The laboratory prototype can produce 1 kg of micro-powder per cycle. The research demonstrates that increasing irradiation doses significantly reduce particle size, enhance crystallinity, and facilitate grinding. Despite these modifications utilizing irradiation and grinding processes, the intrinsic properties, such as chemical composition analysed through FTIR, remain largely unaffected. Thermal analysis using DSC indicates minimal shifts in melting temperatures, suggesting sustained structural integrity under irradiation. The incorporation of micro-powder as additives into FKM polymer compounds results in notable improvements in friction coefficient and mechanical properties.

The integration of ionizing radiation with established recycling and pyrolysis methods offers a promising approach to converting plastic waste into valuable products, mitigating plastic waste while producing new products and alternative fuels/oils, contributing to environmental sustainability. The findings advocate for the potential of radiation-assisted recycling approaches in advancing waste reduction and developing sustainable feedstock/energy sources.

IAEA-CN-332/097

Latest Advancements in Radiation Therapy Technology: A Novel Image-Guided Gamma Ray Radiotherapy System

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This paper presents the multifaceted efforts driving the development of China's nuclear technology application industry. Our work encompasses a wide range of activities crucial for industry growth and international collaboration.

Part 1: Introduction of the Radiation Processing Industry

We provide an overview of the radiation processing industry in China from the perspective of our association. This includes insights into the industry's history, current state, and future prospects, highlighting key achievements and challenges.

Part 2: Development of Irradiation Processing Facilities

We detail the advancements in irradiation processing facilities in China, focusing on technological innovations, capacity expansion, and infrastructure development. These developments are essential for meeting the growing demand for irradiation services in various industries.

Part 3: Modification of Materials by Radiation Processing

We discuss the diverse applications of radiation processing in modifying materials, such as polymers, composites, and textiles. This includes improvements in material properties, such as strength, durability, and chemical resistance, achieved through radiation-induced modifications.

Part 4: Sterilization

We highlight the critical role of radiation processing in sterilization, particularly in healthcare, pharmaceuticals, and food industries. We discuss the effectiveness of irradiation in eliminating pathogens and extending the shelf life of products, ensuring safety and quality standards are met.

Part 5: Emerging Applications

We explore the emerging applications of nuclear technology in areas such as environmental remediation, advanced manufacturing, and space exploration. These innovative applications demonstrate the versatility and potential of nuclear technology in addressing pressing global challenges and driving technological advancements.

Our efforts in these areas underscore our commitment to advancing the China nuclear technology application industry. Through collaboration, innovation, and strategic planning, we aim to drive sustainable growth and contribute to global nuclear technology application advancements.

IAEA-CN-332/104

Radiant Remediation: Harnessing Irradiated Soil Compost for Microplastics Degradation

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Since the 1950s, plastic mulch films have been employed in agriculture to regulate agrichemicals. Microorganisms within soil ecosystems possess the capability to completely mineralize biodegradable polymer-based mulches, rendering them a feasible choice. The utilization of biodegradable mulches presents a challenge due to the prolonged retention of debris post-harvesting, attributed to their slow rate of bio-degradation. Over time in the field, fragments of mulch accumulate and eventually degrade into microplastic particles due to aging, weathering, or exposure to sunlight. Aside from their impact on soil physical, chemical, and biological properties, microplastics (MPs) can impede crop productivity, posing a threat to food security. Moreover, microplastics (MPs) are prone to interacting with and accumulating various environmental pollutants, including microbial pathogens, heavy metals, and persistent organic pollutants. This amplifies their potential for environmental toxicity. Additionally, there is evidence suggesting that MPs transfer between trophic levels in the food chain, which could have adverse effects on human health. Hence, this study aimed to investigate the degradation of micro-fractions of poly-lactic acid (PLA) in soil through the utilization of soil compost sterilized via ionizing irradiation. The experiment involved mixing a known quantity of PLA fragments into soil amended with irradiated compost (IC) for burial testing in pots. Control samples consisted of PLA microfragments blended with soil amended with unirradiated compost (UnC). Carbon dioxide emissions were directly indicative of PLA mineralization and were continuously monitored using an online detector probe. The study assessed the influence of PLA weight, irradiation dose, and soil properties on carbon dioxide emission rates over a 180-day period. Biodegradation behaviors of microplastics were further elucidated through analyses including Scanning Electron Microscope (SEM) imaging, Fourier Transform Infrared Spectroscopy (FTIR), and thermoanalytical techniques. Results revealed that IC treated with a 25 kGy electron beam exhibited the highest degradation, accompanied by the greatest CO2 emission compared to UnC. SEM images of microplastics in IC amended soil displayed extensive structural damage, corroborated by FTIR and thermoanalytical analyses, confirming the biodegradability of PLA micro-fragments in IC amended soil.

Keywords: Microplastics, polylactic acid, biodegradation, soil, compost, irradiation

IAEA-CN-332/106

Study of Pyrolysis of Pre-Irradiated Plastic Wastes by Termogravimetric, IR and GC Methods

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In this work, the thermal decomposition process (350-550 0C) of plastic wastes (PET-1, PP-6,PS-5,MS-1009), irradiated with gamma rays (32-794kGy) was studied by thermogravimetric, IR and GC methods. At the pyrolysis processes of PET-1 samples C1-C5 alkanes and C2H4, C3H6, iso C4H8 hydrocarbons were identified as gas products of pyrolysis at 5500C temperature and Superior and Inferior Heat Values (MJ/m3), Relative Density, Wobbe Index (Superior and Inferior) parameters of the obtained gas mixture in the dose range of 32-794kGy range have been calculated. The Superior and Inferior Heat Values of the obtained gas mixture are 43.07 and 39.45 MJ/m3, respectively. The mass percentage of solid residues and gaseous products resulting from pyrolysis at 550 0C is 16.5 and 40.9 %, respectively, for samples irradiated with a dose of 794 kGy. The mass percentage of liquid products decreases as the dose increases and makes 42.6%. The activation energy of mass loss varies in the range of 50-60 kcal/mol in the used doses. It was shown, that 3424, 2923.4, 2854.5, 1713.4, 1577.7, 1504.3, 1453.2, 1339.7, 1244, 1117.3, 1017.2, 970.49, 872.62, 845.93, 79 2.54, 723.6, 503.38 cm-1 wavelength bands effect of radiation dose is not observed. The intensity of absorption bands observed at the wavelength of 2965.7-2971 cm-1 decreases as the radiation dose increases. New bands with wavelengths of 1601-1683 cm-1, 1406.5-1417 cm-1, 1066-1072 cm-1, and 696-707 cm-1 appear in the irradiated samples.

IAEA-CN-332/107

Development of Compatibilizers Generated from PE/PP Recycled by Using Radiation Processing to be Used for Wood Plastics Composite (WPC)

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Indonesia's food and beverage industries are the largest consumers of plastic, accounting for 60% of plastic production in the country. These industries mainly use PP and PE plastics, resulting in a total plastic consumption of almost six million metric tonnes in 2019. Unfortunately, this leads to a significant accumulation of plastic waste in the environment. It is crucial to recycle single-use plastic products to extend their life cycle and enable further reuse. Additionally, the demand for wood plastic composites (WPC) is increasing worldwide as it is an eco-friendly alternative to wood materials. It is utilized in industries such as construction, building, and automotive engineering, offering advantages like recyclability, water and termite resistance, and environmental friendliness. WPC is composed of plastics and biomass, which are the main raw materials used in its production. The use of recycled plastics instead of virgin plastics in WPC has recently become more popular due to increased awareness of circular economy principles among the community, government, and industries. However, the quality of the composite depends on the compatibility between the plastics and biomass. Poor physical or chemical attraction at phase boundaries reduces the quality of the composite. Thus, compatibilizers play an important role in enhancing the interfacial adhesion between the plastics and biomass. Radiation processing applications using nuclear technology can convert single-use plastic waste into new product materials like compatibilizers, which can be used in WPC. Gamma radiation and electron beam technology are essential in this process, especially when converting PP/PE-based plastic waste into a compatibilizer using surface modification through radiation oxidation. By utilizing PP/PE plastics and biomass waste, we can contribute to decreasing the waste in the environment and promote sustainable manufacturing practices. The methodologies for obtaining a compatibilizer using radiation oxidation are preparation of raw materials, irradiation process, characterization, WPC compounding, and mechanical testing of WPC. The recycled plastics used as raw materials are recycled polyethylene (rPE) and polypropylene (rPP), both post-consumer and post-industrial. The irradiation processing was conducted using gamma rays and electron beam machines 2.5 MeV at various doses ranging from 100-300 kGy with a dose rate of 10 kGy/h or lower. The characterization of irradiated samples using ESR, FTIR, MFI, and contact angle showed increasing in radical peroxides, carbonyl and hydroxyl groups, and MFI, but oppositely the decrease in contact angle, indicated an oxidation process. Testing WPC's mechanical properties revealed that mechanical properties were improved by using 2% of 200 kGy irradiated recycled PE (rPE).

IAEA-CN-332/108

Radiation-Induced Synthesis of Polysaccharide-Based Hydrogels for Efficient Removal of Toxic Dyes from Simulated Solution

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Environmental pollution from industrial wastewater, particularly from toxic dyes, poses a significant threat to both ecological systems and human health. The development of effective and sustainable methods for dye removal is essential for mitigating these impacts. This study addresses the critical issue of removing toxic dyes from industrial wastewater to protect the environment and human health. To address this challenge, a bio-based hydrogel was synthesized using κ-carrageenan/Arabic gum/polyacrylic acid (KCAR/AG/PAAc) by gamma irradiation. The synthesis process leverages the unique properties of polysaccharides, combined with the advantages of gamma irradiation, to enhance the hydrogel's adsorption capabilities.

The influence of irradiation dose on both gel content (%) and swelling percent (%) was studied. Higher doses of gamma radiation were found to significantly increase the gel content and swelling percentage, indicating a higher degree of cross-linking within the hydrogel network. Morphological analysis was conducted using scanning electron microscope (SEM) and atomic force microscope (AFM), revealing that increased irradiation doses resulted in greater surface roughness and height, which correlate with enhanced cross-linking.

The hydrogel's effectiveness in removing toxic dyes from simulated aqueous solutions was thoroughly investigated. The prepared bio-based hydrogel and dye-loaded biohydrogel underwent comprehensive characterization through Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Thermogravimetric Analysis (TGA), SEM, and Energy-Dispersive X-ray Spectroscopy (EDX) analyses. These characterizations confirmed the successful incorporation of the dye molecules into the hydrogel matrix and provided insights into the structural and thermal properties of the hydrogels.

The results indicate that the synthesized bio-based hydrogels are highly effective in adsorbing toxic dyes from aqueous solutions, making them a promising solution for wastewater treatment applications. Future research will focus on optimizing the hydrogel formulation and exploring its practical applications in industrial settings.

Keywords: Adsorption, dye removal, hydrogel, gamma radiation, AFM, polysaccharides, wastewater treatment.

IAEA-CN-332/109

Investigation on Degradation Mechanism of Sulfamethoxazole in Aqueous Solution under Electron Beam Irradiation Based on Numerical Simulation

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Water pollution caused by antibiotics has aroused widespread concern around the world. Not only do antibiotics themselves pollute water bodies, but antibiotics can also induce antibiotic resistance genes (ARGs) in the environment. The removal of antibiotic and ARGs has become a research hotspot in the current environmental field due to their transportation, transfer complexity, and potential risk to biological communities. It has become a global environmental problem and hot issue to be solved urgently.

Sulfonamide antibiotics are produced and used on a large scale worldwide and have been detected in surface waters of many countries. The degradation of sulfonamide drug sulfamethoxazole (SMX) in aqueous solution under ionizing radiation has been studied by several research groups internationally, mainly using gamma ray irradiation, and there is only one research report using electron beam irradiation. However, the degradation mechanism of sulfamethoxazole under electron beam irradiation is still unclear.

Electron beam (EB) treatment is an advanced environmental pollution control technology with higher treatment capacity compared to gamma ray irradiation. The degradation of sulfamethoxazole in aqueous solution under EB irradiation was studied by computer simulation. The numerical simulations were performed using Chemsimul and FACSIMILE programs, and the contributions of oxidant hydroxyl radicals (•OH) and reductants hydrated electrons (eaq-) and hydrogen atoms (H) to SMX were considered. The rate constants of hydroxyl radicals and hydrated electrons for SMX are very high, (8.5±0.3) 10^9 M-1 s-1 and (1.0 ±0.3) *10^10 M-1 s-1, respectively. SMX is easily degraded under EB irradiation. The degradation efficiency increases with the increase of absorbed dose.

The degradation of SMX in aqueous solution under electron beam irradiation is mainly contributed by OH radicals, hydrated electrons (eaq-) also contribute to a certain extent, and H atoms play a smaller role. OH radicals mainly add to sulfanilic acid ring through hydroxylation, and some OH radicals also add to other positions of SMX and form cleavage products.

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Application of Irradiation Processing to Manufacture Pork Liver Paste for the Companion Dog

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The hygienic quality of companion animal's feeds has been considered highly by their owners as well as by the health authorities. Meanwhile, animal organs such as liver, heart and lung, have high nutritional values, and are using to food and the ingredients in human meals and animal feeds. However, their high moisture contents and microbial contamination give the limitation to use them. Therefore, if the spoilage and feed-born outbreaks can be controlled by the alternative methods without any the deterioration of the nutritional and organoleptic qualities, more various types of feed can be supported to the companion animals. Ionizing radiation can be used to guarantee the microbiological safety in the processed meat products. In this study, pork liver paste was developed with cooked and gamma-irradiated pork liver homogenate (PLH) for companion dog feed, and microbial growth and the sensory acceptance of the pork liver paste were tested. Pork liver obtained from a local slaughtering house was boiled for 30 min, chilled and ground to make PLH. Cooked PLH was vacuum-packaged and gamma-irradiated with the designated doses, 5.0, 7.5 and 10.0 kGy. Irradiated cooked PLH of 67%, iced tap water of 20%, defatted soybean powder of 10%, salt of 1.0%, sugar of 1.0%, sodium triphosphate of 0.5%, and spice mix with barbeque flavor of 0.5% were mixed into a bowl cutter for 10 min, stuffed in a vinyl casing with a diameter of 3.0 cm, and cooked at 70℃ for 30 min. Total aerobic bacterial counts (TABC) and TBARS for oxidation were tested. The sensory quality was also evaluated by 20 companion dogs and their owners. Gamma irradiation could reduce TABC in the cooked PLH from 4.58 Log CFU/g of non-irradiated PLH to 1.21 Log CFU/g of 5 kGy-irradiated PLH in about D10 of 0.674 kGy. Non-irradiated PLH appeared the vacuum packaging come untangled by the generation of gas by spoilage after the 3 day storage under the accelerated condition at 40℃. Samples with gamma-irradiated PLH did not visiably show the growth of bacteria on the incubation plates and the sample (Fig. 1), but sample with non-irradiated PLH appeared about 3.76 Log CFU/g at 0 day. During the storage at 40℃ for 10 days, most samples appeared the growth of bacteria, however any TABC did not observed at the sample with 10.0 kGy-irradiated cooked PLH (Fig. 2). TBARS was observed in the range from sample with 5 kGy-irradiated PLH of 6.38 to sample with 7.5 kGy-irradiated PLH of 7.1 dimalonaldehyde mg/Kg without any statistical differences. Sensory evaluations both the companion dogs and their owners appeared the above 5.8 score at the overall acceptance under the 7-score evaluation test.

The results irradiation technology can be conducted to guarantee the microbial safety to the byproducts obtainable from slaughtering process to use the materials and ingredients for companion dog feeds.

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Effects of Electron Beam Irradiation on the Germination of 23 Thai Rice Cultivars

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Rice grains from twenty-three cultivars commonly cultivated in Thailand were irradiated with an 8 MeV electron beam at 0 - 1,200 Gy. Their germination rates were recorded 7 days post-irradiation. The dose-response curve based on germination rates exhibited an S-shape curve. The result can't be plotted in linear regression. It was observed that each rice variety has an individual critical dose. If any varieties were exposed to excess than their critical dose rate, the survival rate was decreased quickly and they almost died at once. The critical dose, defined as the maximum dose before the observed germination rates declined by 20%, ranged from 300 - 600Gy with KhaoBanna and PlaiNgam Prachinburi having the lowest observed critical dose, while RD23, Prachinburi, and Ayuddhya having the highest observed critical dose. The observed LD100, the lowest dose at which no germination was observed, ranged from 460 – 1,200Gy with RD33 and KDML105 having the lowest observed LD100 and SPR1 having the highest dose.

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Effect of Gamma-Irradiation on Ultra-High Molecular Weight Polyethylene Plates Irradiated in Air and Vacuum Conditions

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In this work, we investigated the effect of gamma-irradiation on the physicochemical properties of ultra-high-molecular-weight polyethylene (UHMWPE) plates. The UHMWPE plate was prepared using a hot press method at upper and lower plate temperatures of 160 °C and a pressure of 3.5 MPa for 10 min. The UHMPWE plates were irradiated in air and vacuum conditions in a cobalt-60 gamma source (Gamma-Cell 220 upgraded; Izotop; Hungary) at irradiation doses of 25, 50, 100, and 200 kGy with dose rates of 2.6 kGy/h. To investigate the effect of gamma irradiation on the performance of the UHMWPE plate, the physicochemical properties, hydrophylicity, oxidation index, and thermal properties of the irradiated UHMWPE were analyzed. The results showed that the infrared spectra of irradiated UHMWPE showed a new FTIR peak at 1715 cm-1 that correlated to carbonyl groups in the UHMWPE plate, and the peak intensity increased with increasing irradiation dose up to 200 kGy. Importantly, the UHMWPE plates both irradiated in air and vacuum conditions demonstrated a decrease in the contact angle and an increase in the oxidation index, indicating an increase in their hidrophilicity. However, there are no significant changes in gel fraction values and thermal properties of the unirradiated and gamma-irradiated UHMWPE plates irradiated in both air and vacuum conditions.

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Physicochemical Properties of Nano-Ag/PNiPAAm Hydrogel Nanocomposites: Nanospheres vs. Nanoprisms

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Nowdays, a significant development in material science has emerged, focusing on combining nanoparticles (NPs) with hydrogels. This study aims to investigate how different shapes of AgNPs affect the physicochemical properties of hydrogel nanocomposites, which may be a limiting factor for their application in various fields. The thermosensitivity of poly(N-isopropylacrylamide) (PNiPAAm) makes it highly adaptable and applicable, especially in bioapplications. Due to morphologies, anisotropic AgNPs have distinct physicochemical properties compared to spherical ones. Therefore, we present a two-step synthesis of AgNPs/PNiPAAm hydrogel nanocomposites that includes the chemical formation of both spherical and triangular AgNPs, followed by gamma irradiation induced PNiPAAm polymerization and crosslinking in the presence of NPs. This method integrates materials synthesis and sterilization into one step, enabling biomedical applications. Microscopic analysis (SEM and TEM) and UV-VIS spectroscopy were used to examine nanocomposites' and nanoparticles' morphology and optical properties. Physicochemical parameters of hydrogels were determined by monitoring swelling/deswelling processes. The interactions of AgNPs and polymer matrix were investigated by FTIR spectroscopy, while DFT computations examined the PNiPAAm matrix's adsorption on AgNPs of varied forms. The Ag20/Ag28 clusters and PNiPAAm tetramers were used to mimic non-covalent interactions and demonstrate AgNPs and PNiPAAm binding preferences.

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Pre-Feasibility Study for a Public-Private Partnership Project of a Large-Scale Irradiation Facility in Tunisia

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Tunisia has two pilot irradiation facilities: 10MeV electron beam accelerator and 100 kCi Cobalt-60 gamma irradiator (1999) located at Nuclear Research Centre (CNSTN). These irradiators have low capacity.

The potential market for ionizing radiation treatment is very large. However, there are no industrial irradiation facilities in the Mediterranean region (particularly on the southern shore). Medical device manufacturers in the region then sterilize their products using Ethylene Oxide or in irradiation units in Europe.

Hence the opportunity to study the feasibility of a project to set up a large-scale industrial irradiator in Tunisia, near one of the commercial ports, within the framework of a public-private partnership (PPP). Indeed, Tunisia benefits from a strategic geographical position which would allow it to be very competitive in terms of production costs, strongly linked to the cost of transport and logistics.

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Gamma-Irradiation Induced Synthesis of Ag-Decorated Mg2Si: Ion Beam Analysis Investigation for Enhanced Thermoelectric Performance

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High-quality granular Mg2Si materials were milled for 6 hours using a Ball milling machine. Using gamma irradiation, the milled Mg2Si was decorated with Ag with the assistance of AgNO3. The structural properties show the single phase of the pure sample (Mg2Si) and the production of ratio phases as 76:24 % for the Mg2Si: Ag (Mg2Si@Ag) sample, proof of the decoration process. The morphological investigations exhibit the agglomerations of tiny particles from SEM and nanosized particles ranging from 10:70 nm from TEM. EDX spectra confirm the XRD data by proving the appearance of a remarkable Ag peak in EDX spectra. These findings agree with the results from RBS data that exhibit the coated layer from Ag to Mg2Si nanoparticles with a thickness of 1.197 µm for 7000E15 atoms/cm2 created on the surface. These characteristics were reflected in the DSC data where the existence of Ag reduces the melting point of Mg2Si to 490 °C and influences the thermoelectric performance like the Seebeck coefficient, the behavior of the electrical resistivity, thermal conductivity, and the figure of merit (ZT). While the maximum ZT achieved was 1.5 and 0.42 for Mg2Si@Ag and Mg2Si, respectively.

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The Impact of Gamma Irradiation on the Chemical, Morphological, and Mechanical Properties of Polystyrene Used in Petri Dishes at Various Exposure Time

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This study investigates the effects of gamma irradiation on the structural, chemical, and mechanical properties of polystyrene used in Petri dishes. Polystyrene, widely used in laboratory settings, can undergo changes when exposed to ionizing radiation, potentially impacting its performance and safety. To explore these effects, gamma irradiation was performed at room temperature with doses ranging from 20 to 95 kGy, at a constant rate of 3.8 kGy/h, using the cobalt-60 gamma irradiation facility at the Jordan Atomic Energy Commission. Fourier Transform Infrared Spectroscopy (FTIR) was employed to analyze the chemical changes in irradiated polystyrene, while Scanning Electron Microscopy (SEM) was used to observe surface morphological changes. The mechanical properties, including tensile strength, hardness, and Izod impact resistance, were also evaluated.

Obtained results reveal that increasing the irradiation dose alters all properties differently. A significant change in mechanical properties was observed, while the chemical and structural properties showed only slight changes. Specifically, at 20 kGy, a significant increase in tensile strength was noted, indicating predominant crosslinking. However, at 40 kGy, a significant decrease in tensile strength was observed, suggesting substantial degradation or chain scission. Additionally, a slight change in chemical properties was detected by the appearance of new absorption bands, indicating the oxidation of polystyrene.

Key words: Gamma Irradiation, Polystyrene, Chemical and Mechanical Properties.

IAEA-CN-332/146

Development of Horizontal Flow Constructed Wetlands for Radiotracer Application

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Application of tracer technology in wetland study has never been attempted in Bangladesh. As a part of the continuing coordinated research project (CRP code 22076; BGD-26702), non-radioactive and radioactive tracers were used in a newly developed laboratory scale constructed wetland. The model wetland was designed at a scale of 18x12x15 inch for the purpose of horizontal flow study where different geological materials were utilized as subsurface layers and submerged macrophyte Egeria densa as absorber plant. Objective of the present study was to investigate the geomaterials and natural plants used in the lab-scale wetland, thereby observing the capacity of retaining contaminants. Various flow of water was tried as well as maintaining stable time of water in the wetland. Non-radioactive tracer like Sodium Chloride (NaCl), Potassium Dichromate ($K_2Cr_2O_7$), and Mercury (II) Sulfate ($HgSO_4$) were used as experimental trial for the optimum design of the wetland. Later, a short-lived radionuclide (Technetium; Tc99m) was utilized as radiotracer to observe the migration of radioactive contaminants through the water as well as capacity of retaining in plant and/or geological materials. For radiotracer use, the wetland was covered with the specifically designed lead shielding to protect radiation exposure. Portable gamma radiation monitor was used to measure the radioactivity. The results of using all these tracers were compared and analyzed to conclude on the ideal design of a constructed wetland that can be applicable in managing hazardous wastes.

IAEA-CN-332/147

Applications of Gamma Ray Densitometer Coupled with App Graphical User Interface

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A wide range of equipment and unit operations, such as heaters, tanks, pipelines, separators, distillation columns, heat exchangers, and stabilizers, are frequently used in the petroleum industy. During the operation, a number of malfunctions and problems arise, including blockage or scale deposition in the pipelines, missing, collapsing, or buckled manways, weeping or dumping trays, dry or flooded trays, uneven liquid levels on trays and in parting, foaming on trays or in re-boilers, condensers, and accumulators, improper vapor and liquid distribution in packing, and liquid hold-up as a result of plugging and fouling in the distillation column. Multiphase identification and quantification (gas, oil, water, and particle) in the separators and tanks is also crucial. As a result, issues with equipment and unit operations will have an economic impact on the plant, particularly if the products are off-spec or the unit must be shut down in an emergency. Early failure and malfunction detection enables operators and engineers to have a better understanding of the problem and devise a cost-effective solution. Online monitoring with sophisticated isotope measurement techniques such as the Gamma Ray Densitometer (GRD) is one method for detecting problems while the procedure is still operating. It has been used for decades to conduct inspections without affecting operations. It is a useful, economical, well-established, fast, and powerful diagnostic tool. Data interpretation is critical for determining the fault and restoring normal operation to the equipment. Because the majority of data interpretation is dependent on expertise and experience, it is necessary to combine gamma ray technique with an online model based on data mining, artificial intelligence, or statistical techniques in order to detect and distinguish between normal and abnormal cases. The use of nuclear technology in an oil industry laboratory at the Petroleum Research Center (PRC) (Kuwait Institute for Scientific Research) was recently established through international atomic energy agency (IAEA). This paper describes some of the work done using GRD to scan distillation columns, identify multiphase levels in tanks, and detect scaling in pipes. All works are performed on a laboratory scale. Additionally, a MATLAB App-based graphical user interface (GUI) model was developed for data analysis. The findings demonstrated the value of the gamma ray and App GUI model combination for applications in the oil industry as well as for differentiating between normal and abnormal circumstances.

IAEA-CN-332/150

Performance Evaluation of Multi-Channel Data Acquisition System for Industrial Radioisotopes Applications

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The aim of this paper is to study the performance of different Data Acquisition Systems (DASs) in order to provide a recommendation to the users or to designers about the optimum operation of these systems. Three DASs have been tested in different industrial radiotracer applications experiments;12 Chanels Ludlum DAS, 12 Chanels ALTAIX CAESAR DAS and 36 Chanels KAERI DAS. The performance evaluation was carried out from two points of view: the first is most important technical specifications and capabilities such as; the compatible gamma detectors, High Voltage Supply, Spectroscopy availability Computer Interface and features of Data acquisition software. The second is performance and reliability while working in the work field during different radiotracer experiments specially at an unexpected conditions during the work such as transportation in the field, electricity shutdown and their effect on the high voltage stability, working time, data storage. The results show that the three DASs can be work efficiently in the field, but each of them requires special conditions that differ from one to another. The paper gives the user several recommendations for each DAS and gives the DAS designers several recommendations and specifications that should be considered during the development of DAS for industrial radioisotopes applications

IAEA-CN-332/153

Growth of Amnion Cells and Vero Cells over Electro-Spun Polycarbolactone Nanoscaffolds

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The present study was an attempt to compare the growth of two cell lines (VERO and amion) on two different structures of PCL nanoscaffold designed by controlling kilovoltages (Kv) of the electrospinner at 10 and 14 Kv. Amnion cells, which has larger size than VERO cells showed growth over the scaffolds with smaller pore area. In order to examine the effect of pore size on cell growth: cell adhesion, survival, spatial organization on fibers, proliferation using MTT test, lipid peroxidation and DNA quantification were assayed after four and eight days. There was an enhanced adhesion and proliferation, especially of Vero cells on polcarbolactone scaffolds having significantly lower mean of fiber size and significantly larger pore area in scaffold spinned at 14 Kv compared to scaffold spinned at 10 Kv. Fiber at the macroscale compromised about 20 % in scaffolds spanned at 14 Kv and 8 % in scaffolds spinned at 10 Kv. The number of cells was two folds higher on scaffolds spinned at 14 Kv compared to scaffold spinned at 10 Kv. Mean cell size of Vero cells grown over scaffold spanned at 14 Kv was significantly higher compared to amion cells grown over scaffold spanned at 10 Kv . This study provides proof that spatial topography and the presence of a percentage of fibers at the macroscale and microscale are needed in order to achieve better growth of cells on fibrous scaffolds.

IAEA-CN-332/159

Radiation Synthesis of Advanced Hydrogel-Based Acrylic Acid Derivatives with Highly Mechanical Strength for Use as a Replacement of Cartilage

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Most hydrogels lack the mechanical properties needed for weight-bearing and cartilage replacement applications. This study utilized gamma irradiation to enhance the mechanical properties of a hydrogel based on a new monomer derivative from acrylic acid. A new hydrogel consisting of carbamothioyl monomers of N-(14-amino-3,6,9,12-tetraazatetradecyl) carbamothioyl) acrylamide (ATACA) derivatives from acrylic acid by sequence chemical reactions was used as a new class of biomaterial. The new class of (ATACA) monomers was mixed with fresh acrylic acid (AAc) monomers and subjected to gamma irradiation doses from (10 up to 60 kGy). Three different compositions of p(ATACA/AAc) hydrogels were examined to select the most mechanically suitable to use as cartilage. The concentration of AAc and irradiation doses are the most significant factor influencing the swelling behavior and mechanical properties of p(ATACA/AAc) hydrogel. Gamma irradiation sterilizes the p(ATACA/AAc) hydrogel without introducing pathogens, enhancing its safety for biomedical applications. FTIR analysis confirms the successful synthesis of the hydrogel by identifying specific functional groups in the p(ATACA/AAc). According to SEM analysis, the obtained hydrogels have an opening porous structure and pliable texture that closely resembles normal cartilage tissue. The porous structure observed in SEM images is essential for supporting cell attachment, proliferation, and nutrient diffusion, making it suitable for tissue engineering applications. The rheological properties of the p(ATACA/AAc) (1:1) v% hydrogel prepared at 50 kGy are assessed to determine its suitability for cartilage replacement. A high storage modulus (G' = 2.5 MPa) indicates the hydrogel's ability to store energy elastically, reflecting its dynamic stiffness of 98 N/mm, with elastic recovery around 99%. As well as the p(ATACA/AAc) hydrogel has a compressive strength of more than 10 MPa and exhibited less than 1% strain when subjected to a weight of 105 kg. Furthermore, bone marrow-derived mesenchymal stem cells (BMMSCs) were used to evaluate the biocompatibility and chondrogenic potential of the p(ATACA/AAc) hydrogels. The porous structure and mechanical properties of the p(ATACA/AAc) hydrogels supported the attachment, proliferation, and chondrogenic differentiation of the BMMSCs, demonstrating their suitability as a scaffold for cartilage tissue engineering applications. This suggests that the p(ATACA/AAc) hydrogels have the potential to mimic the natural structure of cartilage and are relevant for cartilage replacement applications.

IAEA-CN-332/163

Modification of Albumin in Nanoparticles Prepared by Gamma Irradiation under Reductive Conditions

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1. Background

The effect of ionizing radiation on proteins has been studied for decades to understand its impact on food and food safety. The most pronounced chemical effects occur when a large proportion of liquid water is in the sample. Radiolysis of water produces reactive oxygen species with harmful effects on biological molecules. However, irradiating the albumin solution with gamma rays, under specific conditions does not yield protein degradation. Instead, it leads to the formation of albumin nanoparticles (albNPs) when using ethanol as a cosolvent and an oxygen-free atmosphere. The final size of albNPs depends on the properties of the solvent, such as the ethanol ratio and concentration, and is independent of the albumin concentration.

This work studies the albumin, which constitutes albNPs, prepared by radiation-induced crosslinking.

2. Methodology

Albumin solution (30 mg/mL) with ethanol 20 and 30 %v/v was degassed by nitrogen bubbling. Samples were irradiated using gamma rays from a 60Co source (PISI, CNEA-Ezeiza) at ten kGy and one kGy/h dose rate. AlbNPs were concentrated by ultrafiltration and purified by size exclusion chromatography (SEC) and characterized by SDS-PAGE electrophoresis and UV-MALDI-ToF mass spectrometer within a mass range of 20,000-80,000 m/z.

3. Results

AlbNPs were prepared by gamma-ray irradiation of an albumin solution containing ethanol. Irradiation was performed using 20 %v/v and 30 %v/v ethanol keeping the temperature below 10 ºC. Purified albNPs were analyzed by SDS-PAGE electrophoresis. Electrophoresis gel showed albNPs of very high M.W. (M.W. > 1,000,000 Da) and a minor amount of free albumin, only in irradiated samples containing ethanol 30 %v/v. In addition, this irradiation condition yields many M.W. bands (M.W. > 135,000 Da) when the sample is treated with mercaptoethanol, and a double band in the albumin M.W. region. MALDI-ToF analysis of albumin showed a M.W. 66,332, and the albumin band from albNPs (double band) yielded a double M.W. peak with M.W. maxima at 66,509 and 71,420 Da. These peaks could be assigned to albumin modified with 4 and 113 ethanolic moieties added to its chemical structure.

4. Conclusions

AlbNPs can be prepared by gamma ray irradiation, which induces protein cross-linking via solvent radiolysis. Hydroxy ethyl radicals (HER) generated by gamma irradiation are the main radical species capable of albumin modification by add-on chemical reactions generating macro radicals. Experimental results support the hypothesis that albNPs comprise a non-covalent aggregation of proteins where the outermost layer is chemically crosslinked by recombination of these macro radicals. These macroradicals form a network that holds the unmodified albumins inside.

These HER add-on chemical reactions onto albumin generate chemical modifications of the albumin structure on the surface of NPs. These chemical modifications are capable of generating immunological responses during in vivo applications.

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The International Bureau of Weights and Measures Commitment on Establishing International References for Activity Measurement

R. Coulon, C. Michotte, V. Gressier - International Bureau of Weights and Measures (BIPM)

The International Bureau of Weights and Measures (BIPM) has developed a robust framework for ensuring the equivalence of activity measurements through its International Reference System (SIR). This system enables National Metrology Institutes (NMIs) and Designated Institutes (DIs) to validate their primary activity standards by comparing samples in BIPM centralized instruments against standards from other NMIs/DIs. The results are recorded in the Key Comparison Database, forming part of the evidence required for Calibration and Measurement Capabilities (CMC) claims. The three BIPM comparison services are introduced below.

SIR – International Reference System

The SIR facilitates the comparison, since nearly 50 years of over 60 gamma-ray emitting radionuclides ranging from 18F to 243Am. The BIPM comparator used is a high-precision ionization chamber, offering uncertainties ranging from 0.05 % to 0.5 % (k = 2), depending on the radionuclide and its activity. The agreement within the Consultative Committee for Ionizing Radiation (CCRI) acknowledges that successful participation for one radionuclide demonstrates the capability to standardize other radionuclides via the same method, detailed in a Measurement Methods Matrix. The SIR is currently updated to achieve a better sensitivity and extend its range of applications.

SIRTI – SIR Transfer Instrument

For radionuclides with short half-lives, the BIPM provides an on-site comparison service using the SIR Transfer Instrument (SIRTI), a well-type NaI(Tl) detector. This service covers radionuclides such as 11C, 13N, 18F, 56Mn, 64Cu, 99mTc, 123I, and 153Sm. The SIRTI is transported and operated by BIPM in collaboration with NMI/DI staff, and when possible, remote control from BIPM is utilized. The results are linked to the SIR and documented in the Key Comparison Database, supporting CMC claims. Copies, linked to the BIPM SIRTI, are currently developed in Regional Metrological Organizations (RMOs), to answer the growing need of comparisons and to extend the number of participants.

ESIR – Extension of SIR

The ESIR system extends the SIR's capabilities to measure non-gamma-emitting radionuclides using liquid scintillation counting. Following a pilot study with 60Co standard solutions, which confirmed ESIR's accuracy and precision, the CCRI has approved the service to start in 2024. ESIR aims to cover radionuclides such as 14C, 35S, 45Ca, 55Fe, 63Ni, 89Sr, 90Sr, 99Tc, 147Pm, 241Am, and 241Pu, with an uncertainty target of 0.5 % (k = 2).

Through these systems, the BIPM strengthens global metrological consistency and supports NMIs/DIs in maintaining high standards of radioactive measurements, thereby ensuring reliable and accurate activity measurements for radionuclides that have present or upcoming applications in nuclear medicine, industry and the environment.

IAEA-CN-332/180

Electron Beam Technology as a Potential Treatment for Surfactants in Water: Degradation and Detoxification LAS

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The discharge of industrial and domestic effluents introduces several toxic and persistent contaminants in aquatic environment, such as surfactants. The foam, reduced biodegradation and negative effects on biota are changes caused by surfactants in water. Suitable improvement of wastewater may require combined treatment processes. Radiation efficacy concerning biodegradability and detoxification of wastewater have been discussed. The surfactant Linear Alkylbenzene Sulphonate (LAS) degradation (> 89%) after radiation was reported by Jiao et al., 2022. This study aimed to assess Electron Beam Irradiation (EBI) for degradation and toxicity reduction of the anionic surfactant LAS. Acute effects in Daphnia similis were evaluated in non-irradiated and irradiated samples at 5kGy. The degradation of LAS by radiation was evaluated by the methylene blue active substance method, followed by UV/VIS determination (652nm). Acute toxicity assays demonstrated high toxicity for non-irradiated samples, with EC50 = 8.4% (8,4 mg/L). Approximately 69% toxicity removal (EC50 = 27.8%) and 97% LAS degradation were obtained at 5 kGy.

Reference

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Applied Stations, Beam Transfer Lines and Radiation Science Research at the NICA Accelerator Complex

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The Nuclotron based Ion Collider fAcility (NICA) project at the Joint Institute for Nuclear Research (JINR) is not limited to fundamental science, but also offers great opportunities for the development of applied research, including studies in radiation biology and radiation materials science, and for single event effects (SEE) testing of capsulated and decapsulated microchips with heavy ion beams. The ARIADNA infrastructure (Applied Research Infrastructure for Advanced Developments at NICA fAcility) for applied research was constructed in 2021-2024 years.

At the Veksler and Baldin Laboratory of High Energy Physics (VBLHEP) of JINR, it is planned to conduct applied research with low- and high-energy heavy ion beams from the NICA injection complex. The description and current status of the Station of Chip Irradiation (SOCHI, 3.2 MeV/nucleon), the Irradiation Setup for Components of Radioelectronic Apparatus (ISCRA, 150-500 MeV/nucleon), the prototype of the detector part of the station ISCRA (DPS-NICA), the Setup for Investigation of Medical Biological Objects (SIMBO, 400-1000 MeV/nucleon), and beam transfer lines are presented.

The SOCHI station was constructed for SEE testing of the decapsulated microchips with low-energy pulsed ion beams extracted from a heavy ion linear accelerator (HILAc). The mounting of the station and beam transfer line was completed in the autumn of 2021. To current date, five beam runs have been carried out. In the near future, it is planned to conduct a series of commissioning runs to optimize irradiation modes and continue experimental studies on the irradiation of microchips.

The SIMBO station was constructed in December 2023 for space radiobiological research and modeling of the influence of heavy-charged particles on the cognitive functions of the primate’s brain, as well as for modeling the behavior of astronauts on long-term space flights when exposed to low doses of radiation.

The ISCRA station was constructed in December 2023 for SEE testing of the capsulated microchips as well as for full-scale modeling of radiation conditions on spacecraft with high-energy ion beams. The technology for radiation hardness tests of capsulated microchips without removing their package with high-energy ion beams was developed in the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory (BNL); it has not been developed in Russia to date. However, now the technology will be implemented at the ISCRA station at JINR. Commissioning runs at the ISCRA station are planned for the second half of 2025.

The DPS-NICA is an integral part of the ISCRA station that allows precise localization of the particle track and energy release, precise localization the most radiation-vulnerable areas of the microchip by linear energy transfer (LET) tomography. The results of the first commissioning run and the methodology of detector planes alignment based on experimental data are presented.

IAEA-CN-332/183

Optimizing Polymer Coatings for Implants and Drug Delivery: Gamma vs. E-Beam Irradiation

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Surface functionalization is a critical process in biomedical applications, enhancing the performance and compatibility of various materials used in medical devices and implants. This study compares the effectiveness of gamma and electron beam (e-beam) irradiation for crosslinking surface layers in two distinct biomedical applications. The first application involves the production of polymer coatings for the surface functionalization of medical implants, while the second focuses on creating polymer coatings over loaded calcium carbonate to delay drug release in drug delivery systems.

In both scenarios, gamma and e-beam irradiation are employed to induce crosslinking in self-assembled monolayers (SAMs) of fatty acids, thereby improving stability, mechanical properties, and resistance to degradation. The comparative analysis reveals that while both irradiation methods significantly enhance the protective characteristics and durability of the surface coatings, they differ in their mechanisms and outcomes. These findings provide valuable insights into the optimal use of gamma and e-beam irradiation for specific applications, guiding the development of more robust and long-lasting surface functionalizations in medical devices and implants.

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Turning Recycled HDPE Pellets Made from Discarded Fishing Nets into Composites with Neutron Shielding Properties

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As a replacement for heavy metals such as lead (Pb), borated polyethylene (BPE) is a very good alternative that is highly useful for nuclear facilities looking for light-weight materials with neutron shielding properties. However, in Thailand, BPE sheets are not commercially available. They can be imported from foreign countries, but at a very expensive cost. Thus, the major goal of this research project is to fabricate composites with neutron shielding properties from plastic waste. Recycled HPDE pellets, made from discarded fishing nets, were mixed with boron carbide at different percentage of B (0, 10, 20, 30 and 40%) to form BPE sheets. Results showed that samples with higher content of boron carbide offered better neutron shielding properties. Taken into consideration both mechanical and neutron shielding properties, the optimum content of boron was determined to be at 10%, agreeing very well with results from a previous study.

IAEA-CN-332/199

About Safety in the Application of Gamma Rays to the Inspection of Concrete Structures

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Gamma rays have been used to observe the interior of concrete structures since the late 1940s, but the application of this technique in the field has been largely limited due to public concern regarding radiation emitted by radioactive sources. Over the past 30 years, THASA, a private company mainly engaged in industrial gammagraphy, has supplied civil engineers with accurate data on rebar diameters and positions, voids in concrete and post-tensioned ducts, and corrosion of steel bars, providing ample evidence that gamma rays offer information that cannot be obtained with other non-destructive techniques and that this can be achieved without violating any established safety standards. In this article we want to present evidence to assuage public concerns by showing that, when proper procedures are followed, gamma rays can be used safely. We will show illustrative examples, the results of measurements and of modeling in support of this claim.

IAEA-CN-332/201

Radiocatalysis in the Treatment of Emerging Contaminants

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Radiocatalysis is a promising advanced oxidation process (AOP) that uses ionizing radiation (such as gamma rays or electron beams) to generate highly reactive species capable of degrading various pollutants, including emerging contaminants. Emerging contaminants (ECs) are chemicals not typically monitored in the environment but that have the potential to cause adverse ecological and human health effects. These include pharmaceuticals, personal care products, endocrine-disrupting chemicals, and various industrial compounds.

In radiocatalysis, the interaction between ionizing radiation and water molecules produces reactive species such as hydroxyl radicals (•OH), hydrogen atoms (H•), and hydrated electrons (e-aq). These reactive species effectively break down complex organic molecules into simpler, less harmful substances.

These reactive species initiate oxidation and reduction reactions with the pollutants, leading to their degradation. The presence of catalysts can enhance the efficiency of radiocatalysis, lowering the activation energy of the reactions and increasing the generation rate of reactive species.

Radiocatalysis has been applied to degrade many ECs, including pharmaceuticals such as antibiotics, analgesics, and hormones detected in water bodies due to improper disposal and excretion. Endocrine-disrupting chemicals (EDCs), such as bisphenol A (BPA) and phthalates, can interfere with hormonal systems in organisms. Studies have shown that radiocatalysis can significantly reduce the concentration of EDCs in water, mitigating their harmful effects. Various industrial chemicals, including dyes, pesticides, and surfactants, pose significant environmental risks.

Advantages of Radiocatalysis

Radiocatalysis has high degradation efficiencies for many contaminants, including those resistant to other treatment methods. It can be applied to various water matrices, including wastewater, surface water, and groundwater. The reactive species generated in radiocatalysis can attack a wide range of organic molecules, making the process non-selective and effective against diverse contaminants.

The technology can be scaled up for large-scale water treatment applications.

Despite its advantages, radiocatalysis faces several challenges. The need for ionizing radiation sources can result in high operational costs. Degradation of complex pollutants can lead to the formation of intermediate byproducts, which may require further treatment. Handling and disposal of radioactive materials pose safety and regulatory challenges.

Future research is focused on developing more efficient catalysts, optimizing process parameters, and integrating radiocatalysis with other treatment technologies to improve overall efficacy and reduce costs. Advances in radiation technology and the development of hybrid systems combining radiocatalysis with other AOPs hold promise for more sustainable and effective water treatment solutions.

In conclusion, radiocatalysis represents a powerful tool in the arsenal against emerging contaminants, offering significant potential for protecting water resources and public health. Continued research and technological advancements are essential to realize its potential and fully address existing challenges.

The progress in the work on the use of radiocatalysis in Mexico is presented.

IAEA-CN-332/202

Effect of Gamma Irradiation on the Mechanical Properties of Polyethylene Filled with Different Reinforcement Agents

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1. Background of the study

Society is demanding for technologies able to decrease the environmental impact associated with post-consumer plastics, especially polyethylene (PE) as it is one of the most consumed plastic today. Beside reducing the production and consumption of virgin PE, add value to products formed by post-consumer PE (PC-PE) are needed in this regard, such as mechanical and chemical recycling, especially those able to develop novel materials with even improved properties that the original matrix (up-cycling). The addition of different fillers into waste PE is one approach to improve the properties of PE toward upcycling, where nanoparticles such as carbon nanotubes (CNT) or graphene (G) are recently attracted attention for the development of multifunctional PE nanocomposites. Another technology for up-cycling PC-PE relates with gamma irradiation to change the microstructure and topology of the polymer, where crosslinking in one of the most characteristic approach. Motivated by these two technologies, the objective of our contribution is to study the effect of gamma irradiation on the mechanical behavior of linear low density PE (LLDPE) filled with two different carbon nanostructures: CNT and G. LLDPE was selected as a model for PC-PE due to its large use in packaging applications.

2. Methodology

A commercial LLDPE (MFI = 0.5 g/10 min) was mixed with CNT or G by using a batch twin-screw melt mixer (Brabender® Plasti Corder) with a capacity of 40 cm3, at 110 RPM during 10 min using an operation temperature of 190°. Once this process is finished, the material is melt pressed at 190 °C in an HP hydraulic press (model D-50) with heating system, and water cooling system. The sample thickness was 1.0 mm for tensile tests. CNT were commercial from Baytubes while thermal reduced graphene oxide was synthesized by a modified Hummer method. The amount of filler was between 0.5 to 20 wt%, without any additive. Samples were exposed to 10, 20 and 40 kGy in a Cs-137 facility (7,07 kCi) from the Chilean Nuclear Energy Commission (CChEN).

3. Results

Our main results show that the addition of CNT and G has a strong effect on the mechanical behavior of both pure and irradiated samples. Before irradiation, nanoparticles increase the elastic modulus of the matrix until a 50%. After irradiation, while LLDPE decrease the elastic modulus as the irradiation increase due to chain scission reactions, nanocomposites showed an opposite tendency increasing the stiffness as compared with irradiated pure LLDPE and the same composite without irradiation.

4. Conclusion.

Our results shows that carbon nanoparticles can stabilize the chain scission reactions during gamma irradiation opening new opportunities to avoid the issues of this technology toward future developments in PC-PE.

IAEA-CN-332/208

Gamma Irradiation Synthesis of Magnetic Nanoparticles with Promising Properties for Magnetic Hyperthermia Applications

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(Superpara) magnetic iron oxide nanoparticles (MNPs) have, due to their biocompatibility, biodegradability and special magnetic properties, versatile applications in biomedicine, ranging from drug delivery to cell separation and contrast media in MRI. Their radiolytic synthesis has only recently gained more attention due to the complex iron oxide chemistry. In this work γ-irradiation, as an efficient and environmentally friendly synthesis technique, is used to synthesize MNPs of various phase composition, size, shape and surface area for the purpose of obtaining MNPs with promising properties for magnetic hyperthermia (MH) cancer cell treatment. The gamma irradiation of Fe(III) precursor aqueous suspensions was performed in 60Co panoramic irradiation facility at Radiation Chemistry and Dosimetry Laboratory, RBI. By optimizing the synthesis parameters such as concentration of Fe(III) precursor, scavenger and polymer, pH, dose, as well as (post-irradiation) heat treatment parameters various MNPs were obtained: spherical and disk-shaped magnetite, disk-shaped feroxyhyte, strontium hexaferrite with high crystalline anisotropy and hybrid MNPs, some of them in the form of highly concentrated stable ferrofluids. Microstructural and magnetic characterization of powder samples were performed by XRD, TEM, FE-SEM, SQUID magnetic measurements, Mössbauer spectroscopy, gas sorption analysis, etc. DLS and ELS analysis provided information on the hydrodynamic radius, surface charge, and stability of MNPs in suspensions. Their magnetic heating efficiency were analyzed by measuring the temperature rise due to an alternating magnetic field. High SAR (specific absorption rate and ILP (intrinsic loss power) values revealed the potential of synthesized MNPs for MH applications. Cytotoxicity tests showed low toxicity of MNPs to healthy cells.

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IAEA-CN-332/210

Regulatory Considerations for Implementing the First Industrial Accelerator in Mali for Mines Samples Analysis: Photonassay Device 'Type PA1408X' of Chrysos Corporation

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Mali is one of main countries in term of mining activities in Africa. Those activities generate so many samples for analysis. Sample collection, preparation and assaying are a vital activity at all stages of a mining project. Competition between to have fast accurate results is a challence for laboratories collaborating with mining facilities.

PA1408X is a chemical-free, non destructive technology that supersedes the traditional fire assay method for measuring gold concentrations in samples. It is the mining industry's most innovative and valuable assaying solution.

PA1408X delivers faster, safer, and more accurate gold analysis, it is an environmentally-friendly replacement for fire assay on-site and in the laboratory. Its operation process is based on hitting samples with high-energy X-rays.

The objectives in this work are first : to put under succesfully regulatory control the first industrial accelerator (category 1) in Mali, promote atomic energy for peace and contribute to the climate change.

In order to be in phase with national regulation in ionizing radiation, the society called MSALABS-MALI Lab contacted the Direction of AMARAP (Malian Radiation Protection Agency) to notify their intention to install a « Chrysos PhotonAssay » inside MORILA mining. To response to the regulatory requirements, several actions have been undertaken such as : identification of companies in charge of importation and installation, sheltering location of equipment, dosimetry and training on radiation protection of workers, security aspects to avoid any unauthorized entrance into the facility and sabotage, protection of public and environment.

After implementing these actions and successful regulatory inspection, MSALABS-Mali Lab has been authorized to use Chrysos PhotonAssay device for samples analysis. Annual inspection of AMARAP has been maintained for MSALABS-Mali Lab.

IAEA-CN-332/216

Utilization of Industrial Gamma Facility in Azerbaijan

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This article explores the utilization of an industrial gamma facility in Azerbaijan, focusing on its diverse applications and benefits in enhancing industrial processes such as food preservation, medical sterilization, and material processing. Examining current practices, the study underscores the influence of gamma irradiation on product quality, safety, and environmental sustainability. The study presents case studies that illustrate successful implementations of gamma irradiation technology across various sectors, highlighting its effectiveness. The abstract discusses collaborative efforts aimed at optimizing its utilization, addressing challenges, and exploring opportunities for future development. Overall, this research underscores the importance of advancing gamma irradiation applications to support industrial growth and sustainable development goals.

IAEA-CN-332/218

The Effects of Gamma-Irradiation on Shelf Life and Microbial Reduction of Fresh Chili (Capsicum Annuum)

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Food irradiation in Malaysia has emerged as a significant technology to enhance food safety and extend the shelf life of various food products. Regulatory support from international bodies like the International Atomic Energy Agency (IAEA) and Food and Agriculture Organization (FAO), along with Malaysian regulations, has facilitated the widespread acceptance and implementation of food irradiation. Food products that are essential for our lives rapidly deteriorate due to the presence of spoilage and pathogenic microorganisms within them. Chili (Capsicum annuum) is one of the world’s most popular vegetables and one of the most cultivated crops in Malaysia. In addition to its economic importance, it has high nutritional and medicinal values due to its high content of ascorbic acid, carotenoids, tocopherols, flavonoids, and capsaicinoids. However, the market value of chili is limited by post-harvest conditions due to its short shelf life. This situation has led to an increased need for a sustainable approach that employs safe methods to combat microbial infections and prolong the shelf life of chili during the post-harvest phase using gamma irradiation. The cleaned chili was divided into 5 groups (1, 7, 14, 21, 28 days) subjected to 0, 0.5, 1.0, 1.5 and 2.5 kGy of Cobalt-60 radiation. The microbial reduction was assessed using a total aerobic microbial count (TAMC) and a total yeast microbial count (TYMC) assay. From this study, it is expected that gamma-irradiation will be able to prolong the shelf life of fresh chili for more than 21 days. Assessments of microbial reduction will be evaluated, and the optimum dosage of Cobalt-60 radiation will be determined. These findings will surely contribute to better management of chili production, preservation, and sustainability in the future. As research and development continue, the future of food irradiation in Malaysia looks promising, with the potential to further enhance food security and sustainable agricultural practices.

IAEA-CN-332/220

PHITS Simulation for Gamma-Ray Laminography of Distillation Columns

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Gamma-ray column scanning is a non-destructive technique that uses gamma rays to inspect the internal structure of distillation columns, identifying defects and blockages. This method offers high penetration, accurate detection, and real-time results, making it ideal for industrial applications. Expanding on this concept, gamma-ray laminography provides detailed cross-sectional images by combining multiple gamma-ray projections. This advanced technique allows for more comprehensive analysis of complex structures. This study will used PHITS software to simulate the gamma-ray laminography of a distillation column for the purpose of obtaining 2D cross-sectional images. First, the column's geometry and material properties are modelled within PHITS. Gamma-ray sources and detectors are then positioned around the column to simulate multiple projection angles. The software calculates the interaction of gamma rays with the column, generating projection data. LabVIEW is used to reconstruct a 2D image from gamma-ray laminography data which involves several key steps. First, the gamma-ray projection data collected from the PHITS simulation is imported into LabVIEW. Next, a custom LabVIEW program is developed to process this data, applying algorithms such as filtered back projection to reconstruct the image. Finally, the reconstructed 2D image is displayed on the LabVIEW interface, allowing for detailed analysis and visualization of the distillation column's internal structure.

IAEA-CN-332/221

Physico-Chemical Properties of BNC and BNC-Diatomite Blends in Combination with Low Doses of γ-Irradiation

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The problem of recycling plastic packaging is becoming more acute every year, as it is produced in large quantities and has a significant impact on the environment. The development of sustainable and environmentally friendly materials to replace non-environmentally friendly synthetic polymers and fossil petroleum derivatives has become a major priority.

Cellulose is one of the biodegradable bio-compounds with high stiffness that can be used to increase the mechanical strength of biodegradable polymers. Due to its marvellous properties and wide range of applications, tremendous efforts have been made in recent years to develop a cost-effective manufacturing process for bacterial nanocellulose (BNC). The final shape and supramolecular structure of the BNC, which affect its functionality, flexibility, structural and mechanical properties, are mainly influenced by the bacterial species and the in situ and ex situ modifications of the BNC. In the in situ method, changing the composition of the culture media, the cultivation conditions and the addition of certain materials such as polymers or nanomaterials prior to the formation of the BNC can lead to the formation of BNC with improved physical, chemical and functional properties. The most commonly used and effective culture medium is Hestrin-Schramm, but its high cost limits the possibility of achieving high productivity in a large-scale production system. To overcome these problems, the investigation of alternative media for microbial cultivation as cheap and sustainable sources of carbon and nitrogen from agricultural residues is carried out. In this work, Hestrin-Schramm media and culture media produced from agricultural waste is compared. Furthermore, the influence of low irradiation doses on the BNC yield using the bacterial strain Gluconacetobacter xylinus is presented.

BNC blended ex situ with inorganic nanofiller such as diatomite improved interaction with the polymer matrix. The analysis of the physical and chemical properties of BNC is carried out using different characterization techniques: Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), scanning electron microscopy (SEM), differential scanning calorimetry (DSC).

We believe that this study can help turn biowaste into a value-added product for the production of nanocellulose. BNC and diatomaceous earth composites are expected to have the potential to serve as sustainable packaging materials with desirable properties such as mechanical strength, thermal stability and barrier properties.

IAEA-CN-332/233

An Airborne Platform for the Surveying of Natural Radionuclides in Geological and Environmental Applications

R. le Roux (Stellenbosch University)

Radionuclides in sediment are naturally occurring radioactive isotopes with primordial origins, dating back to the formation of the Earth. Common radionuclides include uranium-238, thorium-232, and potassium-40. These primordial isotopes are released through the weathering and erosion of rocks and minerals, eventually transported and deposited in sediments via fluvial, aeolian, and marine processes. Their presence provides valuable information about sediment provenance, transport pathways, and the geological history of an area.

Measuring and mapping natural radionuclides in an area is essential in understanding the geological history and evolution of a region by providing insights into the origin and movement of sediments. Natural radionuclides can also serve as tracers for studying sediment transport processes and rates, which are important for managing erosion and sedimentation.

This work presents the development and use of an airborne platform for measuring and mapping natural radionuclides in geological and environmental applications. It represents a significant advancement in geophysical surveying and environmental monitoring and enables the rapid and extensive collection of radiometric data over large and inaccessible areas. The system facilitates the creation of detailed radiometric maps that reveal the distribution and concentration of radionuclides. Examples of these maps are also presented.

IAEA-CN-332/244

Strategies to Build an Inclusive Participation and Involvement of Women for Their Professional Career Growth and Advancement: A Case for the Ghana Atomic Energy Commission

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Background of the Study: The contributions by female scientists to nuclear science and technology and the nuclear industry is widely known. However, the nuclear industry is still male dominated with women underrepresented and consisting fewer than a quarter of the workforce in the industry worldwide. The underrepresentation of women in leadership roles of an organization is noted to affect the organizational culture, innovation capabilities, and overall performance. Research has consistently shown that diverse teams, including those with a good representation of women in leadership, are more innovative, productive, and better equipped to tackle complex challenges. The Ghana Atomic Energy Commission (GAEC) is a public service organization established in 1963 to promote peaceful application of nuclear and allied techniques for the socioeconomic development of Ghana. Women in leadership positions at GAEC currently is less than 20%; an all-time low since the establishment of the institution. To address the issue of underrepresentation of women in leadership positions, the Ghana Atomic Energy Commission has taken steps to institute some measures and strategies to enhance women's participation, career growth, and advancement within the organization.

Methodology: Through a series of one-on-one interviews, focus group discussions and administration of questionnaires, baseline information will be obtained, which when analyzed, will indicate empirically the existing challenges to women professional advancement at GAEC.

Results: The study’s outcome will be the basis for the proposal of effective solutions, development of actionable policies, establishment of mentorship programmes and the creation of a more inclusive and supportive work environment for women in the organization to thrive. In this report, strategies and efforts being employed to build an inclusive participation and involvement of women for their professional career growth and advancement at the Ghana Atomic Energy Commission will be presented. Key points of these strategies and their expected outcomes will also be highlighted.

Conclusion: Since underrepresentation of women in the nuclear industry is a global problem, it is hoped that the outcome of this report and presentation will be beneficial to other nuclear institutions facing similar challenges, and who are intent on addressing the United Nations Sustainable Development Goal 5 on Gender Equality.

IAEA-CN-332/252

Comparison of Gamma and Electron Beam Irradiation for the Increased Production of D-Mannose from Spent Coconut Kernel

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The coconut industry generates significant quantities of agro-industrial residues. These residues are known to contain valuable compounds such as D-mannose, renowned for its diverse industrial applications in the food, pharmaceuticals, and poultry industries. In this study, we explored the comparative effects of gamma-ray and electron-beam radiation, alongside varying dose levels (0, 5, 10, 20, 50, 100 kGy), on the extractability of D-mannose from spent coconut kernel (SCK), using various analytical techniques (TLC, HPLC-UV, FT-IR). Results revealed a significant increase in the extraction of mannan-containing compounds from irradiated SCK ($p<0.05$). Notably, electron beam irradiation emerged as the optimal method for enhancing the extractability yield. These findings underscore the potential of SCK as a sustainable source of high-value bioactive natural products. Enhancing the utilization and valorization of abundant agro-industrial residues highlights the broader significance of this research in addressing the negative economic and environmental impacts of postharvest losses, as well as the generation of new production systems that promote sustainable competency in agriculture towards a more globally competitive and circular economy.

IAEA-CN-332/253

Ionizing Radiation Effects on Natural Rubber and Silicone Rubber Used in Medical Devices and Applications

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Polymers are extensively utilized in medical devices, implants, and drug delivery systems due to their lightweight nature and resistance to sterilization processes, making them economically advantageous. A significant percentage of single-use polymer-based medical devices worldwide are sterilized using ionizing radiation through two common methods: gamma irradiation with cobalt-60 radioisotope, and electron beam irradiation using an electron accelerator or X-rays. However, gamma irradiation presents challenges related to safety, transportation, supply, and disposal of the cobalt-60 source.

This study aims to compare the effects of gamma and electron beam irradiation at various doses and dose rates on natural rubber (NR) and silicone rubber (SR), both commonly used in medical applications. Initially, vulcanization conditions were optimized using a moving die rheometer (MDR). The NR and SR test samples were then subjected to gamma irradiation at two dose rates: High Dose Rate (HD) of 213 Gy/h and Low Dose Rate (LD) of 18 Gy/h, across six doses (10, 20, 30, 40, 60, and 80 kGy). Electron beam irradiation was conducted at a single dose rate (1 kGy/s) with doses of 10, 20, 30, 40, 60, 80, and 120 kGy. For both irradiation methods, the swelling ratio, gel fraction, and crosslink density were measured for both irradiated and non-irradiated NR and SR samples. Structural, mechanical, thermal, dynamic-mechanical, and morphological properties were analyzed using a Universal Testing Machine, FTIR, TGA, DSC, DMA, and SEM.

The study revealed changes in mechanical properties due to concurrent and competitive crosslinking and chain scission reactions as irradiation doses increased for both types of rubber and irradiation methods. It was concluded that the standard 25 kGy sterilization dose did not result in significant differences between gamma and electron beam irradiation for either type of rubber.

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IAEA-CN-332/255

Validation of the Installation and Operational Qualification of the 2.5 MeV Electron Beam Irradiation Facility of the DOST-Philippine Nuclear Research Institute

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The 2.5 MeV Electron Beam Irradiation Facility of DOST-Philippine Nuclear Research Institute has been operational since 2014. Before commencing operations, installation qualification (IQ) and operational qualification (OQ) experiments were conducted to determine the main characteristics of the facility and evaluate its capability to deliver specified, controllable doses reproducibly. The relationship between absorbed dose and key parameters, such as beam energy, beam current, beam width, and conveyor speed were established. Following major repairs in 2022, IQ and OQ experiments were repeated to verify that the accelerator could still operate effectively and deliver appropriate doses within defined acceptance criteria. Depth-dose distribution measurements using aluminum wedge and stack technique were performed to determine beam energy. Measurements of beam width and length at different distances from the scanner, dose uniformity in scanning and traveling directions, and the dependence of surface dose on product height were also conducted. Using materials like polystyrene, polylactic acid, and cardboard sheets, the experiments established dose distribution, edge effect, surface dose as a function of beam current and conveyor speed, and irradiation reproducibility. CTA and B3 WINdose dosimetry systems were used for dose measurements. The results confirmed that the accelerator can accurately deliver specified, controllable doses in a reproducible manner.

IAEA-CN-332/263

X-Ray Radiation-Induced Surface Modification of Polypropylene via RAFT-Mediated Graft Polymerization Glycidyl Methacrylate

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In this study, x-ray irradiation was used to assess its applicability in surface modification via the reversible addition fragmentation chain transfer (RAFT)-mediated radiation-induced graft polymerization (RIGP). Previously, gamma and electron beam (EB) were used for the graft polymerization of glycidyl methacrylate (GMA) on the surface of polypropylene (PP) fabric, but this time, x-ray irradiation was used. After subjecting the samples to x-ray irradiation (varying dose and monomer concentration), the resulting grafted material, (PP-g-PGMA) was weighed for determination of degree of grafting (Dg) and was also subjected to further characterizations. Obtained Dg ranges from 2-17% and depends on the grafting conditions. An increase in the monomer concentration results to an increase in Dg which is a similar trend when using gamma or EB irradiation. On the other hand, varying the absorbed dose does not affect the Dg. Irradiated samples with RAFT agent exhibit a more efficient grafting than those samples without RAFT due to the reduction of irreversible termination. The characterizations such as FTIR, XPS, XRD, SEM and GPC gave results that strongly supports the successful grafting as well as the characterization of the polymers formed. These results showed the possible use of x-ray for surface modification through RAFT-mediated RIGP.

IAEA-CN-332/265

Comparative Effects of Gamma Rays, Low Energy Electron Beam and High Energy Electron Beam on Microbial Quality of Cloves (Syzygium Aromaticum)

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The study compared the effects of gamma rays, low energy electron beam (LEEB), and high energy electron beam (HEEB) on microbial quality of cloves. Whole cloves were purchased from a local market in Accra, Ghana, and packaged in zip-lock bags. Samples were exposed to irradiation doses of 2, 4, 6, 8, and 10 kGy, using Gamma Chamber 5000 Co-60 source, ILU-6 accelerator (250 keV), and ELEKTRONIKA 10-10 accelerator (9 MeV). Un-irradiated cloves served as control. Standard pour plate procedures were adopted to analyse the samples for indicator and index organisms and for pathogens such the total viable counts (TVC), total coliforms (TC), Staphylococcus aureus, Escherichia coli, Bacillus cereus, Salmonella spp., and yeast and mould counts. The control sample had low microbial counts of 2.44log cfu/g. Irradiation significantly reduced TVC from 2.44log cfu/g in the control to below detection limit in all the samples irradiated at 8 kGy. Gamma irradiation at 2 kGy inactivated all faecal coliforms and Bacillus cereus in the samples. S. aureus in the samples exposed to LEEB were only inactivated completely at 8 kGy. Though gamma rays and HEEB were most effective in decontaminating the clove samples, LEEB has potential for surface decontamination of cloves.

Key words: Cloves, Electron beams, Food safety, Gamma rays, Microbial load

IAEA-CN-332/318

Preparation of a Radiation Grafted Proton Exchange Membrane from ETFE Film for Fuel Cell

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Gamma radiation grafting of acrylonitrile (AN) and sodium styrene sulfonate (SSS) on ethylenete trafluroethylene (ETFE) were investigated. Grafting was carried out at 50kGy and reaction time was 4h at 80°C. Monomer solutions with different monomer ratio (AN: SSS = 1:1, 2:1, 3:1, 4:1, 5:1, 6:1, 7:1 and 8:1) in water were used to optimize degree of grafting. Degree of grafting was 25% for AN:SSS= 8:1. The grafted films were amidoximated by treatment with hydroxylamine hydrochloride at 80°C for 4h. Amidoximation varied with degree of grafting. The prepared membranes were characterized with FTIR and SEM analysis. Ion exchange capacity of the amidoximated films reached 0.6 mmol/g for 12 % amidoximation. The water uptake capacity of the membranes were determined at different temperature (60°C, 80°C, 100°C) as a function of soaking time (1−24 h). Water uptake for 12% amidoximated sample were 4.2 % at 100°C for 24 h soaking time. Oxidative stability of the membrane was investigated for different H2O2 concentration (0.01M, 0.02M, 0.05M) at 80°C. Sample with 12% amidoximation showed weight loss of 1.5 % at H2O2 concentration 0.005 M and soaking time 24 h. The tensile strength of the pristine ETFE and amidoximated ETFE were 60MPa and 54 MPa respectively. Proton conductivity of the amidoximated membrane was found to be 0.06 S cm-1 (RH=100%, Temp=30°C). The results indicate the amidoximated membrane prepared from AN and SSS have good prospect as fuel cell membrane.

IAEA-CN-332/341

Monitoring Program for Detection of Irradiated Food as a Tool for Raising Consumers' Awareness and Promoting Trading

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In order to enforce correct labeling and to detect non-authorized products, monitoring of irradiated food is an essential tool.The national monitoring program of irradiated food was realized by the Radiation Physics Laboratory RAD-LAB in Skopje, as the only laboratory in the country for detection of irradiated food that has an EN 17025 accreditation. The protocol for implementation of the monitoring program ensures maximum accuracy of the results.This monitoring programbegan as a tool for full implementation of the Law on Food Safetyand Rulebook on special requirements for food produced by ionizing radiation, which has harmonized national legislation with European Directives.

Collection of randomized samples from the market is performed by authorized inspectors. Hundreds of samples were tested in the frame of the monitoring program, in the period from 2018 to 2020.The total distribution of products is 62 % spices, 9 % seasonings and 29 % dried herbs.

Samples were tested with two standard testing methods for detection of irradiated food – photostimulated luminescence (PSL) and thermoluminescence (TL). All samples were first tested with PSL, while 17.85% were additionally tested with TL.

In this monitoring program, 6.43% of the tested samples have indications that they have been treated with ionizing radiation, 92.86 % of the tested samples have no indications that they have been treated with ionizing radiation, while 0.71%cannot be identified as irradiated or unirradiated.Approximately half (55.56%) of the samples identified as irradiated were labeled with the international label "Radura", which is used for labeling irradiated food according to the General Standard for Labeling of Food Packaging - Standard for the Labeling of Prepackaged Foods CODEX STAN 1-1985 of FAO and WHO. However, this symbol is not accepted by national and European regulations. All samples marked with "Radura" belong to the group of spices. There were also 3.85% labeled with "Radura", but there are no indications that they have been treated with ionizing radiation. A total of 10% are non compliant samples, i.e. samples that do not meet the requirements.

In addition to the government's commitment to following and implementing EU directives, this monitoring program is important to protect consumers and their rights and to help companies to follow the rules and their implementation and to promote trading of this kind of food.

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Fabrication of Wood Plastic Composite from Sawdust and Recycled Polymer Wastes: Gamma Irradiation Effect

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As Background

This study focuses on the fabrication of Wood Plastic Composite (WPC) from sawdust (SD) and recycled low-density polyethylene (rLDPE) waste using gamma irradiation. Recycling thermoplastics with natural polymers offers an eco-friendly alternative that conserves natural resources, reduces waste, and lowers material costs. Sawdust, a byproduct of the wood industry, poses environmental challenges, while post-consumer LDPE is a significant component of global municipal waste, necessitating effective recycling solutions. Gamma Irradiation can enhance the polymer bonding.

Methodology

Sawdust was sourced from local sawmills in Yangon. Sawdust was screened to remove the impurities and then dried in an oven at 60 C for 24 hrs to reduce the moisture content. rLDPE flakes were obtained from the recycled plastic market. rLDPE were ground and sieved using a 500 μm mesh to remove oversized particles. The power was dried in an oven at 60°C for 24 hours to eliminate moisture. Both the raw sawdust and PE powder were irradiated in a Gamma Chamber 5000 at a dose rate of approximately 500 Gy/hr to achieve the required dose. A 1:1 mixture of 150 g of irradiated sawdust and rLDPE powder was homogenized and hot pressing into WPC boards at 160°C. The physical and mechanical properties of these boards were then evaluated.

Results

Gamma irradiation significantly improved the physical and mechanical properties of the WPC. Bending strength increased from 3455 psi at 0 kGy to 15503 psi at 30 kGy as shown in Figure 1. Water and oil absorption decreased notably with increased irradiation, indicating enhanced interfacial bonding and material performance. The results of this results are shown in Table 1.

Figure 1: Bar chart for Bending Strength of WPC

Table 1: Result for Physical and Mechanical Properties on fabrication of WPC through Irradiation

Dose (kGy) Physical properties Mechanical Properties

Water absorption (WA) Oil absorption (OA) Densities (g/cm3) Hardness Impact Strength (kJ/m2)

0 kGy 27.531 14.631 0.809 93.75 12.7

10 kGy 1.857 0.424 1.098 95.05 11.8

20 kGy 0.975 0.386 0.959 93.75 14.4

30 kGy 0.564 0.309 1.062 91.75 16.15

Conclusion

Gamma irradiation effectively enhances the properties of WPC made from waste SD and rLDPE. The findings suggest a promising method for producing high-performance, eco-friendly composites.

Ongoing research aims to optimize the irradiation dose and the ratio of SD to rLDPE for optimal material properties.

Key Words: Wood plastic composites, Saw dust, recycled LDPE, Gamma irradiation, Hot pressing

IAEA-CN-332/396

Recycling of Cross-Linked Material from Cable Industry by Ionizing Radiation

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As economies continue to grow and develop, solid waste disposal has become an increasingly serious problem. Since ionizing radiation is able to change the structure and properties of polymer and it is applicable to almost all types of polymers, radiation holds great promise for solving the polymer waste problem. Of particular interest is the problem of recycling cross-linked materials. Since radiation cross-linked cables have improved properties compared to conventionally manufactured cables, the production of radiation cross-linked cables is expected to increase. This will generate large amounts of polymer waste. In cable recycling, only copper is extracted, while the polymer insulation is landfilled or incinerated. Therefore, there is a need to develop technologies for the reuse of this waste.

The aim of this work was to determine the possible consequences of radiation treatment for cross-linking new materials containing cross-linked recycled material from the cable industry as filler. From the polymers conventionally used for the manufacture of cables, two polymers were selected: ethylene vinyl acetate (EVA) and ethylene propylene diene terpolymer (EPDM). Mixtures containing 5%, 25% and 50% simulated recycled material were produced. The samples were exposed to a high energy electron beam produced by the Electronika 10/10 accelerator. Recyclate was added in the form of granules and powder.

The addition of the recycled material (EVA) does not have a significant impact on the stress at break, however, a significant decrease in the elongation at break is observed. The stress at the break of all samples increased significantly after irradiation, this increase was independent of the amount of recycled material that was contained in the simulation. The EPDM samples that contain 5% of recycled material, after being irradiated have a higher stress at failure, compared to the sample that lacks recycled material and having comparable values of break stress and Young's modulus. The addition of recyclate in the form of powder did not significantly affect the mechanical properties of the samples. No significant changes in the thermal properties of the samples were observed for samples with different amounts of recycled material, before and after the process of compatibility.

IAEA-CN-332/421

Technical Cooperation: Contributions of the IAEA in Latin America and the Caribbean for the Recycling of Synthetic and Natural Polymers

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In 2022, the regional project RLA1020 was launched: Promotion of Radiation Technology in Natural and Synthetic Polymers for the Development of New Products, with Emphasis on Waste Recovery. Eleven participating countries collaborated to mitigate the environmental impact of natural and synthetic polymer waste through irradiation techniques.

Through training and development initiatives, partnerships with the productive sector are fostered to create value-added products from polymer waste. This effort aims to enhance scientific and technological transfer and increase the demand for irradiation services across the region. Regional strategies promote integration, cooperation, harmonization of efforts, and establish a productive and technological foundation for sustainable development.

Examples of developments include antimicrobial materials, construction components, railway sleepers, and the utilization of feathers, among others, using the TRL method and tools such as EBEAM. Many of these initiatives are linked to the NUTEC Plastics initiative. Several countries are currently conducting technical and economic feasibility studies to support the establishment of polymer recycling plants based on radiation technologies.

IAEA-CN-332/463

Shunt Impedance Measurement of a 6 MeV Standing Wave E-Linac

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The shunt impedance of accelerating tubes is an important parameter. It determines how effectively the accelerator can convert supplied RF power to an accelerating gradient. The shunt impedance of the RF accelerator tubes is measured using the perturbation technique. The shunt impedance is calculated after plotting the electric field profile using a bead pull measurement. The calculation is done using a Matlab program which first calculates the plot area and then uses appropriate variables to give the final value of the shunt impedance. This paper describes the method and calculation of the shunt impedance of a 6 MeV standing-wave tube that operates in π /2 mode at the frequency of 2998.5 MHz. At the $\pi/2$ mode frequency of 2998.5 MHz, the value measured of the effective shunt impedance of the aluminum tube was achieved, 83.25 MΩ/m. They are also compared with the results simulated by a 3D eigensolver obtaining a good agreement.

IAEA-CN-332/488

Enhancing Methane Production from Municipal Sewage Waste through Electron Beam Technology

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Managing industrial, agricultural, and municipal waste is a global challenge. Rapid urbanization and increasing population demands necessitate sustainable waste management technologies. Waste recycling allows for extracting value from waste, a process known as waste valorization. This involves converting waste materials into higher-value products, such as quality chemicals, fertilizers, fuel, energy, and economically beneficial products. Public opinion and regulatory concerns are driving the treatment of wastewater plant residuals into value-added products. Ionizing technologies, with their diverse capabilities, can significantly contribute to valorizing municipal sewage waste streams. To explore these opportunities, a virtual US-India Technical Cooperation Exchange titled "Applicability of Ionizing Technologies and Advanced Materials for Environmental Remediation" was held on November 18, 2021, between scientists from the National Center for Electron Beam Research (NCEBR) in Texas and the Bhabha Atomic Research Centre (BARC) in Mumbai. A critical gap identified was the need for empirical data on methane generation from sludge at varying doses. Laboratory experiments at NCEBR evaluated the impact of pre-treating sewage sludge with electron beam (eBeam) technology before mesophilic anaerobic digestion. Electron beam doses of 5 kGy and 10 kGy were tested for their effects on the sludge's physical properties, chemical composition, and methane generation. The study utilized sludge samples at 3% solids content. At a 10 kGy dose, there was a notable change in the sludge's physical properties, with sludge flocs breaking down and viscosity reducing by 47% and 52% at 5 kGy and 10 kGy, respectively, compared to the untreated control. Methane production increased on day eight by 30% and 53% at 5 kGy and 10 kGy, respectively. Additionally, a 10 kGy eBeam dose significantly reduced microbial pathogens. These findings demonstrate that eBeam technology is an effective method for valorizing municipal sewage sludges, offering advantages over cobalt-60-based gamma technology.

IAEA-CN-332/466

Planned Destruction of PFAS in Soils and Sediments using a Mobile Electron Beam Technology Platform

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Since the 1970s, aqueous film-forming foams (AFFFs) have been used at U.S. Department of Defense (DOD) installations for firefighter training and emergency response. Per- and polyfluoroalkyl substances (PFAS) used as active ingredients in AFFF have impacted underlying soil and groundwater. Other than offsite incineration as the remediation technology, very few destructive treatment technologies are currently available to treat PFAS in soil and sediments. We are proposing a compact mobile electron beam (eBeam) technology platform for demonstrating effective and innovative PFAS destructive technology. The overall goal is to design, fabricate, integrate, and demonstrate a prototype mobile eBeam technology platform. The mobile system will be designed to focus on solids and slurries, and liquids. The mobile system will be designed with all the necessary critical safety requirements including shielding and ozone abatement. The accelerator energy will allow for self-shielding with the beam power optimized to meet the target throughput of up to one drum of PFAS-impacted solids per day. The mobile platform's weight will be configured to meet the US Department of Transportation (DOT) requirements. The electrical power source will designed to support both grid power and electrical generators. The mobile platform will be designed to operate indoors or outdoors. The presentation will discuss the accelerator, shielding, and material handling system.

IAEA-CN-332/738

Effects of Doping- Rare Earth and High Energy Irradiation on Silicon Carbide in Nuclear and Advanced Application

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The progress in SMR technology and accidental tolerance capable TRISO TRi-structural ISOtropic) fuel, designed for high-temperature reactors, includes multiple layers that encapsulate the fissile material. The termost layer, typically made of SiC, acts as the primary barrier against the release of fission products. A highly explored area for optimizing commercial nuclear fuel efficiency is managing the Kr/Xe fission gas budget, as these gases act as time limiters due to thermal fission gas swelling or nucleating high swelling behaviour (HSB) structures' expansion. This investigates the potential benefits of doping this SiC layer with rare earth elements to improve its performance within the TRISO fuel structure as well as for long storage -stability. An alternative approach involves introducing these gases along with other reactive evaporation products such as H, He, Sr, and Li into the grain or sub-grain. This is done to form the HSB or rim structures, followed by MeV Ar+ high energy irradiation. Such studies are critical for better understanding the behaviour of SiC and SiC(x)ReO(x-1) under these conditions. Pre-irradiation and post-irradiation examination are understood and studied via characterization techniques like RBS, FESEM, XRD and TEM techniques.

IAEA-CN-332/056

Development of AMP-PAN Based Composite for Cesium Speciation in Aqueous Media

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134Cs, 135Cs and 137Cs radioisotopes are released during nuclear fission. They have high radioactivity and active environmental mobility. Because it has a relatively low boiling point, when released at high temperature, Cesium radioisotopes easily volatilize in the atmosphere and are transported transboundry through the air, posing health risk.

The scope of this study is the radiation assisted synthesis of AMP-PAN composite using ammonium molybdenum phosphate (AMP) and acrylonitrile (AN) based components and to remove cesium radioisotopes in different environments. Both structures in the AMP-PAN composite maintain their durability in harsh acidic environments and in the presence of high radiation (nuclear accidents). Long-step radiochemical separation method is used in gamma spectroscopic analysis of cesium isotopes. It also is aimed to replace from radiochemical separation method to chromatographic column seperation using AMP-PAN composite.

AMP-PAN composites were synthesized by irradiating mixtures containing AMP and AN in different weight percentages at a dose of 5 kGy. FTIR, XPS, Thermal analysis (DTA-TGA) analyzes were used in the characterization of the synthesized composite materials.

As a result of the characterization studies, it was observed that the composite containing 6% AMP by weight demonstrated a higher tendency to form polymer-metal composites. Additionally, the thermal stability of the synthesized AMP-PAN composite materials was evaluated by TGA analysis. As a result of the analysis, AMP-PAN composites were stable up to 300 °C with approximately 10% weight loss, and AMP enhanced the thermal stability of PAN in which it was incorporated into its structure. It was determined that it increased its stability and the highest stability was found to contain 6% AMP by weight.

The interaction of AMP with the polymeric component in the composite structure was evaluated with XPS and the change depending on the amount of AMP was examined.

Determination of Cs+ adsorption capacity of AMP-PAN composites was performed with AAS. It was determined to be 0.6% - 23%, 1% - 32%, 1.5% - 33%, 3% - 43%, % 4.5 - 72%, 6% - 85% (AMP-PAN% - adsorption%), respectively. To better understanding of Cs+ ion selectivity of the composite, the mixture of ions (Li, Be, B, Sc, V, Cr, Mn, Co, Ni, Cu, Zn, Sr, Sb, Cs, Ba, La, Eu, Ho, Yb, Tl Pb, Th, U, As, Se(77)-Se(78)) was flown through the chromatographic column filled with the highest adsorption capacity composite and analyzed by HR-ICP-MS. It was observed that Cs+ ions was adsorbed with the capacity of 85%, and other ions, except Tl ion, passed through the column without adsorption.

In order to determine the performance of the composite in gamma spectroscopic analyzes for separating Cs radioisotopes from marine water, marine water containing active Cs radioisotopes was passed through the chromatographic column filled with composite and the activity of Cs radioisotopes was measured by Gamma Spectroscopy.

As a result of the study, a promising result was obtained in the adsorption of Cs+ ions onto the AMP-PAN composite synthesized using radiation technology and in the removing of radioactive Cs radioisotopes leackage from environment.

IAEA-CN-332/178

Radiation Crosslinking of Stearic Acid Monolayers on Vaterite: Towards Effective Drug Delivery Systems

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Vaterite, a metastable polymorph of CaCO3, is distinguished by its small size, biocompatibility and large specific surface area, making it a promising system for inorganic drug delivery. When a drug-loaded vaterite system is sealed within its pores by a biocompatible coating, the release of the drug can be delayed and/or controlled. Biocompatible fatty acids exhibit the ability to form organized monolayers on the surface of vaterite. During exposure to ionizing radiation, a monolayer of fatty acids further stabilizes by crosslinking them into thin biocompatible polymer coatings that could further delay the release of absorbed drug molecules.

This study investigated the conditions for forming a monolayer of stearic acid on the surface of vaterite and its radiation crosslinking, as well as the properties of the resulting material. In addition, vaterite was loaded with two different dyes, calcein and rhodamine B, to mimic the drug molecules. The release of the dyes from the vaterite particles was investigated in simulated body fluids (Hanks' solution).

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IAEA-CN-332/241

Electron Beam Grafting of Modifiable Ionic Liquid Adsorbents and Their Adsorption of Uranyl Ions

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The enrichment and recovery of uranium from seawater or acidic wastewater are crucial for the nuclear fuel industry, necessitating efficient and cost-effective adsorbents. Electron beam (EB) irradiation-induced solid-liquid grafting is an emerging, green, and efficient method. In this study, a novel vinyl ionic liquid was synthesized using vinyl imidazole and propyl-1,3-sultone as raw materials. This ionic liquid was grafted onto silicon-based materials via a thiol-ene click reaction induced by a 10 MeV electron beam. Chelating fragments were further modified onto the ionic liquid using Michael addition, resulting in the e-HMS@IL series of adsorbents. Benefiting from the high grafting efficiency of electron beam irradiation and the hydrophilicity and zwitterionic structure of the ionic liquid, the adsorbent achieved a maximum UO22+ adsorption capacity of 185.9 mg/g. It demonstrated optimal adsorption performance within a pH range of 3-13 and remained reusable for over five cycles. The EB-graft method is cost-effective, completing the grafting process within seconds, and the resulting ionic liquid adsorbents are amenable to further modifications. This study provides a novel approach for the preparation of new adsorbents.

IAEA-CN-332/376

Enhancing Hydrophilicity and Hydrophobicity of Polyethylene Hollow Fiber Membranes through Electron Beam Modification

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This work focuses on enhancing the hydrophilicity and hydrophobicity of polyethylene (PE) hollow fiber membranes. The modification was performed by immersing the PE hollow fiber membrane into an aqueous solution of functional molecules, followed by electron beam (e-beam) irradiation. Four different hydrophilic components—2-hydroxypropyl acrylate, ethylene glycol diacrylate, polyvinylpyrrolidone-3.5K, and poly (ethylene glycol)-3.350—were used to increase hydrophilicity. Conversely, two hydrophobic reagents—octadecyl acrylate and 2-ethylhexyl acrylate—were used to enhance hydrophobicity. For comparison, membrane samples were irradiated under wet and dry conditions without the presence of hydrophilic or hydrophobic polymers. Permeation tests were conducted for water filtration to compare the flux of modified and unmodified membranes. Hydrophilic grafting resulted in an increased flux, while the reference module showed the lowest flux value. Due to challenges in using water contact angle measurements for assessing the hydrophobic and hydrophilic effects on PE hollow fiber membranes, liquid entry pressure (LEP) tests were employed instead. The LEP method indicated that the untreated membrane was quite hydrophobic at the highest pressure tested. In contrast, hydrophilic modification resulted in lower pressure at the membrane surface, indicating improved water wettability. Hydrophobic modifications approached the levels observed in the reference membranes but did not exhibit as much hydrophobicity as the reference module. After determining the optimal dosages and concentrations, further characterization experiments were conducted. These included scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), porosimetry, tensile testing, and zeta potential analysis.

Keywords

Polyethylene hollow fiber membranes, Radiation-induced grafting.

IAEA-CN-332/378

Gamma Radiation Induced Synthesis and Stabilization of Silver Nanoparticles: With Special Reference to Textile Applications

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At present, silver nanoparticles (AgNP) modified raw materials have been utilized by the textile industry and their products are readily available in the market as antibacterial clothing. The current research was designed to investigate the gamma radiation induced synthesis of AgNP and their stability on radiation grafted polyester fabric. Range of monomers including Acrylic Acid, Styrene, Methyl Methacrylate and Vinyl Acetate were grafted onto recycled polyester fabric, followed by AgNP synthesis via reduction of silver ions. Both steps were performed under N2 atmosphere, at 15 kGy radiation dose and utilizing aqueous solution of AgNO3 as silver ion source. Possibility of merging the two steps into a single simultaneous irradiation process also been experimented. Grafting reaction was evaluated by Fourier-Transform Infrared (FT-IR) spectroscopy, while existence of AgNP on the fabric was confirmed by X-Ray Fluorescence (XRF) spectroscopy. UV-Visible spectrophotometric analysis and Particle Size analysis were conducted to supernatant solution from the synthesis, in order to identify the Surface Plasmon Resonance (SPR) band and the particle size distribution of AgNP respectively. Surface morphology of the fabric was examined by Scanning Electron Microscopy (SEM) and crystalline structure of AgNP was confirmed by X-Ray Diffraction (XRD) studies. The experimental results demonstrated successful modification of polyester fabric with AgNP by the gamma irradiation process.

Keywords: gamma radiation, silver nanoparticles, textile, polyester, grafting

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Gamma Irradiation-Induced Structural Modification of Flavonoids: Enhancing Physiological Activity and Water Solubility for Novel Drug Discovery

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Flavonoids are plant-derived natural compounds with notable antioxidant and anti-inflammatory properties, making them promising pharmaceutical candidates. However, their poor bioavailability limits their therapeutic applications. This study investigated the potential of gamma irradiation to modify flavonoid structures and improve their physicochemical and biological properties. Gamma irradiation successfully induced structural modifications in several flavonoids, including chrysin, genistein, biochanin A, and luteolin. When chrysin was dissolved in methanol and exposed to gamma irradiation, hydroxyethylation occurred at the C4 position, producing a derivative (CM1) with significantly enhanced anti-inflammatory efficacy and water solubility, showing superior therapeutic effects in a colitis mouse model. Additionally, hydroxymethoxylation at the C8 position (CM2) disrupted the C=O double bond and conferred immunotolerance-inducing properties not present in the original chrysin. Similarly, gamma irradiation of genistein and biochanin A in ethanol led to the addition of hydroxyethyl groups, resulting in derivatives with improved antioxidant activities. In the case of luteolin, gamma irradiation in methanol introduced a hydroxymethyl group, enhancing its whitening effect and yielding a novel compound, GLM, with immunotolerance-inducing properties. These findings suggest that gamma irradiation is a powerful tool for the molecular modification of flavonoids, overcoming solubility and bioavailability challenges while enhancing biological efficacy. Collectively, this approach holds significant potential for the discovery and development of novel drug candidates in the pharmaceutical industry.

Keywords: Gamma irradiation, Drug discovery, Radical reaction, Flavonoid

IAEA-CN-332/417

The Effect of Composition and Ionizing Radiation on Starch-PVA-Alginate and starch-PVA-alginate-crystalline nanocellulose Films

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Key Words: ionization radiation, Starch, PVA, Alginate

Biopolymer films derived from renewable resources are crucial for sustainable packaging and biomedical applications. This study examines the impact of composition and ionizing radiation on the physicochemical properties of starch-polyvinyl alcohol (PVA)-alginate-crystalline nanocellulose (CNC) films of two different starches; native wheat starch and pre-irradiated corn starch. Films were prepared using solvent casting, with varying starch-PVA ratios (45:50 to 45:40), incorporating alginate in proportions of 5%, 10% and 15%, CNC at the level of 0%, 1% or 2%, and glycerol (20% or 30%). The films were irradiated using electron beam and gamma rays at doses of 5, 10, and 15 kGy.

Results showed that CNC addition improved elongation at break but reduced tensile strength. The 1% CNC formulation showed the best tensile strength (9-12MPa), while 2% CNC had the best elongation at break (up to 400%). Films with 5% alginate and 20% glycerol showed the lowest swelling capacity, whereas those with 15% alginate reveal much higher swelling than the others. The contact angles were consistent across all systems.

Irradiation induces beneficial increase in elongation at break, and in contact angle with decrease in swelling capacity. Wheat starch systems had higher gel content (showing higher crosslinking) than corn starch systems, with radiation decreasing gel content due to degradation.

In summary, the selected films formed in the examine systems indicated good properties that can be additionally improved by radiation treatment. Pre-irradiated corn starch outperformed native wheat starch. The films with 1 % CNC reveal better properties as compared to the other ones. This highlights the potential of pre-irradiated corn starch, alginate, and CNC to optimize biopolymer films for packaging application.

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IAEA-CN-332/016

Assessment of Radioactivity, Potentially Toxic Elements and Human Health Risks in the Most Consumed Staple Food in the Republic of Congo

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Natural and artificial radioactivity, potential toxic elements (PTEs) and associated heath risk in the most consumed staple in the Republic of Congo have been investigated in the prospective phosphate mining area of Hinda district. HPGe gamma spectrometer and atomic absorption spectrometry were used to analyze the levels of radionuclides and heavy metals, respectively. The mean activity concentrations of the radionuclides were found to be 57.43 ± 0.40 Bq/kg, 12.86 ± 0.19 Bq/kg, 15.16 ± 0.34 Bq/kg, 2.00 ± 0.78 Bq/kg, 493.13 ± 15.21 Bq/kg and 1.62 ± 0.06 Bq/kg in cassava roots and 22.55 ± 0.11 Bq/kg, 1.640 ± 0.004 Bq/kg, 5.44 ± 0.01 Bq/kg, 4.32 ± 1.20 Bq/kg, 62.22 ± 0.10 Bq/kg and 0.52 ± 0.25 Bq/kg in cassava leaves for 210Pb, 226Ra, 228Ra, 228Th, 40K and 137Cs, respectively. The mean concentrations of the heavy metals decreased in the following order Pb > Cu > Cd. The mean concentrations of both radionuclides and PTEs, except for Cu, exceeded recommended limits. The radiological annual effective dose to the age groups, infants (0-1 year), children (2-10 year) and adults (> 40 year) was determined including the cancer risk. The result shows all values below 10-4, indicating no population morbidity is expected due to the consumption of cassava roots and cassava leaves in the present study area. The average daily dose and hazard quotient showed that Pb is the major threat to all age-groups. The hazard index revealed that children are more liable to non-cancer effects through oral intake.

Keywords: Natural and artificial radionuclides, potentially toxic elements, Human health risk, Hinda district, Republic of Congo.

IAEA-CN-332/192

Synergistic Effects of γ-Irradiation and Zeolite Catalyst for Improving Pyrolysis Process of Polypropylene

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Polypropylene (PP) is one of the most commonly used polymers for many applications worldwide because of its high chemical resistance and low cost. However, PP waste disposal has substantial negative influences on the environment. Nowadays, thermal decomposition methods, such as pyrolysis, are gaining attention to reduce the number of PP plastic wastes and produce good quality pyrolysis liquid oil and solid char to be used in fuel applications. Various methods, including the use of catalysts, have been employed to increase the efficiency of the pyrolysis process. In this study, we investigated the effect of γ-irradiation on the catalytic pyrolysis of PP using zeolite as a catalyst. The irradiation processing was conducted using gamma rays at an irradiation dose of 20 kGy and a dose rate of 5 kGy/h. Electron spin resonance and fourier transform infrared analyses on irradiated PP showed that gamma-irradiation induced the formation of free radicals in PP structure, which are converted into peroxides, hydroperoxides, and finally, into carbonyl compounds. To investigate the effect of γ-irradiation on the catalytic pyrolysis of PP, we performed thermal gravimetry analysis and gas chromatography measurement. The results showed significant shifts in the conversion T50 values of pristine PP, irradiated PP 20 kGy, and irradiated PP 20 kGy with catalyst towards lower temperatures, indicating enhanced catalytic activity induced by irradiation treatment and the use of zeolite as a catalyst. The activation energy in the cracking process decreased from 300 kJ/mol for pristine PP to 255 kJ/mol for irradiated PP 20 kGy with catalyst. Moreover, the combination of γ-irradiation and zeolite catalyst increased liquid production yield and selective production of aromatic compounds. These suggest that the synergistic effects of γ-irradiation and zeolite catalyst could help the cracking process more efficiently and effectively.

IAEA-CN-332/251

Synthesis of Carrageenan Plant Growth Promoter Using Low Energy Electron Beam

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Radiation processing has long been an effective industrial tool for production of functional materials without the use of toxic initiators, offering economic, technical, and environmental advantages. In recent years, electron beam accelerators have emerged as the preferred technology for such applications, however, the acquisition cost of high energy units can be very restricting for local industries. Low energy electron beams (LE-EB) have lower unit costs, require less maintenance and are usually self-shielded, making them the more accessible technological choice. They take up modest space and can be integrated in existing processing lines. To evaluate their applicability for the production of radiation modified products, LE-EB was used to synthesize the kappa carrageenan (KC) plant growth promoter (PGP) developed by the Philippine Nuclear Research Institute, which was previously produced using gamma and mid-energy electron beam. In this study, a 250-keV self-shielded machine (Iwasaki) was used to degrade KC solutions, following their molecular weight profile through gel permeation chromatography. Results show that optimum application of dose, dose rate, concentration and solution thickness allowed for the reproduction of the active fragments of the KC-PGP, providing a proof of concept for the technical feasibility of LE-EB for this purpose. This should soon be accompanied by a more comprehensive design of feeding mechanism to enable continuous production along with a thorough financial feasibility to make the technology more accessible for industry.

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Impact of High Energy Electron Beam Irradiation on Mycotoxin Levels of African Nutmeg (Monodora Myristica) Powder

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This study investigated the impact of high energy electron beam on mycotoxin levels of African nutmeg powder. African nutmeg powder was bought from a local market in Accra, Ghana, cleaned, milled, packaged and irradiated using electrons of energy 9 MeV at doses of 2, 4, 6 and 8 kGy. Un-irradiated African nutmeg powder sample was used as a control. Mycotoxin levels of samples were determined using appropriate standard methods. Aflatoxins B1 and B2 (AFB1 & AFB2) as well as Ochratoxin A (OTA) were detected in the African nutmeg powder samples. High energy electron beam irradiation significantly ($p < 0.05$) reduced the AFB1, AFB2 and OTA of the African nutmeg powder with increasing irradiation dose. AFB1, AFB2, and OTA decreased significantly from 42.43 µg/kg, 10.11 µg/kg, and 6.72 µg/kg for control to 21.40 µg/kg, 5.37 µg/kg, and 2.25 µg/kg, respectively for 8 kGy treatment. Aflatoxins G1 and G2 were not detected in any of the samples. A dose of 8 kGy was effective in reducing the mycotoxin levels below the permissible limit in food. This study suggests that, high energy electron beam irradiation is effective in reducing mycotoxin levels in African nutmeg powder.

Key words: Food safety, High energy electron beam, Monodora myristica, mycotoxins

IAEA-CN-332/395

Modification of Recycled Plastics for Application in Composite Materials by Electron Beam

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In efforts to recycle plastics, the impact of electron beam radiation on recycled high-density polyethylene (HDPEr) was studied. HDPEr was irradiated at doses of 5, 10, and 15 kGy. Gel fraction and thermogravimetry (TGA) analysis was done, and a mixtures containing 1 to 5% iHDPEr were prepared using an extruder with other recycled plastics and calcium carbonate and mechanical properties were evaluated through bending tests.

Analysis of the iHDPEr gel fraction revealed an increase with higher applied doses, while thermogravimetry indicated an elevated degradation onset temperature correlating with dose. These findings underscore a dose-dependent molecular modification of HDPE due to radiation exposure. In the mixtures, a minor modification elastic modulus and flexural strength were observed, particularly with iHDPEr irradiated at 5 kGy.

These results demonstrate a modification in the irradiated material that impacts both its processability and the properties of the resultant compound. The improved mechanical properties suggest that the irradiated material can be reused without significant loss, facilitating its use in the production of new materials.

IAEA-CN-332/482

The Significance of Education Training and Certification in Radiation Science and Technology

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Comprehensive training and strict certification processes are vital for the development and safety of radioactive materials. They ensure that professionals are well-equipped, uphold the highest standards of safety and effectiveness, and they drive innovation. Radiation workers require specialized knowledge and skills to safely utilize ionizing radiation in various applications. Educational programs in radiation science and technology are increasingly incorporating multidisciplinary approaches, combining fundamental principles of science and engineering. Academic curricula need to be continually designed to provide comprehensive theoretical knowledge and practical skills, often featuring hands-on laboratory work, simulations, and internships. Training programs are essential for both initial education and capacity building. They cover topics such as radiation safety, dosimetry and operation of radiation equipmentTo ensure professionals stay updated with the latest technological advancements,frequent training and continued education courses need to be adopted and maintained together with any regulatory changes. This is a critical component in ensuring the competency and credibility is achieved by everyone in this field. Organizations for example IAEA provide accreditation to institutions that meet the stipulated standards required, fostering excellence and safety in radiation science and technology. Integration of digital tools and e-learning platforms enhance accessibility and flexibility in education and training making them important and effective. Advanced training and Certification can be expensive hence hindering access.Adequate funding for education programs and research is crucial especially in less developed countries. standardization of requirements for certification ensures only qualified professionals handle activities involved in radiation science.

KEYWORDS: Education, Training, Certification

IAEA-CN-332/500

Boosting Bioactive Compounds in Chlorella Sorokiniana: The Role of Gamma Radiation

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Bioactive compounds in microalgae contribute to their nutritional and functional value, making them promising ingredients for food and feed applications. Selenium (Se) is one such essential micronutrient, playing a key role in antioxidant and immune functions. Because European soils have low Se content, supplementation strategies are needed.

Organic Se forms, particularly those integrated in microalgae biomass, present superior absorption and lower toxicity, compared to inorganic forms. In addition to Se enrichment, optimizing the production of other bioactive compounds in microalgae could provide further nutritional and functional benefits.

It has been demonstrated that under specific irradiation conditions (dose and dose rate), ionizing radiation stimulates biomass growth in higher plants and algae, thereby contributing to food security and safety. Taking this as reference, this study evaluates the impact of gamma radiation on the synthesis of bioactive molecules in C. sorokiniana, particularly under Se-enriched conditions.

Heterotrophic C. sorokiniana grown with 30 mg Se.L-1 accumulated 150 μg total Se.g-1 biomass (preliminary results). Different irradiation doses (1-4 kGy) at a dose rate of 0.5 kGy.h-1, were applied during various microalgal growth phases: lag, exponential and stationary. Experiments performed indicate that a dose of 1 kGy at the late exponential growth phase did not affect C. sorokiniana growth rate or global productivity ($p>0.05$). However, the opposite effect was observed when the dose was applied at the beginning of the growth phase.

Studies on the influence of gamma irradiation on the composition of bioactive compounds, including Se species, antioxidant activity, and other key metabolites were studied. For future perspectives, the process will also be optimized for e-beam processing of C. sorokiniana.

IAEA-CN-332/167

Comprehensive Analysis of Lithic Materials and Mortars for the Conservation of the Holy Archangels Michael and Gabriel Church

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This paper presents the comprehensive analysis of lithic material and mortars from the Holy Archangels Michael and Gabriel Church in Ceplenița. Constructed in 1802, this monumental building is part of the Cantacuzino-Pașcanu Mansion Complex. Initially serving as a court chapel, the church now functions as a parish church. To facilitate the rehabilitation and conservation of this historical monument, a series of meticulous investigations were conducted to identify the constituent materials and quantify existing degradations. These investigations included macroscopic examinations, moisture determinations, and salt analyses.

A significant emphasis was placed on the use of X-ray fluorescence (XRF) spectroscopy, which proved instrumental in determining the elemental composition of the binding mortar, identifying the ratio between binder and aggregate, and assessing the stratification of construction elements. XRF spectroscopy, known for its precision and non-destructive nature, allowed for an in-depth analysis of the plaster composition and the lithic material used in masonry, flooring, and stairs. Additionally, petrographic analysis and chemical analysis complemented the XRF results by providing detailed insights into the mineralogical and chemical characteristics of the materials.

The importance of these investigative techniques lies in their ability to provide accurate and detailed data, pivotal for making informed decisions about conservation strategies. Understanding the material composition and degradation patterns enables conservators to select the most compatible and effective materials and methods for restoration. This approach ensures the longevity and structural integrity of the monument while preserving its historical authenticity.

The findings from these investigations have laid a solid foundation for the rehabilitation and conservation efforts of the Holy Archangels Michael and Gabriel Church, contributing to the preservation of its historical and architectural value for future generations. The application of advanced analytical techniques like XRF spectroscopy demonstrates the vital role of scientific methods in cultural heritage conservation.

IAEA-CN-332/299

Radiotracer and Natural Radioactivity Methodology and Technologies Applied in Panama

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Background of the study

As part of the IAEA National Project PAN 1002 "Strengthening the Operation of the Panama Canal through Erosion and Sediment Transport Analysis using Nucleonic Control System Applications, Radiotracers and FRN and CSSI methodologies", the aim is to strengthen the use of these technologies in sediment study and transport in the country, particularly within the Panama Canal basin, continuing the established research line of projects PAN 1001 and RLA1013, also under the IAEA. To achieve this, and in view of current trends in the use of natural substitutes in tracer studies, experts proposed the use of 'black sand' as a natural tracer. Black sand contains elements such as thorium or uranium whose low levels of radioactivity could potentially allow their use as tracers.

Methodology

The study methodology in this case was to identify beaches near the city of Panama that had black sand. Two study points were selected for our study: Playa Gorgona and Playa Chame, both located in the province of Panama Oeste, Panama. Measurements were made using a NaI (TI) probe and a data acquisition system (DAS) for radiotracer applications. This equipment was adapted to be portable for the measurements.

Results and Conclusions

Measurements were taken on both beaches, with the probe recording counts per second (CPS) at each point sampled. These measurements were then used to profile the measured surface area using software (Figure 1). After reviewing the readings, preliminary conclusions indicate that neither beach surveyed contains the type of black sand with sufficient radioactive elements to be used as a natural tracer. However, this study sets a precedent for future research in other parts of the country or the investigation of alternative tracer types.

IAEA-CN-332/343

Soil Redistribution Studies within the Panama Canal Watershed Using FRN and CSSI Methodologies

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Background of the study

The PAN 1002 National Project "Strengthening the Operation of the Panama Canal through the Analysis of Erosion and Sediment Transport using Applications of Nuclear Control Systems, Radiotracers and FRN and CSSI methodologies" is based on the results of the PAN 1001 and RLA1013 projects, in which the profile of the sediment layer in operational areas of the Panama Canal was analyzed. For this project, the use of two techniques was proposed: FRNs to analyze soil redistribution processes together with CSSI to establish the origin of the sediment layer that reach the Canal's operational areas. It should be noted that these methodologies are based on tracers present in the environment.

Methodology

The methodology used was as follows: 19 source sites and 7 mixing sites were identified for sample collection within La Zanguenga stream micro-watershed (an important area in the national pineapple production) for CSSI analysis. FRN samples were also collected at these points, and additional transects were established to carry out the complete modeling of the study area.

Results and Conclusions

In Panama, 27% of the national territory is affected by soil degradation, causing a decrease in agricultural and livestock production. Previously obtained results in La Zanguenga stream micro/watershed (a traditional area for the development of productive activities, especially pineapple cultivation), show the following indicators:

• Annual erosion rate in pasture area with low slope: from 1.50 to 2.70 ton/ha/year, indicating that between 1.27 to 2.28 cm of soil has been lost in the last 58 years.

• Annual erosion rate in pasture zone with moderate slope: 5.50 to 7.20 ton/ha/year, indicating that between 4.65 to 6.04 cm of soil has been lost in the last 58 years.

• Annual erosion rate in pineapple cultivation area with moderate slope: 21 ton/ha/year, indicating that 17.76 cm of soil has been lost in the last 58 years.

IAEA-CN-332/037

γ-Irradiation Synthesis of Cellulose Acetate/ Acrylic Acid Functionalized Zinc Oxide Nanocomposite for Decontamination of Dye Pollutants from Wastewater

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In this study, zinc oxide functionalized cellulose acetate/ acrylic acid (CA/AA/ZnO) nanocomposite was synthesized by γ-irradiation and utilized as adsorbents for the decontamination of methylene blue (MB) and crystal violet (CV) dyes from wastewater. The effect of irradiation dose on gel content and swelling percentages of CA/AA/ZnO nanocomposites were studied. Using 20 kGy the maximum gel content (%) of 96.3% and the highest swelling (%) of 168.7% were achieved. Different analytical techniques were used to characterize CA/AA/ZnO nanocomposite. XRD results confirmed successful incorporation of ZnO nanoparticles inside the CA/AA polymer matrix. The calculated average crystallite size of ZnO nanoparticles and CA/AA/ZnO nanocomposite were 46.8 and 39.3 nm, respectively. Factors affecting the adsorption of MB and CV dyes were evaluated as a function of time, adsorbent dosage, dye concentration, pH and temperature. The adsorption capacity of CA/AA/ZnO nanocomposite towards MB and CV increased with increasing time, dye concentration, pH and temperature. The optimum adsorption capacity of CA/AA/ZnO nanocomposite toward MB and CV dyes were 269 and 241 (mg/g), with removal percentage of 96% and 87.5%, respectively at the optimum conditions of pH 9 and 7, 35 min time, 300 mg/L dye concentration and 0.3 g adsorbent dosage, respectively. The removal efficiency of CA/AA/ZnO nanocomposite towards MB dye was higher than that of CV dye. The CA/AA/ZnO nanocomposite is an effective and fast adsorbent for the remediation of different dyes from wastewater with good recyclability characters.

IAEA-CN-332/118

Fleshfingered Citron (Citri Sarcodactylis Fructus) Treated by 30 kGy-Gamma Irradiation Regulates Lipid Metabolism and Promotes Fat Browning in 3T3-L1 Adipocytes

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Obesity is described as an abnormal fat accumulation, which is caused by an imbalance in the excessive intake of high-calorie foods and reduced energy consumption. Traditional treatments for obesity, such as diet restriction and exercise, are also available, but adjunctive pharmacotherapy may be recommended. Some drugs used for obesity treatment carry the risk of serious side effects, and several have been withdrawn from the market.

Citri Sarcodactylis Fructus (CSF) is the dried fruit of Citrus medica Linn. var. sarcodactylis Swingle, also known as “five-finger orange” and “miluo orange”, and “Foshou” or “Buddha hand citron” in China. Recently, it reported the impact of Co-60 gamma-ray irradiation treatment on the content of active chemicals and their function. As the main ingredients and activity changes are proportional to the irradiation dose, it is used as an important reference material for the use of radiation technology to enhance the efficacy of functional foods.

Here, we investigated the effect of CSF gamma-irradiated with 30 kGy on the protein and mRNA levels of several pathways involved in fat browning in 3T3-L1 white adipocytes. Depending on the gamma irradiation dose of CSF, differentiation of adipocytes was promoted or inhibited (Fig. 1).

In addition, the mechanism related to the regulation of thermogenic proteins mediated by the AMPK signaling pathway was studies. CSF gamma-irradiated with 30 kGy induced fat-browning in 3T3-L1 adipocytes. This study presents the effect of CSF gamma-irradiated with 30 kGy on brown adiposity and provides the potential of CSF-derived substances as anti-obesity agents.

IAEA-CN-332/164

X-Ray and Gamma Irradiation to Prepare Biohybrid Albumin/Gold Nanoparticles

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Background

Inorganic nanoparticles (NPs) are being intensively studied for applications in human diagnosis and cancer treatment exploring different approaches. However, the true potential of NPs will be unlocked through biofunctionalization with biological molecules.

Biohybrid nanoparticles (bioh-NPs) prepared from inorganic NPs coated with a protein multilayer offer an attractive strategy for in vivo applications compatible with the human body. Bioh-NPs based on gold NPs (AuNPs) and albumin coating can be prepared by radiation-induced cross-linking. This method avoids the use of chemical cross-linkers to stabilize the nanoconstruct.

X-rays and γ-rays are both low-linear energy transfer ionizing radiation. Nonetheless, the interaction cross-sections of X-rays with matter are quite different from that of γ-rays with matter. The interaction of X-ray photons with heavy elements can dramatically increase local dose in the vicinity of NPs, which could affect protein crosslinking. Therefore, X-ray irradiation could be an alternative technique to prepare bioh-NPs involving multilayer protein coating.

Methodology

AuNPs suspension was dispersed in albumin solution and ethanol 30 %v/v and degassed using Argon. Samples were irradiated using a 5BKhW-6 (W) X-ray tube with a tungsten anode at two different photon energy spectra (applied voltage 32 and 46 kVp, anode current 70 mA). Sample irradiation with gamma rays from a 60Co source was performed at PISI (CNEA-Ezeiza).

Results

The albumin/AuNPs aggregates dispersed in an ethanolic solution were irradiated with X-rays at different energies (see Section 2) and different absorbed doses in the range of 1 to 10 kGy. The samples were studied by extinction spectra in the visible region (plasmonic signal) and characterized by the maximum plasmon wavelength (λp) and the half maximum wavelength (λm). Plasmonic data for all irradiated samples show a small shift toward longer wavelengths. Meanwhile, the gamma-irradiated sample (at ten kGy) shows the most extended λp shift and the smallest λm shift, showing completely different behavior from the X-ray irradiated samples. Under these experimental conditions, plasmonic signal is indicative of changes in the protein coating.

Remarkably, the diameter of the irradiated bioh-NPs shows that the sample irradiated at higher photon energy to the absorbed doses of 4 kGy or above exhibited increased NP diameters (similar to gamma irradiation). Meanwhile, the samples irradiated at lower photon energy showed a wide NP size distribution and irradiation to the highest absorbed dose yielded NPs of small hydrodynamic diameter.

Conclusions

Bioh-NPs prepared using ionizing white X-ray radiation, with different maximum energies in the aqueous ethanolic media produced different nanostructures and properties than those irradiated with gamma rays. Experimental data suggest that the secondary photoelectrons emitted from the NPs are mainly responsible for the protein cross-linking. However, due to the difference in photon energy spectrum, the photoelectrons generated by X-rays of lower energy produce secondary electrons of relatively low energy and, therefore, the energy deposition becomes more local in the nanometer range. Further studies are needed to determine the energy deposition zone of secondary electrons by adjusting the X-ray energies.

IAEA-CN-332/177

Performance Enhancement of Patinated Bronze Coated with Polymer Nanocoatings

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Bronze is one of the most popular metals used for works of art and cultural heritage objects. Often, bronze is covered with a thin layer of corrosion products known as patina, in order to enhance its aesthetics and ensure its protection. Due to increasing atmospheric pollution and acid rain, protective patina can be washed off and the bare surface exposed to the unwanted and uncontrolled corrosion processes. This exposure can alter the appearance and stability of the bronze, changing the color of the original surface and causing localized corrosion, which results in chronic material deterioration. Therefore, it is essential to additionally protect patinated bronze surfaces.

This study investigated the possibility of protecting bronze and its patina from corrosion using gamma-irradiation crosslinked self-assembled molecular layers of behenic acid. The obtained surface was characterized using a variety of techniques, including metallographic examination, Scanning electron microscopy, Raman spectroscopy, FTIR spectroscopy, X-Ray diffraction analysis, and colorimetry. The wettability of the surface was studied by contact angle measurements. In order to study the longterm stability of the coatings, the samples were artificially aged in a UV chamber. The stability of the obtained coatings (new and artificially aged) was investigated in a solution simulating acid rain using electrochemical methods (Tafel extrapolation method and electrochemical impedance spectroscopy).

The results showed that the corrosion resistance of bronze covered with patina increased with the application of polymer nanocoatings.

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IAEA-CN-332/254

Toxicity Reduction in Pharmaceutical Compound Mixtures Using Electron Beam Irradiation

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The presence of pharmaceutical compounds in surface waters has been widely documented, representing potential risks to environmental and human health (Adeleye et al., 2021; Souza et al., 2022). This study aims to evaluate electron beam irradiation, as a promising technology, to reduce the toxicity of pharmaceuticals in water. Acute toxicity tests were conducted with three different mixtures of pharmaceuticals: a) Sulfadiazine + Fluoxetine, b) Caffeine + Fluoxetine, and c) Metformin + Fluoxetine. Results indicated that the antibiotic SDZ + FLX mixture resulted in 23.1% and 16% toxicity reduction for Daphnia similis microcrustacean and for the marine bacterium Vibrio fischeri, after 2.5 kGy. The stimulant CFN + FLX mixture resulted in a toxicity reduction of 42.4% and 25.3% respectively, for both organisms, at 2.5 kGy. However, the antidiabetic MET + FLX mixture, only the bacterial assay resulted positive for the toxicity removal: 21.9% less toxic for V. fischeri. The mixture of MET + FLX was more toxic than mixture A and B for daphnidae. Electron Beam Irradiation is effective for the degradation of organic molecules and toxicity is an indispensable parameter for understanding the formation of irradiation by-products.

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IAEA-CN-332/282

Application of Stable Water Isotopes Deuterium and Oxygen-18 and Artificial Tracers to Study Water Flooding in Oil Reservoir

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Water flooding is an important operation in oil recovery. Water is injected in the oil formation through the injection well to maintain the formation pressure and displacement of oil toward the production wells. The interwell connectivity and movement of the injected water are investigated by using the artificial tracer which is injected in the injection well and monitored its breakthroughs at the production wells. However, in many cases the existing formation water also takes part in water flooding that influences the oil recovery efficiency, meanwhile the artificial tracer is only able to provide the information of injected water. Water stable isotopes Deuterium and Oxygen-18 and chemical compositions of produced water were used as the natural indicators to investigate the participation of the formation water in water flooding. The combination of the artificial tracer and natural indicator may bring valuable information of water flooding mechanism in management of water flooding operation as well as in planning EOR applications. Examples of application of the artificial tracer and natural indicators such as water stable isotopes and chemical compositions in water flooding studies in the fractured basement and sandstone reservoirs in Cuu Long Basin, Vietnam are presented in this paper.

IAEA-CN-332/285

A New Kind of Concrete using Irradiated Plastic Waste: A Solution for Reducing Greenhouse Gas Emissions

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Research has delved into the utilization of recycled plastics in concrete as a strategy to enhance the mechanical properties of concrete, offering a dual benefit of repurposing waste plastic and mitigating carbon emissions by partially replacing cement. Despite these efforts, there is a challenge in developing a cement formulation that accommodates plastic additions while maintaining high compressive strength. This study investigates the efficacy of incorporating electron beam-irradiated plastic as an additive in cement paste samples (comprising Portland cement, additives, and water) to enhance its proprieties in term of tensile and compressive strength. To determine the optimal conditions, polyethylene terephthalate (PET) was subjected to electron beam irradiation at three different doses (0, 10, 50, and 100 kGy). The study investigated the effects of replacing 10% of the cement volume with PET waste. Various tests, including workability, compaction factor, compressive strength, split tensile strength, and water absorption, were conducted to assess the properties of the resulting concrete. Our findings underscore the need to account for radiation effects when assessing concrete performance, especially when integrating irradiated plastic materials. The study revealed that, when compared to standard concrete, there were no significant changes in the workability and air content of the various concrete mixes tested. However, the tensile strength showed a consistent increase in all samples that included PET. Notably, a reduction in water absorption was observed in PET-containing samples. While there was a decrease in compressive strength, it remained within the acceptable range for structural concrete with 40 MPa, suggesting favorable outcomes in the overall performance of the concrete. These insights are valuable for comprehending the behavior of irradiated plastic concrete and can inform decision-making in construction and material selection.

Key words: Ionizing radiation, polymers, concrete, plastic waste (PET), compressive strength.

IAEA-CN-332/290

Radiation Safety of Industrial Radiography Facilities in Uganda

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Industrial radiography is a non-destructive testing method that uses ionizing radiation to inspect materials and components for hidden flaws. The technique typically employs high-energy X-rays or gamma rays from radioactive sources such as Iridium-192 or Cobalt-60 to reveal internal defects in materials like welds, castings, and pipelines without causing damage. This technique is crucial in various industries, including manufacturing, construction, and aerospace, where it ensures the integrity and safety of critical structures and equipment. While essential for quality control and safety inspections, ionizing radiation necessitates strict safety protocols to protect workers and the public from potential radiation hazards. These facilities, which often operate in open or semi-controlled environments, require stringent radiation protection protocols to ensure the safety of both the workers and the surrounding communities. In Uganda, the Atomic Energy Council (AEC) is the regulatory authority responsible for overseeing the safe use of ionizing radiation, including in industrial radiography facilities.

The objective of this study was to assess the level of radiation protection in industrial radiography facilities in Uganda

This study used a descriptive design for all the 05 industrial radiography facilities in Uganda with a total of 15 radiation sources based on inspection report findings for inspections carried out by the Atomic Energy Council, the Nuclear regulator of Uganda. The study assessed radiation protection in terms of the authorization status of the facilities, status of qualification and training of personnel, monitoring of the workers, demarcation of controlled and supervised areas, and warning systems.

The results indicated that 4 facilities (80%) were authorized to possess and use the radiation sources, all 05 facilities (100%) had qualified personnel, 3 facilities (75%) had trained their workers, 4 facilities (80%) monitored their workers for occupational exposure, 4 facilities (80%) had well demarcated controlled and supervised areas, and there were visible radiation warning systems in 4 facilities (80%).

In conclusion, there were sufficient radiation measures in some facilities. However, the existence of some facilities in the industry that were not compliant with some requirements meant there was a need for stronger regulatory measures to ensure full compliance across the industry.

IAEA-CN-332/291

Disinfection and Preservation of Archived Newspapers by Radiation Processing Technologies

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Newspapers are witness of culture and historical milestones. These or similar items are made of cellulose based paper and can be deteriorated by cullutytic molds and bacteria if not preserved properly. To determine the applicability of ionizing radiation for conservation of these materials, archived newspaper samples were collected and subjected to different doses of radiation (2.0, 4.0, 6.0, 8.0, 10.0 and 15.0 kGy) by cobalt-60 gamma source to disinfest and disinfect selected newspaper samples. Number of total bacteria and fungi present in the sample were 1.2E5 cfu/g and 1.9E4 cfu/g respectively which became below detection limit after irradiation with 8 kGy. 5 of the fungal and 2 of the bacterial isolates exhibited cellulase producing potential. Considering mechanical properties, tensile strength increased non-significantly at the highest irradiation dose (15 kGy). DSC and TGA indicated thermal stability of main components of paper was not changed at the highest irradiation dose applied. FTIR could not detect the presence of C=O radical. SEM could not detect any significant change in the cellulose structure. Molecular identification of the cellulase producing bacteria and fungi is required along with analyzing effect of irradiation on samples from diverse sources to depict the irradiation effect more clearly.

IAEA-CN-332/293

A Leak Detection Displacement Technique Using Radioactive Tracers for Industrial Applications

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The displacement technique as a method of leak detection without locating leak spots has been developed in the Laboratory of Diagnostic Methods at the Institute of Nuclear Chemistry and Technology in Warsaw. The principle of this radiotracer technique involves introducing a radioisotope tracer into a regulated object which is linked to a compensating tank and a container filled with the same tracer via a system of tubes. Once the test pressure in the measuring system is balanced, scintillation probes with collimators are positioned on a specific tube to detect tracer movement and identify leaks. Three detectors are positioned side by side with every two detectors being 2 meters apart from one another. A Kr-85 or bromine bromide labeled Br-82 bromine as radiotracer is used. At least 100 kBq is injected all at once, and the system is set to measure for 1 second. Specialized software computes the transit times between each detector, which are then converted to the flow rate parameter Q [dm3/h]. A leak is deemed present in the installation if the Q value exceeds 500 cm3/h. This method is included in the new ISO standard proposal.

In this work, the principle of displacement technique will be presented. The method will be compared with other routinely used leak detection techniques. The advantages and limitations of this method will be highlighted. A case study of the measurements provided for industry will be shown.

IAEA-CN-332/303

Research and Application of S-Band High Power Travelling Wave Accelerating Tubes

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S-band electron linear irradiation accelerators are extensively applied in the fields of industrial irradiation, sterilization and agriculture. the travelling wave accelerating tube is the core component with simple structure, good stability and high beam power capacity. In recent years, the high intensity linear accelerator team from China Institute of Atomic Energy (CIAE) has carried out research on S-band travelling wave accelerating tubes, and established an end-to-end development system from beam dynamics to high-power testing. During the COVID-19 epidemic, a 2.5MeV/5kW high-power travelling wave accelerator tube was developed for the sterilization of medical wastewater, which adopts a variable-phase-velocity and uniform-phase-velocity bunching structure to significantly improve the capture efficiency of the electron beam in the low-energy region. For the research and production of medical hydrogel, a 5MeV travelling wave accelerating tube was developed with an average power of 5-10kW. For the demand of radiation processing industry, a 10MeV high-power travelling wave accelerator with constant impedance and short bunching structure was developed, with an average beam power of up to 24kW, with the ability to further increase the beam power

IAEA-CN-332/305

Utilizing Atmospheric Aerosols and Pb-210 as Tracers for Atmospheric Pollution

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Background:

Atmospheric aerosols and radioactive isotopes are crucial for monitoring and understanding atmospheric pollution. Aerosols, originating from natural sources like dust and sea spray, as well as human activities such as industrial emissions and vehicle exhaust, affect the climate and pose health risks. Radioactive isotopes, both natural and anthropogenic, help trace the movement and deposition of pollutants. Analyzing their concentration and distribution offers valuable insights into the sources, transport pathways, and residence times of atmospheric pollutants, thereby enhancing air quality management and pollution mitigation strategies.

Methodology:

This study analyzed 16,070 daily and 608 weekly air filter samples collected from the Helsinki metropolitan area between 1962 and 2005. The primary objective was to perform source apportionment analysis, specifically using the Potential Source Contribution Function (PSCF), to identify potential sources of stable lead (Pb) and radioactive isotope 210Pb. Examining the elemental concentrations over this 44-year period reveals factors affecting their concentrations, seasonal variations, and the impact of reduced emissions following the implementation of EU regulations. Additionally, the distribution of 210Pb and other radioisotopes provided substantial information as tracers to quantify various atmospheric processes. The specific activity of 210Pb serves as a reliable indicator for distinguishing between local and remote emission sources of Pb on the air filter samples.

Results:

The study identified the atmospheric concentrations of 210Pb and stable lead (Pb). The highest Pb values were recorded in the 1960s. Since 1970, when deliberate measures were implemented to combat air pollution, a significant decline has been observed, with average annual Pb concentrations decreasing by 94.58%. Additionally, 210Pb concentrations saw a smaller reduction of 50.96%. Factors influencing 210Pb concentrations in the air include seasonal variations, atmospheric pressure fluctuations affecting the origins of air masses, local radon emanation rates, temperature inversions, and more. The maximum concentrations for both 210Pb and Pb occurred during the winter and spring seasons.

Conclusions:

Using NOAA trajectory data for this 44-year time series, the main source areas of these components were estimated. Although sources have varied over the years, the primary sources of the highest Pb concentrations were industrial activities, particularly dusting actions such as mining and the metal industry, and traffic. For 210Pb, the main source areas were predominantly from the eastern and southeastern regions of the measuring site, with significant concentrations also originating from the north.

IAEA-CN-332/316

Quality Management in Radiation Dosimetry and Radiation Processing for Low and High Dose Irradiation

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Abstract

Since 1979, Gamma Source Division (GSD) of Bangladesh Atomic Energy Commission has been pivotal in advancing radiation dosimetry and gamma irradiation services for research samples and commercial products in Bangladesh. GSD employs various dosimetry systems, including Fricke, Gafchromic, Amber-perspex, and Ceric-cerous. Dosimetry intercomparison data showed very little variation (~1%) determined with reference Alanine dosimeters, highlighting dose measurement reliability and precision. Calibration of Gafchromic HD-V2 and MD-V3 resulted with a total uncertainty of merely 2% and 2.6%, respectively. Dose mapping using Alanine dosimeters for high and low dose irradiation, at 17, 27, 37, 84 and 130 cm SSD resulted dose rates of 96.0, 45.0, 29.7, 7.6, 3.31 Gy/min with little discrepancies with Fricke and Amber Perspex. Application of continuous rotation of products reduced Dose Uniformity Ratio. Apart from radiation dosimetry, GSD undertaken several steps like Quality Assurance Plan Development, Process Validation, Routine Process Control, Product Testing, Documentation, and Audit, to ensure proper quality management for radiation processing. About 2,204 food samples and 18,878 medical, polymer & other samples of 20 research organizations and 386.58 tons of food products and 37,858 cft of medical and pharmaceutical products of about 60 commercial companies were successfully irradiated by GSD in the last ten years.

IAEA-CN-332/321

Nitrofurantoin and Furazolidone Degradation Using Low Irradiation Doses Combined with Microbial Antibiotic Decomposition

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The presence of low antibiotic concentrations in wastewater leads to disruptions of natural processes of organic matter mineralization and also affects both local flora and fauna. Wastewater represents an ideal growth medium for microorganisms that thrive in these conditions forming a stable microbial community. Low antibiotic concentrations in wastewater force some of the present heterotrophic or pathogen microorganisms to develop antibiotic-resistance genes to cancel the effect of the antibiotic. In a microbial community, various gene exchanges are realized so the community will transfer and adopt these antibiotic-resistance genes. Among these microorganisms, pathogens are also present. They can also transfer these resistance genes making them harder to combat using low doses of prescribed antibiotics thus the occurrence of antibiotics resistance “superbugs”.

Nitrofurans are widely used in the treatment of urinary tract infections in humans and also in veterinary medicine studies show that they are present in low concentrations in various wastewaters but studies about their effect on the environment and their biodegradation are scarce.

The main aim of this study is to investigate the ability of some soil-isolated microorganisms to decompose nitrofurantoin and furazolidone correlated with low doses of irradiation of antibiotics suspensions to reduce the concentration of these antibiotics and to prevent the appearance of antibiotic resistance genes.

IAEA-CN-332/323

Microorganisms Metabolic Behavior and Surviving Rate Variation Induced by Different Conditions of Irradiation

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The study aims to explore radioresistance and metabolic behavior under different irradiation conditions of two microorganism strains isolated from a collagen gel product: Carnobacterium maltaromaticum and Rhodotorula sp. Both microorganisms have importance in food and drug industries.

Two methods were used to estimate the fraction of survivors after irradiation: direct counting after surface sprade on solid culture media and turbidimetric measurement of bacterial growth in liquid media. To estimate the D10 value, irradiation was performed in a self-shielded irradiator GC-5000 (1.7 kGy/h) and outside the product conveyor of the semi-industrial irradiator SVST C-60 (0.2 kGy/h), in a dose range from 0.3 to 1.2 kGy.

Preliminary results show variations of D10 values when irradiated at different dose rates (~tenfold), at room temperature for both tested strains.

The turbidimetric measurements clearly show the stimulatory effect of a lower dose rate at the bottom of the dose range.

Collagen-gel based medical devices, due to its growth supportive nature, as well as irradiation in ultra-low temperature conditions (e.g. dry ice) may induce additional differences in radiation resistance.

In addition, turbidimetric method can improve the determination of D10 by decreasing the intrinsic errors of surface spade method.

IAEA-CN-332/327

Applying luminescence Methods for Detection of Irradiated Wheat

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One of the main problems in the production and storage of wheat is infestation by pests that can cause considerable losses and can be vectors for different pathogenic bacteria and parasites. Thus, post-harvest control of wheat is essential. Among the new prospective approaches for controlling wheat storage is gamma irradiation. This non-thermal, energy-efficient and environmentally friendly method can be used to control cereal storage problems and for improving microbiological safety and storage stability of foods.

Although food irradiation is a proven safe process, it is necessary to have control during its implementation. This stems from the consumers' right and for the authorities to be informed if food has been irradiated. Implemented methods for detection should serve as prevention of illegal irradiation, multiple irradiations and to check up on compliance with labeling regulations.

Luminescence methods, including photostimulated luminescence (PSL) and thermoluminescence (TL), have been used for detecting irradiation in different kinds of food, but there are no reference studies on their sensitivity for detection of wheat. The aim of this study is to compare luminescence methods in detection of wheat irradiated with different doses of gamma radiation.

Samples for this study were exposed to gamma irradiation with different doses in the range 0.2 kGy-10 kGy.

Detection by luminescence methods of the irradiation was performed in the Radiation Physics Laboratory RAD-LAB in Skopje, which is the only accredited laboratory in the country for detection of irradiated food. It was concluded that PSL can be used as a first detection method when irradiation is performed with higher irradiation doses, but for very low irradiation doses it should be combined with TL in order to obtain reliable results.

Moreover, it was concluded that all irradiated samples are microbiologically safe, and at the same time, they have not lost their nutritional value during irradiation.

IAEA-CN-332/331

Gamma Irradiation Disinfection of Damaged Paper: Influence of Dose Rate on Radioresistance of Some Molds

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Molds were isolated from gamma irradiated paper of a large newspaper collection, belonging to the National Library of Romania, that was treated at IRASM, in Nov. 2023. Their resistance to 7.0 – 9.5 kGy intrigued us, so the molds were further investigated.

The D10 values proved significant different between the two irradiators: a SVST Co-60/B industrial Gamma Irradiator and a Gamma Chamber CG-5000 experimental irradiator. As such, the total absorbed dose was not equally effective at the two dose rates, of 0.2 and 1.7 kGy/h, respectively. This raises the question over the efficacy of gamma disinfection, for a given treatment dose, in low dose-rate irradiators. It can also explain the apparently high resistance of the isolates, since a low dose-rate (0.3 kGy/h) was used for newspaper irradiation.

The dose-response was not a perfectly linear logarithmic curve, showing a dose window that appeared slightly stimulating. The curve hump was in the low-dose range, but it shifted to higher dose, as the dose rate decreased.

Isolated molds confirmed to have cellulolytic activity. Due to their versatile metabolism, molds are, by far, the main culprit organisms in paper damage, especially in moist storages. Concerns about optimal timing for irradiation are addressed.

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IAEA-CN-332/333

Advanced Treatment of Wastewaters: Integrating Gamma Radiation and Bioremediation for Persistent Organic Pollutant Degradation

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Gamma radiation was employed in lab-scale experiments to study the efficiency of ionizing radiation treatment (AORP) joined with biological treatments (BIO) for the degradation of organic matter and pathogenic organisms while retaining essential nutrients. In this research, wastewater contaminated with acidic organic and organo-metallic dyes underwent parallel experiments involving gamma radiation degradation and flocculation, as well as bioaccumulation in extremophile bacterial strains. These experiments aimed to assess the potential of HPLC as a quality control analytical technique for optimizing AORP-BIO technology in textile wastewater treatment. The employed chromatographic method was based on a previously developed one for the detection of dyes in historical textiles [1].

Additionally, the assessment of degradation compounds was performed by screening residual dyes using HPLC-DAD before and after irradiation. In the bioremediation process using bacteria, an optimal bioremediation time was identified, in order to prevent the process from becoming reversible due to biomass death and the migration of persistent organic pollutants back into the wastewater. The evaluation of this technology combining ionizing radiation, an advanced oxidation and reduction process with biological treatments was conducted, demonstrating its viability for the decomposition of stubborn organic pollutants and the treatment of refractory organic wastewater.

IAEA-CN-332/342

New Approach for the Qualification of NDT-Operators in the Field of Civil Engineering

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The qualification of NDT-Operators in the field of civil engineering is often not based on a formal training and examination as used in the "metall world". The existing system of ISO 9712 does not fit here. The reasons are multiple:

- Standards for concrete products don’t know NDT

- NDT methods for concrete lack standardization

- concrete structures are often unique, which leads to single case Inspections

- Concrete is a relatively cheap material compared to steel.

Aging infrastructure, higher traffic loads and limited resources in Germany led to an NDT-Initiative to improve the reliability of Non-destructive tests on infrastructure.

On outcome was the definition two standards for the qualification and certification of NDT-Operators in Civil Engineering. While the certification process is comparable to ISO 9712, the qualification system is quite different.

Instead of a method-oriented system it is application-oriented and could combine several methods for one inspection task. As an example, for the verification of reinforcement UT and Radar is used.

Before qualifying in an application each operator is required to pass a basic module.

German providers prepared all course materials and a range of test blocks and trained several groups of operators. The interest for such training is rising, coming from specialized test provides, institutes and authorities.

IAEA-CN-332/345

Gamma Scan in Oil Distillation Columns: Comparison of the Results Obtained from Scanning a Prototype Oil Distillation Column with Results Obtained in Real Columns

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The Gamma scan technique in petroleum distillation columns is a technology that uses nuclear radiation from an isotope that emits high-energy gamma radiation through a collimated source . in electricity through the photoelectric effect, this electrical signal is digitized (sampling and quantization), the average of the signal packets received in a given time is calculated, the matrix is created with the values of the signal averages over time in generated, converted to decimal, and finally displayed. The technique allows knowledge of the chemical processes and physical states of the internal components of a column, it is a non-destructive technique and is carried out without interrupting production, reducing shutdown time, avoiding waste of resources, allowing "real time" observe" the performance of the distillation process, enabling predictability and planned maintenance. The objective was to analyze the effectiveness of this technique on the constructed prototype (subjected to certain conditions that simulate real states) through the analysis of the data resulting from this measurement, comparing them with data obtained in real columns, available in the literature, to find out if the prototype simulates the real conditions of a petroleum distillation column. Adopting the experimental method, a 60Co source, with an activity of 1.72 mCi, a directed beam collimator, and a NaI scintillation detector were used to measure the gamma rays passing through the distillation column prototype. the National Center for Nuclear Energy, Science and Techniques of Morocco, in Rabat; the wires that connect both the source and the detector are graduated to the millimeter to ensure that the source and detectors are in line-of-sight, a cable carries the information from the detector to the Dataloger , through the comparison of the standard deviation and uncertainty of the matrices obtained in real columns taken from the literature that have identified the same phenomena, identified the same patterns, the standard deviation and uncertainties of the matrices obtained in the pototype were compared with those of the matrices obtained in the real columns analyzed. The results obtained indicated standard deviation and uncertainties with the same trends, demonstrating that the prototype can simulate the real conditions of an oil distillation column.

IAEA-CN-332/351

Ionizing Radiation as a Tool to Valorize Food and Agro-Industrial Wastes

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Background of the study

The growing demand by consumers for healthier food has driven the food industry to seek new, cost-effective, and natural alternatives to synthetic preservatives. On the other hand, the antimicrobial resistance is currently a serious global problem since some antibiotics could be non-effective in the treatment of infectious diseases, becoming increasingly urgent to find solutions to deal with this problematic. In this context, the natural bioactive compounds present in food and agro-industrial wastes can be potential effective agents for these purposes.

Methodology

In this work, ionizing radiation, gamma and electron beam radiation, was applied to different food and agro-industrial wastes (oregano; lettuce; avocado – pulp and peel; olive pomace; pineapple wastes – core, pulp and peel; eggshell membrane) to evaluate its feasibility in improving the extractability of bioactive compounds, as well as the bioactivities of the obtained extracts.

Results

E-beam radiation was used to study the stability of aqueous and ethanolic lettuce extracts during storage at -80 ºC. Low energy electron beam (LEEB) at 4 kGy generally improved total phenolic and flavonoid contents of lettuce ethanolic extracts stored up to 28 days, while the aqueous extracts from irradiated lettuces demonstrated higher antidiabetic and antiproliferative activities. Water demonstrated to be the most adequate solvent to extract phenolic compounds from oreganos and LEEB at 5 and 10 kGy indicated to enhance the antioxidant activity by DPPH radical scavenging activity. Furthermore, high energy electron beam (HEEB) could increase the antioxidant activity of eggshell membrane and egg white powder using irradiation doses up to 500 kGy, as well as isolated egg proteins lysozyme and ovalbumin. Enhanced antimicrobial and antiproliferative activities could also be highlighted for irradiated samples. Gamma irradiation at 5 kGy was suitable to improve at least 2-fold the extractability of bioactive compounds from olive pomace with higher antioxidant, antimicrobial, antidiabetic, anti-inflammatory and antiproliferative properties. The obtained natural extracts were tested as potential preservatives by delaying the oxidation of fresh-cut apples, achieving promising results for growth inhibition of bacteria, filamentous fungi and coliforms along 12 days of refrigerated storage. Avocado is a very perishable food and, consequently, high amounts of wastes are generated. Gamma irradiation at 4 kGy suggested an increased extractability of bioactive compounds from peel, also improving its antioxidant and antimicrobial potential. For the processing pineapple wastes, aqueous extracts obtained at room temperature seemed to contain higher phenolic compounds concentrations and antioxidant activity in comparison with the ethanolic extracts, and a preservation of these parameters were observed using gamma radiation at 4 kGy.

Conclusion

The outcomes of this comprehensive work can contribute to foster the use of ionizing radiation as a sustainable process, while providing helpful information in developing new ingredients for food and pharmaceutical industries and paving the way to the implementation of the circular economy concept.

IAEA-CN-332/355

Enhancing Microplastic Detection with Electron Beam Technology

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The issue of microplastic pollution represents a substantial global environmental challenge, with the current analytical techniques, such as Raman microscopy and TED-GC-MS, being both time-consuming and expensive. Simple differential scanning calorimetry (DSC), which is readily available in many laboratories, has been proposed as a more efficient and cost-effective alternative following enrichment through electrostatic separation. Nevertheless, the challenge of differentiating polymer mixtures with similar DSC signals, such as HDPE and PP—two extensively utilized plastics—remains a significant obstacle, impeding the broader application of this method.

This study investigates the potential of electron beam treatment to enhance the physical properties and electrostatic separability of these polymers. Microparticles of the size fractions 63–200 µm, 200–630 µm, and 630–1000 µm of HDPE and PP were produced by cryo-milling and sieve fractionation. The particle size distributions were subsequently verified through laser diffraction analysis. Subsequently, samples with known MP contents were meticulously combined. The particle mixtures were distributed as a monolayer on a Petri dish and subjected to electron beam treatment at the Steigerwald electron beam facility at HTW Dresden. The acceleration voltage was set to 150 keV, and doses between 7.5 and 150 kGy were applied. Subsequently, the samples were stored at room temperature for varying periods of time. Subsequently, the mixtures were fractionated in the electro-separator in one and three stages, after 1, 2, 4, 8, 24, and 48 hours. Subsequently, the polymer type and the content of each polymer in the fractions were determined using differential scanning calorimetry (DSC).

Our experimental findings reveal that after electron beam pretreatment, high-density polyethylene (HDPE) and polypropylene (PP) can be effectively fractionated using a corona roller separator. This is attributed to the differential storage properties of absorbed primary electron charges induced during low-energy electron beam treatment, which facilitate the separation under optimal conditions.

These insights not only enhance the differential enrichment of HDPE and PP for a rapid and cost-effective microplastic analysis, but also have significant implications for optimizing plastic recycling processes. The study highlights the potential of electron beam radiation as a pretreatment method, advancing both microplastic analysis and plastic waste management strategies.

IAEA-CN-332/359

Quality Management Practice for Radiation Processing in Myanmar using Alanine-EPR Dosimetry System

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Keywords: Gamma irradiation, Alanine-EPR dosimetry system, dose difference, uncertainty

1. Background

In Order to enhance the Quality Management System (QMS) of irradiation facilities, Quality Assurance/Quality Control (QA/AC) practice is very crucial. This practice is intended to support the implementation of Quality Management System of future irradiation facilities in Myanmar. Gamma Chamber GC 5000 is currently used for the research and development of food irradiation, sterilization, polymer modification and environmental application in Myanmar. Alanine- Electro Paramagnetic Resonance (EPR) dosimetry system can be used in wide range of dose (<10Gy-150kGy). The result of dose difference between target dose and measured dose, and measurement uncertainty is presented.

2. Methodology

For QA/QC purpose, in order to verify absorbed dose using GC 5000 gamma irradiator, alanine dosimeters are irradiated with (10kGy,20kGy,30kGy ,40kGy,50kGy) with dose rate of Gamma irradiator is 0.691 kGy/hr at irradiation time in Myanmar. Alanine dosimeters are sent and read out by Electro Paramagnetic Resonance EPR at institute of nuclear chemistry and technology INCT, Warsaw, Poland. From results, it is found that dose difference between target dose and measured dose is 5.8% to 20.6%.

3. Result and Discussion

Target dose & Measured dose and uncertainty are presented in Table 1. In this measurement, uncertainty with k=2(two standard deviations) is used in 95% confidence. Dose difference is considerably higher so it is needed to optimize our current dosimetry calculation method based on GC producer and other influence parameters to reduce the difference for better accuracy of dosimetry system.

Table 1. Measurement of Target Dose & Measured Dose and its uncertainty

Target dose [kGy] Measured/Absorbed dose [kGy] Dose Difference (target dose-measured dose)/target dose 100% Uncertainty [kGy]

10 8.03 19.7 0.36

20 15.88 20.6 0.72

30 24.88 17.06 1.13

40 34.66 13.35 1.57

50 47.10 5.8 2.14

Combined standard Uncertainty $\boldsymbol{uc}$ = √($\boldsymbol{u1}$ $\mathbf{2}$ + $\boldsymbol{u2}$ $\mathbf{2}$ + $\boldsymbol{u3}$ $\mathbf{2}$,+ **-**, Expanded Uncertainty U=k $\boldsymbol{uc}$, Dose measurement uncertainty is commonly expressed for a coverage factor k=2 providing about 95 % level of confidence.

4. Conclusion

This dose verification practice work is intended to enhance the QMS system for irradiation facilities and continue to perform the QA/QC practice such as dose mapping, dose distribution with different types of dosimeters for future facilities in Myanmar. Implementation of QMS system for radiation processing facilities are being performed in connection with international organization for better performance under RAS 1028 project.

IAEA-CN-332/371

Studying of the Mechanical Resistance of Reinforcement Concrete by Using Ultrasonic Waves

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Introduction: It is well known that It is possible to measure of mechanical properties of concrete directly by using destructive and nondestructive methods. ultrasonic wave is one of very useful nondestructive method usually used to determine homogeneity, mechanical concrete properties including its resistance. Objectives: in this work, we investigated the effect of Concrete moisture percentage, concrete temperature, and the effect of rebar in concrete on ultrasonic pulse velocity. In addition, the experimental relationships between pulse velocity, dynamic and static modulus of elasticity and mechanical resistance of concrete were also studied. Moreover, the effect of the ratios C/Agg, C/W, and S/G on the change in concrete durability and the speed of ultrasonic waves were also investigated. Methodology: In this method, pulses are generated, which are ultrasound waves that spread through the tested part, and their transmission time is determined. These waves travel in elastic media, just as sound waves travel in the air. Longitudinal waves propagate at the highest speed, followed by transverse waves and finally surface waves. The speed of propagation of these waves is related to both the elastic properties of the medium and the specific gravity of the material. Results: It was found that the speed of the pulse through a solid body depends on the density of the tested material and its elastic properties. In addition, it was noticed that the pulse speed for water-saturated concrete is higher than for air-dried concrete, and the moisture has a lesser effect on the speed of high-resistance concrete than low-resistance concrete. Moreover, in general, thermal changes in the range between 10 - 30 do not affect the speed measurements, however, if the temperature changes exceed the previous range, corrections must be made to the pulse velocity values. It was observed that the Abrams cone dip increases with a decrease in the C/Agg ratio and with an increase in the W/C ratio. Moreover, it was noted that the concrete resistance is almost constant and is not affected by the C/Agg ratio. Therefore, the strength of concrete is not related to the amount of cement in the concrete mix and the strength of concrete cannot be changed by changing C/Agg.

Keywords Ultrasound Pulse, Echo, Non-Destructive Tests

IAEA-CN-332/372

Impact of Radiation Parameters on the Physicochemical and Electrochemical Properties of Vinyl Imidazole-Grafted ETFE

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Radiation-induced grafting is a versatile method for modifying polymers, making it particularly suitable for a range of applications, including the synthesis of advanced polymer electrolytes for electrochemical applications. The technique involves the incorporation of ion (cation/anion) conductive groups onto polymer backbones through gamma radiation.

Grafting vinyl imidazole onto a polymer backbone presents a promising approach for synthesising the stable ion exchange membranes for various electrochemical applications . Various studies have been reported to graft vinyl imidazole through radiation grafting using pre irradiation method. However low grafting yield of Vinyl Imidazole grafted polymer, limits the use of radiation induced grafting.

It has been observed that during radiation grafting, dose rate, total dose and method used (pre-irradiation or mutual) are important parameters which affect the grafting yield and the subsequent properties of the grafted membranes.

In this study, we investigated the impact of dose rate on the physicochemical properties of the grafted films prepared through direct method. Specifically, 1-vinylimidazole was grafted onto Ethylene tetrafluoroethylene (ETFE). ETFE films with a thickness 25 µm, cleaned with ethanol solution, were cut into dimensions of 4 x 4 cm^2. Reaction mixtures containing varying quantities of 1-vinylimidazole, ferrous sulphate, and water were prepared in glass reaction tubes. The cleaned ETFE films were immersed in these reaction mixtures and the reaction mixtures were irradiated using gamma (γ) radiation to graft 1-vinylimidazole onto the ETFE films via a mutual irradiation technique. Two gamma (γ) radiation sources were employed: (i) a Co-60 source with a dose rate of 4.779 kGy/hr located at the Department of Physics, Indian Institute of Technology, Roorkee,India and (ii) a Co-60 source with a dose rate of 1.522 kGy/hr at the Inter-University Accelerator, New Delhi, India. After grafting reaction in the aforementioned reaction conditions, the graft copolymer films were washed well in methanol overnight to remove unreacted monomer, followed by drying for 24 hours in the oven at 60°C. The procedure continued till the appearance of constant weight. The degree of grafting (DOG) of the grafted ETFE films (ETFE-g-1VIm) calculated by weight method.

The grafted films were characterize through FTIR, SEM, Raman spectroscopy, and XPS. Both mechanical and electrochemical properties of the films were evaluated. Our results indicate that, in addition to factors such as monomer concentration, solvent, and total dose, the radiation dose rate significantly affects the properties of the grafted membranes. The percentage of grafting remained relatively consistent across different dose rates (see Fig. 1). Notably, membranes synthesized at the higher dose rate of 4.7 kGy/hr exhibited favoured graft copolymerization with minimal homopolymerization. In contrast, grafting at a lower dose rate of 1.522 kGy/hr led to excessive homopolymer formation. The film produced at the higher dose rate displayed a uniform structure, as confirmed by FESEM. Additionally, the membrane prepared at the higher dose rate demonstrated superior electrochemical performance in alkaline water electrolysis tests. This study highlights the importance of optimizing the dose rate to enhance the functional characteristics of grafted polymer membranes and tailor their physicochemical properties.

IAEA-CN-332/375

An Overview of Activities at the Co-60 Gamma Irradiation Facility at the Ruđer Bošković Institute

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The Co-60 gamma irradiation facility at the Ruđer Bošković Institute (Radiation Chemistry and Dosimetry Laboratory) is the only of the kind in Croatia and a significant resource for research, development, and contract services related to irradiation technologies. Established in 1962, the facility has been providing services since 1983 and offers a range of capabilities for various applications. It is a semi-industrial, panoramic, dry-storage type irradiator with maximum capacity 120 kCi, while current (July, 2024) activity is around 30 kCi.

The facility offers a wide range of doses and dose rates, from Gy to MGy, suitable for applications across different fields. These applications include radiation processing, radiation chemistry, material science, radiobiology, and accident dosimetry.

The facility serves various industries, primarily for sterilization of medical devices, accessories, instruments and implants; microbiological decontamination of pharmaceuticals, cultural heritage preservation, and pasteurization of products like herbs, teas, seeds and microgreens. Gamma radiation facility at RBI has implemented EN ISO 13485:2016 standard for Quality Management System in Sterilization of medical devices and has been certified since 2021.

Ongoing research projects at the facility involve topics such as recycling polymer waste, nanomaterial synthesis, cultural heritage preservation, material properties improvement, and radiation resistance of detectors and electronic components in collaboration with CERN.

In this presentation, an overview of the diverse activities and applications of radiation processing in Croatia will be showed, along with insights into the main challenges and obstacles faced in this field.

IAEA-CN-332/381

Advocacy for Establishing a Center of Excellence for the Development of Irradiated Veterinary Vaccines in Africa

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Africa faces critical challenges from zoonotic and transboundary animal diseases, significantly impacting animal health, food security, public health, and the economy. Diseases such as rabies, brucellosis, anthrax, Rift Valley fever, Ebola, and Peste des Petits Ruminants (PPR) pose severe threats. Addressing these requires a collaborative "One Health" approach, integrating veterinary, public health, and environmental sectors. Veterinary vaccines are essential for protecting animal health, ensuring food security, reducing economic burdens, safeguarding public health, addressing emerging diseases, meeting regulatory standards, and driving research and development. Despite over 22 vaccine manufacturers in Africa, Tunisia, like many other African countries, relies on imported veterinary vaccines. The prevalent method for pathogen inactivation in vaccine preparation is chemical treatment. However, irradiation techniques (gamma rays, X-rays, and electron beams) have emerged as promising alternatives, offering several significant advantages. Currently, only one commercial vaccine, Bovilis Huskvac (MSD Animal Health), uses gamma irradiation for inactivation. A concept note advocating for establishing a Center of Excellence for the Development of Irradiated Veterinary Vaccines in Africa, leveraging Low-Energy Electron Irradiation (LEEI), was submitted to the International Atomic Energy Agency (IAEA) in June 2024. This center will focus on research, development, and production of irradiated vaccines, aiming to enhance the region's capacity to manage zoonotic and transboundary animal diseases. The establishment of such a center aligns with United Nations Sustainable Development Goals as well as with the goals of the IAEA and its Third International Conference on Applications of Radiation Science and Technology (ICARST-2025). The proposed center will contribute to sustainable development, economic stability, and public health improvement in Africa by advancing the use of irradiation technologies in veterinary vaccine production. Tunisia, with an ongoing two projects — Technical Cooperation (TC) Project and a Coordinated Research Project contract (http://www.aquavac-ir.tn/) about fish irradiated vaccines — has been leading this initiative. The development of the quality control process for irradiated vaccines will receive support from AU-PANVAC, while the efficacy of these vaccines will be validated through field studies. Additionally, Tunisia has been developing innovative technology for producing vaccinal recombinant proteins using radiation-inducible promoters, shuttle vectors, and radioresistant bacterial strains, and the AFRAVAC-IR project will help transfer this technology to other African countries.

IAEA-CN-332/386

Assessing the Use of UAV Assisted Gamma Column Scanning: A Futuristic Perspective

P. Baricholo (National University of Science and Technology) – Zimbabwe

We report on the possibility of using unmanned aerial vehicles in gamma column scanning. Use of unmanned aerial vehicles offers a number of benefits from a safety and execution time perspectives. Their use will minimise exposure of personnel to ionising radiation as both source and detector could be mounted on these vehicles. Using this technology will reduce the scan time. During a scan, both source and detector are mounted on two drones that are operated synchronously to move on opposite sides along the length of the column. In this research, we assess the feasibility of the proposal and evaluate the possibility of implementing the technology in future scans. Major drawbacks that could be encountered are evaluated and possible counter measures proposed. Advancement of technology requires that implementation of gamma column scanning also follow current technology trends.

IAEA-CN-332/391

Use of Gamma Irradiation as a Pretreatment in Brewer’s Spent Grain (BSG) Protein Extraction

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BSG is an insoluble solid brewing industry by-product, with significant amounts of valuable components, as dietary fiber and proteins. Due to microbiological instability and low shelf-life, it is currently used as a low-cost feed for cattle. The main objective is extract BSG’s protein using gamma irradiation as a pretreatment. Samples of BSG, Pilsner variety, were obtained by brewing beer. Doses from 0.0 to 10.0kGy (7.0kGy/h) were applied to the BSG. The samples were dried and stored under refrigeration. These were characterized by moisture content, crude protein, total lipids, fatty acid composition and colour. The lower doses were effective to extend enough the shelf-life. Oil content ($p=0.8840$) and protein ($p=0.3010$) there were no significant differences. The colour difference was significant ($p<0.001$). The saturated lipids present significant differences ($p=0.0364$) between control and 10kGy. Furthermore, monounsaturated ($p=0.6830$) and polyunsaturated ($p=0.595$) lipids are statistically not significant for all treatments. The maximum ratio of recovered protein was 47.29±2.98% M.d. The figure1 shows how Band-4 (MW~70kDa) is nearly undetectable in the control but increases with higher irradiation doses, while Bands-7 (MW~40kDa) and Bands-8 (MW~30kDa) decrease. The use of gamma irradiation as a pretreatment in the extraction of BSG’s protein can be a good alternative to drying.

IAEA-CN-332/392

Gamma Radiation as a Tool to Reduce Emerging Organic Pollutants in Sewage Effluents

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The consumption of synthetic compounds that are incompletely metabolized by humans has increased substantially. Inefficiencies in conventional wastewater treatments allow these compounds, known as emerging organic compounds (EOCs), to enter water bodies, causing various environmental impacts. Developing efficient sewage treatment technologies is crucial. Ionizing radiation is recognized for its ability to degrade pollutants. This study aimed to assess gamma radiation (60Co-750 kCi) as a tool to enhance biodegradability and reduce the concentration of EOCs in sewage effluents. Sewage effluents containing 50 ppm of atenolol, sildenafil, or methylparaben were irradiated with doses of 0, 2, and 4 kGy. Biological oxygen demand (BOD5) and chemical oxygen demand (COD) were measured, and the biodegradability index (expressed as BOD5/COD) was calculated. The results demonstrate that irradiation significantly reduced BOD5 while increasing COD (see figures 1 and 2), leading to a substantial improvement in biodegradability (see figure 3) across all treatments. In conclusion, gamma radiation has proven to be an effective tool for removing EOCs from real sewage effluents contaminated with these pollutants.

IAEA-CN-332/405

Synergy between IAEA and EU Programs on Accelerators Applications

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The EU and IAEA took steps to strengthen their cooperation in a range of nuclear activities, including nuclear science applications, during the fifth annual Senior Officials Meeting (SOM). IAEA DG Rafael Mariano Grossi emphasized the importance of EU as a major partner and supporter of the IAEA. It was the first time IAEA DG to speak at the European Parliament. The official EU statement 67th GC „The Euratom R&T program will complement the achievement of Horizon Europe's objectives. In the non-power application field,…". A good example of the implementation of this idea in the field of radiation processing are the activities of the Radiochemistry and Radiation Technology Section, Department of Nuclear Sciences and Applications. The general topical areas are being formulated in the framework of CRPs and, in the case of Europe, under regional projects. Nowadays, in a project RER1024, "Enhancing the Use of Radiation Technologies for Improved Resource Efficiency", The R&D work is based on the application of radiation sources, mostly electron accelerators. Also EU important projects support activities in the development and application of accelerators and their engineering, like I.FAST and providing access to the facilities EuroLabs .The objective of I.FAST is to work on particle accelerators, which currently face critical challenges related to the size and performance of future facilities for fundamental research, the increasing demands coming from accelerators for applied science, and the growing applications in medicine and industry. The EURO-LABS enables international teams to get access to research infrastructure with the support of the Horizon Europe EU Programme. INCT is leading a Euratom, Non-Power Applications project called RADOV. Finally, the Erasmus+ project provides collaboration with countries from all over the world. The main partners of INCT in the mentioned projects are representatives of the MS, which were linked thanks to the IAEA-mentioned programs. The INCT CC of IAEA RAPID makes it possible to coordinate these actions .Important to mention both IFAST & EuroLabs covers all type of particle accelerators. In EU HITRIplus several work packages are focusing on developing novel technologies to provide better and cheaper and IAEA RER6039 "Developing Human Resources for Setting Up an Ion Beam Therapy Centre within the Joint South East European International Institute for Sustainable Technologies" covers many aspects of the work going on in EU financed project. Diffusion of the developments between experts working on heavy ion accelerators and electron beam accelerators, may lead to goal related to expected innovations "better, cheaper, more efficient - to save electricity and preserve environment".

I.FAST – Innovation Fostering in Accelerator Science and Technology (No 101004730); EURO-LABS – EUROpean Laboratories for Accelerator Based Sciences (No 101057511); RADOV – RADiation harvesting of bioactive peptides from egg prOteins and their integration in adVanced functional products (No 101061694); Erasmus+ – 21 projects for mobility and Strategic Partnership "Joint innovative training and teaching/learning program in enhancing development and transfer knowledge of application of ionizing radiation in materials processing" (2014-1-PL01-KA203-003611); HITRIplus - Heavy Ion Therapy Research Integration plus (No 101008548)

IAEA-CN-332/406

Radiotolerance in the Developmental of Diatraea saccharalis

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The study forms part of a research project framed in the CRP D61026, aimed at comparing various pest species to determine the most radiotolerant. The investigation commenced with the sugarcane borer Diatraea saccharalis Fabricius (Lepidoptera: Crambidae), a significant agricultural pest in South America due to its destructive impact on sugarcane, corn, rice, and wheat. To assess the impact of gamma radiation (60Co) on both larval and pupal development stages, the pests were reared on an artificial diet under controlled conditions. Larvae were subjected to doses ranging from 100-200Gy, while pupae were exposed to doses spanning 150-350 Gy at a rate of 14Gy/h. The percentage inhibition of normal adults emergence was measured in both cases. Findings indicate that pupae exhibit greater radiation tolerance; larvae demonstrated complete inhibition above 100 Gy, whereas pupae showed 48-57% inhibition within the range of 150-350 Gy. Further investigations are warranted to determine an effective dose resulting in complete inhibition for pupa development stage. Although larvae were more radiosensitive stage than pupae must be considered as it is in this last developmental stage that we find pests in agricultural products; therefore, studies to determine effective quarantine treatment doses should focus on this developmental stage.

IAEA-CN-332/408

Implementing Chile's First Human Tissue Processing Facility under Clean Room Standards: Enhancing Tissue Quality and Safety for Chilean Patients

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In Chile, the National Tissue Bank was created by the Ministry of Health in 2017 under the eaves of the San Borja Arriarán Hospital, in order to provide tissues with clinical quality for the entire country. It is a public institution, the only multi-tissue bank at the national level, which has been working since the beginning joint with the Chilean Nuclear Energy Commission to deliver safe products for clinical use to the National Health Network. After the fire that destroyed the National Tissue Bank facilities in January 2021, processing activities have been carried out in temporary rooms adapted for work with human tissues, pending the infrastructure replacement project in charge of the Health Service – Ministry of Health.

This year 2024, the Chilean Nuclear Energy Commission and the National Tissue Bank have developed a project with funding from the Ministry of Social Development for the implementation of a Biological Tissue Laboratory with clean room quality, the first in the country, which will be used to process human tissues and cells for therapeutic purposes and generates a new space for R+D. This new facility of approximately 100 m2, physically located in the Nuclear Research Center La Reina, was designed by adapting the old infrastructure available, to have two grade B laboratories, intended for the preparation of tissues for implantation and cell and tissue culture, and support areas such as reception, refrigerator/freezer room, sterile supplies room, in a grade C environment. The laboratory is expected to be launched over the next few months and thus be able to develop new tissues and products under the highest international standard. To date, we are working on the qualification of the HVAC system, protocols design, equipment plan and implementation, with the support of the IAEA through the CHI1020 project to strengthen the capacities of human resources, equipment and expert guidance.

Having developed and established the processes that will be carried out in this new facility, we project that the National Tissue Bank will be able to increase its annual production by 30% and in turn be able to develop new products such as amniotic tissue graft in oversized sheet presentation for major burn injuries, human skin from cadaveric donors and supporting bone tissue such as long bone. In joint work with the Chilean Nuclear Energy Commission, tissue radiosterilization will continue to be carried out, as well as improvement of processes and R+D initiatives that allow new tissues and presentations, develop new therapeutic tools based on tissues and cells, contributing to providing quality, timely and accessible treatments for the chilean patients along the country.

IAEA-CN-332/410

Principal Component Analysis as a Crucial Strategy for the Development of Hydrogel Dressings with Gamma Radiation

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Hydrogels are polymeric structures which can be used as wound dressings. The goal of this work was to develop two types of methodologies for preparing hydrogels and then, to use a statistical strategy to select the most appropriate method. Polyvinylalcohol/polyvinylpyrrolidone hydrogels were prepared by: 1) Synthesis with gamma radiation (GA) to make radiochemical hydrogels (RH) and 2) Synthesis with GA and thermal cycling to make hybrid hydrogels (HH). Doses range from 15 kGy to 50 kGy (60Co - ~750 kGy) were used and macroscopic characteristics like swelling, dehydration (D%), exponential diffusion (n), water diffusion coefficient (D) and gel fraction (GF) were evaluated. Principal Component Analysis (PCA) and statistical analysis were performed. According to PCA, HH treated with 25 kGy to 40 kGy had better macroscopic characteristics than RH which had higher ability to swell than HH. In addition, as the dose increased the swelling decreased, GF and dehydration increased. The n values followed a Fickian process, except for 50 kGy and D were between 1.8 x10-7 and 6.2 x10-7 cm2/min. In conclusion, the statistical strategy was an innovative approach that allowed to select the best conditions to make hydrogels with desirable characteristics to be used as wound dressings.

IAEA-CN-332/412

Shelf Life Extension and Quality Improvement of Ground Beef Through Plant Extracts and E-Beam Technology

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Food safety is a global health concern, and several instances have been associated with foodborne disease outbreaks that affect consumers, food industries, and the global economy. Ground beef is a highly sought-after and popular source of muscle food due to its significant protein content and the supply of various essential nutrients in a form that can be readily absorbed by the body. The primary issues affecting the safety and quality of ground beef during storage are microbial contamination of beef products and the oxidation (rancidification) of lipids and proteins within the beef matrix. In fact, ground meat is prone to rapid bacterial growth, which can cause food-borne illness and quality control issues. Irradiating ground beef is an effective method to prolong its shelf life; however, excessive irradiation doses can lead to lipid oxidation, reduced overall acceptability, and alterations in the product's organoleptic characteristics. Various research studies conducted globally have explored the use of natural antioxidants to inhibit lipid oxidation in different food items. For instance, extracts such as rosemary, pomegranate rind, and thyme powder have demonstrated effectiveness in minimizing lipid oxidation in meat patties. This research investigates the impact of a combination of low-dose irradiation (2 kGy) and plant extracts on the shelf life and microbiological quality of ground meat. Ground meat samples underwent treatment with thyme herb extracts, electron beam irradiation, and a combination of both. Treated samples were then stored at 4°C and regularly assessed for microbiological, physiological, and sensory attributes. The microbiological analysis of the treated ground meat samples revealed a significant decrease in total Coliforms, E.coli, molds and yeasts; and Staphylococcus spp. counts with an increase in irradiation dose. Initial findings indicated that the addition of thyme herb extracts to ground meat samples led to a notable reduction in TBARS values, elimination of unpleasant odors, and enhancement of sample color. Furthermore, the combined treatment of thyme herb extracts and 2kGy irradiation prolonged the shelf life of the tested samples by 10 days under the proper refrigeration conditions in comparison to samples treated solely with irradiation.

IAEA-CN-332/414

GPR Investigation on the Masonry Supporting Giotto's Mural Painting, Bardi Chapel, Santa Croce Basilica at Florence, Italy

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The wall of the Bardi' Chapel, in the Santa Croce Basilica at Florence (Italy), are fully covered by precious mural paintings executed by Giotto in the early XIV century and illustrating the life of Saint Francesco, now in need of conservation intervention. For this purpose, GPR investigation has been performed on the walls for investigation both the masonry structure and assemblage and the plaster thickness. GPR survey had been executed with more antennas operation at different frequencies for investigating in depth or in detail: Stream T (900 Hz), C thrue (1500 Hz), C thueES (2000 Hz). The results are fully satisfying revealing a full masonry (60 cm thick) constituted by two external curtains in blocks of hard sandstone and a core of mortar and stone elements half-hazardly assemblage. Plaster has a first layer smoothing the roughness of the masonry; over, two subsequent layers appear present, as also confirmed by two small essays appositely executed: an older one and outside the Giotto's layer supporting the mural painting.

IAEA-CN-332/418

Determination of Sublethal Doses in Deteriorating Insects of Cultural Heritage: Breeding, Damage, and Behavior

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Organic Cultural Heritage assets are susceptible to attack by various deteriorating organisms, primarily fungi and insects. While there are various treatments available for their control, the application of ionizing radiation has proven to be effective, safe, and highly efficient.

The objective of this study was to determine the sublethal doses necessary to halt the damage caused by insects. This approach ensures that insects do not immediately die but lose the ability to continue causing harm.

For this study, the carpet beetle species Anthrenus verbasci was bred, and radiosensitivity tests were conducted using gamma radiation (60Co) ranging from 500 Gy to 1000 Gy, at a rate of 10 kGy/h.

Figure 1 presents the results of insect longevity at different doses. It was observed that mortality occurred between 15 days post-treatment at doses between 800 and 1000 Gy. During survival, feeding behavior, locomotion, and developmental cycles significantly decreased or were interrupted. Regarding material properties, no significant differences were observed compared to control samples.

An advantage of using sublethal doses is that doses lower than those causing insect mortality result in fewer adverse effects on treated materials.

IAEA-CN-332/422

Gamma Irradiation: Sensory Shelf Life for Fine Cut Salamín (Argentinian Dry Fermented Sausage)

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The use of gamma-radiation technology enhances food safety by eliminating pathogenic like Listeria monocytogenes in Fine Cut Salamín (FCS), a traditional Argentinian dry-fermented sausage (comprising pork, beef, bacon, salt, sugar, spices, wine and lactic-acid bacteria). In this research, the effects of gamma radiation (0 and 4kGy, 60-Co, ~750 kCi) on Sensory Shelf Life (SSL) test of vacuum-packed FCS during 120-days refrigerated-storage (4±0.5ºC) were analyzed. SSL and sentimental analysis was study. Figure 1 shows the results obtained. This study found that SSL was of 120 days, as the rejection percentage did not exceed 50% in either of the two treatments (control and 4kGy). Furthermore, samples had been the same rejection percentage for both treatment at 120 days. However, the consumer sentiment analysis revealed that irradiated samples at 120 days had been more flavorful compared to control samples. Moreover,the taste could be the determining factor in determining SSL test.

In conclusion, FCS vacuum-packaged and irradiated with 4kGy has an acceptable SSL up to 120 days, although further studies would be needed to establish the full lifetime of FCS.

IAEA-CN-332/423

Transformation and Mitigation of Toxicity of Pharmaceutical Pollutants with Ionizing Radiation

M. Vogt, A. Larrandart, B. Borda, C. Barrenechea, M. Espinosa, M. Espantoso, M. Mazzei, P. Babay, Y. Dalto (Comision Nacional de Energia Atomica), Ariana Rossen (National Institute of Water), E. Munarriz, F. Kronberg (University of Buenos Aires) – Argentina

A portion of pharmaceuticals consumed by humans and animals reach sewage effluents, and conventional treatment plants struggle to eliminate them effectively. This study investigated the transformation of emerging organic contaminants like drugs: atenolol, carbamazepine, sildenafil citrate, and preservative: methylparaben (50 ppm in distilled water), using gamma radiation (60Co - ~750 kCi - 1 to 4 kGy). The chemical transformation was quantified through UV-Vis spectroscopy, HPLC-MS, COD, and toxicity assays with seeds, algae, and nematodes. Additionally, the degradability post-treatment was assessed by BOD with drugs dissolved in real effluents.

The results showed a reduction in peak areas and COD with increasing radiation dose. The addition of inorganic ions resulted in a slight decrease in removal efficiency. HPLC-MS revealed that over 90% of the compounds were removed with 2 kGy, except for methylparaben. Seed assays indicated no toxicity of the compounds up to 10 ppm. A mixture of the four compounds (10 ppm each) in the nematode Caenorhabditis elegans demonstrated adverse effects on reproduction, which were reversed with 0.5 kGy. The DBO of the drugs inoculated into real effluents significantly decreased with doses of 2 and 4 kGy. These findings underscore the potential of ionizing radiation treatments to be integrated into wastewater treatment plants for effective micropollutant removal.

IAEA-CN-332/425

Automated Irradiation System for the Production of Gaseous Radioisotopes in a Research Nuclear Reactor

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Some gaseous radioisotopes are produced to meet requests from companies specialized in using them as radiotracers, for quantitative and qualitative assessments of industrial plants, such as leak detection in heat exchangers and underground transport pipes. Among the gaseous radioisotopes for this purpose, 41Ar and 79Kr stand out, as they have a number of relevant physical and chemical properties and the production of these radioisotopes in research nuclear reactors takes place by subjecting the natural isotopes (40Ar and 78Kr) to a neutron flux, so that the atoms in the gas undergo the nuclear reaction (n,γ) and become radioactive. At the IEA-R1 Research Reactor, production takes place using an Irradiation System developed at the Radiation Technology Center for this purpose. The aim of this study was to automate and modernize this system for remote operation, following the ALARA (As Low As Reasonably Achievable) principle, by automating its components, the Programmable Logic Controller (PLC), installing solenoid and pneumatic valves, a pressure transmitter, mechanical adaptations and developing its own supervisory software. Subsequently, leak tests were carried out, the new operating procedure (without radioactive material) was tested and, finally, after approval by the Reactor's Internal Safety Committee, an irradiation was carried out to obtain an estimated Activity of 960 mCi (41Ar) and verify radiological safety for future irradiations reaching higher Activities. After the tests and initial irradiation, it is concluded that the automated system is suitable for use in the production of the gaseous radioisotopes 41Ar and 79Kr, providing greater radiological safety for its operators.

IAEA-CN-332/430

Detection of Irradiated Food

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The Laboratory for Detection of Irradiated Foods detects technologically irradiated foods using ionising radiation sources. Spices, herbs, herbal products, teas, dried and fresh vegetables, mushrooms, fruits, shrimps, mixtures of spices and herbs, including food compositions such as sauces, flavour additives, flavoured pastas, food supplements, phytopharmaceuticals, plant extracts and foods containing bones (meat and fish), egg shells and nuts are tested using by electron spin resonance (ESR), photostimulated luminescence (PSL) and thermoluminescence (TL) methods.

The Laboratory for Detection of Irradiated Foods performs measurements in the field of:

- Detection of irradiated food containing bone by ESR spectroscopy according to the guidelines of the EN 1786:1996 standard.

- Detection of irradiated foodstuff containing cellulose by ESR spectroscopy according to the guidelines of the EN 1787:2022 standard.

- Detection of irradiated foodstuff containing crystalline sugars by ESR spectroscopy according to the guidelines of the EN 13708:2022 standard.

- Thermoluminescence detection of irradiated food from which silicate minerals can be isolated according to the guidelines of the EN 1788:2001 standard.

- Detection of irradiated food by photostimulated luminescence according to the guidelines of the EN 13751:2009 standard.

The Laboratory for Detection of Irradiated Foods has been accredited by the Polish Centre for Accreditation since 1999 and operates in accordance with the management system appropriate to the scope of its activities and meets the requirements of the EN 17025:2017 standard.

To avoid the unintentional presence of microorganisms in the finished product, manufacturers often sterilise foods (e.g. plant ingredients) using ionising radiation. Foods irradiated with ionising radiation should follow the guidelines of the European Directive, which states that the words "irradiated" or "treated with ionising radiation" must appear on the product label.

IAEA-CN-332/434

Enhancing ABS Swabs Production: Proven Resistance to Radiation

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The need for reliable nasopharyngeal and oropharyngeal swabs has surged, highlighting the importance of robust, safe and sterile materials in medical devices. Our analysis focused on Acrylonitrile Butadiene Styrene (ABS) swabs, analyzing their performance under various irradiation conditions.

ABS was irradiated in air environments with doses of 40 kGy and 60 kGy, using a 60Co gamma source (750 kCi) and an electron accelerator (11 MeV). The mechanical properties were analyzed through tensile tests while thermal and chemical properties were studied by Differential Scanning Calorimetry (DSC) and Fourier Transform Infrared Spectroscopy (FTIR), respectively and viscoelastic properties were studied through rheometry with sinusoidal dynamic oscillation. Accelerated aging tests were conducted to simulate long-term usage.

Results showed no notable differences in ABS properties between aged and non-aged samples in terms on mechanical and chemical properties, with ABS maintaining thermal stability post-irradiation. Although chain scission was detected through rheometry assays, ABS exhibited resilience to radiation.

Our findings confirm that ABS is an adequate material for swabs and possibly for other medical device production requiring radiation sterilization, ensuring microbiological safety and physical and chemical stability.

IAEA-CN-332/435

Mitigation of Emerging Organic Pollutants Using Ionizing Radiation: Ecotoxicological Analysis

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In recent years, different strategies to tackle environmental pollution have been gaining global attention. Increasing world population, agricultural and industrial developments have generated large volumes of polluted wastewater. As a result, cost-effective treatment technologies are being sought.

Recent research has demonstrated the effectiveness of ionizing radiation (electron and gamma beams) in the decomposition of emerging organic contaminants (EOCs) and the elimination of microorganisms and parasites. This technology offers a novel, additive-free, and cost-effective option for the treatment of drinking water, waste, and groundwater.

In this study, five drugs were selected: atenolol, carbamazepine, ciprofloxacin, methylparaben, and sildenafil citrate. Solutions of each drug at 50 ppm were irradiated using gamma radiation (60Co - 750 kCi) at 2 kGy. Acute toxicity assays of the irradiated products and their controls were conducted using the alga species Selenastrum capricornutum, evaluated in terms of relative growth (cells/ml, 96 h, 20 °C). The results showed reduced growth development when exposed to irradiated drugs compared to the control drugs, suggesting further study is warranted to confirm feasibility through analysis of doses both lower and higher than those used for toxicity removal in algae.

IAEA-CN-332/437

Impact of Gamma Irradiation Sterilization on the Biochemical Stability and Biocompatibility of Collagen-Based Wet Medical Devices

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Collagen type I hydrogels are widely used in biomedical applications due to their biocompatibility, biodegradability, and because they enhance cell attachment and proliferation. One of the most difficult aspects of their production is achieving thorough sterilization while preserving structural and functional qualities of collagen. Gamma irradiation is considered to be the most efficient method of sterilization because it can penetrate deep into materials. Unfortunately, it can cause structural damage, unwanted cross-linking and denaturation of collagen, which alters its physical-mechanical characteristics and bioactivity. For this reason, optimization of the radiation dose is critical, especially to control the (bio)chemical alterations it can trigger.

The aim of the study was to evaluate the changes in the (bio)chemical and biocompatibility behavior induced by different dose windows for gamma irradiation sterilization of type I collagen gels, according to the ISO 11137 standard.

Collagen hydrogel samples were sterilized using two doses in the usual sterilization range (15-40 kGy) under protective conditions (dry ice, –79 °C) as well as at room temperature. Irradiation-induced changes in total free amino acids content, soluble polypeptides fraction, free radical scavenging capacity, as well as bio- and hemo-compatibility in correlation with resistance to collagenase hydrolysis were investigated. The study found that protective irradiation assisted by dry ice increased the stability and antioxidant capacity of collagen, while irradiation at room temperature decreased the content of free amino acids. In addition, irradiation at room temperature increased collagen cross-linking, evidenced by a lower release of hydroxyproline under the effect of collagenase. The hemolytic capacity of the irradiated samples was moderate in the case of irradiation at room temperature and weak in the case of protective irradiation, exceeding, however, in both cases, the limits imposed by international standards. The biocompatibility of the collagen hydrogel samples was also tested in vitro using primary human dermal fibroblasts cultures (HDFa) as a cell model. Measurement of metabolic activity (MTT assay) and lactate dehydrogenase (LDH) release assay indicated that the collagen hydrogel exerts significant cytotoxic effects for all irradiated samples, but only for irradiation at room temperature the mechanism of induced cell death appears to be related to the loss of cell membrane integrity.

The investigation will continue by adjusting the fraction of collagen content in the dry matter of the hydrogel samples, and by adapting the irradiation doses to values that ensure that the biocompatibility meets the internationally adopted requirements for medical devices.

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IAEA-CN-332/440

Soil Redistribution Studies within the Panama Canal Watershed Using FRN and CSSI Methodologies

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The treatment of food waste through anaerobic digestion in Continuous Stirred Tank Reactors (CSTRs) is a promising method for biogas production and waste reduction. This work investigates the application of radiotracers in CSTRs to analyze flow dynamics and optimize the treatment process. Radiotracer techniques provide detailed insights into mixing patterns, hydraulic residence time distribution, and overall reactor performance. By tracing the movement and distribution of radiotracers within the CSTR, the study will reveal critical information about internal flow behaviors that affect biogas production and reactor stability. The findings are expected to indicate significant opportunities for optimizing CSTR operations, ultimately enhancing the efficiency and sustainability of food waste management. Improved mixing and accurate determination of hydraulic residence time can lead to increased biogas yields and more stable reactor performance is also a target for the study. This research will contribute to the broader field of waste-to-energy technologies by demonstrating the value of advanced analytical methods in optimizing biochemical processes. The insights gained from this study will help in designing and operating more efficient CSTR systems, promoting renewable energy production and environmental sustainability.

IAEA-CN-332/441

NDT-CE in an Icon of Popular Culture: The Boca Juniors Stadium

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Since the dawn of humanity, specific places have been used in different ways for manifestations of popular culture. That description is applicable today to many spaces where sports are practiced. In this paper, we shall present a set of Non-Destructive Tests in Civil Engineering (ND-CE), carried out to characterize part of the concrete structure of an important football stadium in Buenos Aires: The Boca Juniors Stadium, known as “La Bombonera” (“The Chocolate box”). These tests were carried out at the request of the owner´s structural advisor, due to some concerns about the structural safety and integrity of the structure, built in stages between 1940 and 1950. The techniques used allowed the quality of the concrete to be evaluated; the type, placement and integrity of reinforcing bars; and the durability aspects of this historical stadium.

IAEA-CN-332/442

Irradiation-Assisted Catalytic Conversion of Fructose to 5-Hydroxymethylfurfural using Sulfonated Bamboo Biochar

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The production of 5-Hydroxymethylfurfural (HMF) from fructose is a crucial step in the synthesis of renewable and sustainable bioplastics such as polyethylenefuranoate (PEF). Traditional catalytic methods used for this process often face challenges such as low efficiency, environmental concerns, and difficulties with catalyst recovery. Utilizing sulfonated bamboo biochar (SBB) as a green catalyst in irradiation-assisted catalytic conversion offers a potential solution to these problems. The SBB was prepared by functionalizing bamboo-derived biochar with –SO3H groups through sulfuric acid treatment. This SBB then was employed for the dehydration of fructose to produce HMF. Characterization of the SBB was conducted using Fourier-transform infrared spectroscopy (FTIR), Brunauer-Emmett-Teller (BET) surface area analysis, and field emission scanning electron microscopy (FESEM) to determine their structural, morphological, chemical, and porous properties. The study systematically explored the effects of various reaction parameters, including SBB concentration, electron beam irradiation dose, reaction time, and catalyst loading. Results showed that electron beam irradiation significantly improved fructose conversion efficiency to HMF. Optimal conditions for achieving the highest yield (~70%) were found to be an absorbed dose of 50 kGy, a reaction temperature of 60°C, a reaction time of 60 minutes, and SBB loading of 30 mg. Electron beam irradiation plays a significant role in the conversion of fructose to HMF in acidic solutions by generating reactive radicals that accelerate the dehydration process, potentially improving catalyst activity, and reducing side reactions. The enhanced yield compared to non-irradiated conditions demonstrates that combining SBB with electron beam irradiation not only increases catalyst efficiency but also substantially improves HMF selectivity and overall yield, making this method a promising approach for the sustainable production of PEF.

IAEA-CN-332/443

Establishing a Qualification and Certification Scheme for NDT-CE in Malaysia

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Malaysia enforces stringent building codes and standards to ensure the safety of civil engineering structures. However, similar to other countries, Malaysia is not completely immune to structural failures, which can result from various factors such as poor construction practices, lack of maintenance, natural disasters, or human error. Challenges related to civil engineering structure safety in Malaysia include issues with aging infrastructure, inadequate maintenance of buildings and bridges, and occasional landslides or flooding in certain regions. These challenges can lead to structural failures, compromising public safety and causing economic losses. Non-destructive testing in civil engineering (NDT-CE) methods, including radiography and other complementary modalities, have proven effective in assessing the integrity of critical buildings and structures. Despite the availability of these methods and the substantial need for inspection, the inspection of civil engineering structures in Malaysia is currently not performed by qualified and certified NDT personnel. The absence of local training centres and NDT certification bodies offering training and certification for this sector underscores the need to establish a qualification and certification scheme in NDT-CE. This paper presents the efforts of the Department of Skills Development (DSD) to establish a qualification and certification scheme for NDT-CE in Malaysia. Supported by the International Atomic Energy Agency (IAEA) and the Malaysian Society for Non-Destructive Testing (MSNT), this initiative aims to enable personnel performing NDT inspections on civil engineering structures to be certified in NDT-CE methods in accordance with ISO 9712. The paper highlights and discusses the steps taken to develop the National Occupational Skills Standard (NOSS) for NDT-CE, which outlines the skills and knowledge required for competent personnel performing inspection methods, and a National Standard for the qualification and certification requirements of personnel performing NDT-CE. The realization of this qualification and certification scheme will enable Malaysia to produce competent, qualified, and certified personnel for the inspection of civil engineering structures.

IAEA-CN-332/454

Contribution on Synthesis and Characterization of pH- and Temperature-Responsive Poly(2-Hydroxyethyl Methacrylate-co-Acrylamide) Hydrogels by Gamma Photon Irradiation: Doxorubicin Release

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Abstract

1) Background of the study

Hydrogels remain one of the most widely studied technologies in the clinic with a wide spectrum of biomedical applications such as in drug delivery and tissue engineering. They are three-dimensional polymeric networks capable of absorbing liquids, whether water or body fluids, without dissolving and releasing them over time. In order to evaluate the effect of composition on the properties of this copolymer system, in this work we prepare poly(HEMA-co-AAm) hydrogels with different compositions by γ irradiation and characterize them in terms of morphology, swelling behaviour and mechanical properties. The thermodynamic and network parameters derived from swelling and mechanical measurements are compared and discussed.

The main objective of this work was to obtain, 2-hydroxyethyl-co-acrylamide methacrylate (HEMA-Am) hydrogels bygamma photon irradiation.

2) Methology

From an experimental design using the method of copolymerization and simultaneous radio-induced cross-linking using gamma radiation in water mixtures at a radiation dose of 10 kGy. Hydrogesl were characterized by infrared spectroscopy. Dynamic and equilibrium swelling of hydrogels in water and in buffer solutions were investigated.

3) Results

Using Scanning Electron Microscopy, it was verified that the pore size decreases with the increase in the absorbed dose (see fig 1).

Figure1. Morphology by SEM image of the lyophilized (HEMA-Am) xerogels for the copolymer: (A) 3 kGy, (B) 10 kGy, (C) 40 kGy.

The new hydrogels were sensitive to pH and temperature. Swelling was non–Fickean and increased with increasing the acrylamide content. Temperature dependence of the equilibrium water uptake of copolymers exhibited a discontinuity around 35oC resulting from the weakening of the hydrogen bonds between the hydroxyl groups of HEMA and the amide groups of Am . The thermodynamic and network parameters derived from swelling and mechanical measurements are compared and discussed. They exhibit a strong dependence on the AAm content in the hydrogel.

4) Conclusions

Temperature and pH sensitive poly(HEMA-co-AAm) hydrogel networks were synthesized by γ-irradiation of aqueous solutions of acrylamide and 2-hydroxyethyl methacrylate at a 10 kGy doses. The doxorubicin release was governed by copolymer composition, the absorbed dose and their self solubility in water media.

IAEA-CN-332/455

Electron Beam-Induced Crosslinking of Polyethylene for Advanced High-Voltage Cable Insulation

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As electric aircraft technology advances, the demand for high-performance insulation materials capable of withstanding elevated voltages and harsh operational conditions is paramount. The utilization of radiation crosslinking using electron beam irradiation for enhancing the dielectric performance of polyethylene (PE), may overcome this issue. Thus, this study aims to investigate the improvements in mechanical and dielectric properties of crosslinked polyethylene (XLPE) to meet the rigorous demands of aerospace environments. Various doses (0-200kGy) were employed to induce crosslinking in polyethylene, using Irganox 1035 as an antioxidant. Gel content analysis was conducted to assess the degree of crosslinking before and after irradiation. Microstructural changes were investigated using scanning electron microscopy (SEM) and differential scanning calorimetry (DSC), revealing significant alterations in material structure due to radiation crosslinking. Mechanical tests showed that irradiated XLPE samples exhibited a tensile strength of nearly 30 MPa, which shows better performance as compared to unirradiated PE. Dielectric performance was critically assessed through AC breakdown voltage tests which is essential for high voltage insulation in electric aircraft. The results revealed a substantial enhancement in the AC breakdown strength of the XLPE (170 ± 5 KV/mm) compared to the non-irradiated variant (130 ± 7 KV/mm). Crosslinking forms a network of covalent bonds between polymer chains, creating a rigid structure that restricts charge carrier movement and improves the material's resistance to electrical breakdown. Additionally, X-ray diffraction (XRD) result results revealed that XLPE exhibited increased in crystallinity, contributing to a more stable molecular structure and enhanced insulation by creating stronger barriers to electrical conduction and reducing dielectric failure. The findings demonstrate that the optimized crosslinked polyethylene exhibited superior tensile strength, elongation, and dielectric breakdown strength, which are crucial for the reliability and safety of aerospace applications. This study not only underscores the potential of electron beam radiation as an effective method for enhancing performance of XLPE but also addresses the specific needs of electric aircraft insulation systems.

IAEA-CN-332/461

Eco-Friendly Archeological Consolidation of Earthen Structures: Advanced Polymer Synthesis and Radiation Technology for Sustainable Preservation

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This research evaluates the use of consolidation materials in conserving culturally significant earthen structures, focusing on the environmental impact of these chemical interventions. The study proposes improved methods for treating mudbrick that do not harm the local environment or contribute to atmospheric carbon emissions and keep the authenticity of the mud brick properties. Traditional conservation materials can cause long-term damage by emitting carbon dioxide and other gases, exacerbating the greenhouse effect and acid formation that degrade architectural integrity. This paper introduces a methodology to assess the carbon footprint and acid formation potential of consolidation materials used in earthen structures, while also exploring radiation technology to enhance these materials' properties and reduce their environmental impact.

The research investigates the design of polymer blends or copolymers using ionizing radiation to create materials that offer improved sustainability, better compatibility with original mudbrick, and reduced environmental impact. By exploring alternative materials, the study aims to develop advanced, environmentally friendly conservation methods effective in preserving earthen structures.

The applied study focuses on the church at Thmuis.The structural remains of the church include a bell tower, a front façade, and a large nave with various galleries, primarily constructed from mudbrick with granite column fragments. Archaeological evidence shows a spiral staircase in the bell tower and stairwells descending below the visible structure. Sections of the bell tower and walls stand as tall as three stories; however, accounts from residents in the neighboring town indicate the tower was taller in the 20th century. The church and its buildings are framed by a road or alleyway to the north and a forum or plaza to the south, covering approximately 1,140 square meters.

Current erosion at Tell Timai is escalating for two reasons. Firstly, the sloughing of mudbrick is thinning the walls, making them more susceptible to failure. Secondly, the proliferation of dogs burrowing under the walls for shade, associated with a nearby garbage dump, undermines the structural integrity.

Minor conservation work was done in 2012 to reinforce the church walls. After morphological and chemical studies of mudbricks from the site, traditional methods were used to duplicate the bricks, with red ochre added to distinguish them from the originals. Mud plaster was applied to coat the bricks. There is a significant need for green conservation approaches.

This paper explores using radiation technology in synthesizing materials for conservation purposes. Techniques like gamma irradiation can improve polymerization, enhance consolidant properties, and reduce the need for harmful chemical additives. Additionally, the research investigates designing blends or copolymers using ionizing radiation to achieve enhanced performance and environmental benefits. These advanced techniques aim to create more durable, environmentally friendly materials for conserving mudbrick structures, ensuring their longevity while minimizing environmental impact.

IAEA-CN-332/477

Microbiological Quality of Green Leafy Vegetables and Effect of Electron Beam Irradiation on the Survival of Escherichia coli O157:H7 and Salmonella spp. in Rocket During Refrigerated Storage

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In the last decade, there has been an increasing need for fresh leafy greens and ready-to-eat vegetables as consumer attitudes have shifted towards healthier diets. Nevertheless, vegetables, known to provide dietary fiber and essential nutrients, are often associated with cases of foodborne illnesses. The desire for enhanced fresh food safety motivates the need for nonthermal food treatments to maintain nutritious quality, extend shelf life, and pathogens control. Ionizing irradiation has proven to be a secure and reliable nonthermal method of food processing and preservation. Therefore, herein, the level of indicator bacteria (coliforms and Escherichia coli), bacterial pathogens (Staphylococcus aureus, Bacillus cereus, and Salmonella), molds and yeasts was assessed in 92 samples of leafy vegetables (rocket, basil, lettuce, and spinach). Additionally, the efficiency of E-Beam irradiation to reduce food-borne pathogens in artificially contaminated Rockets was evaluated. For this purpose, rockets contaminated with E.coli O157:H7 and Salmonella were irradiated at doses of 0, 1, 2, 3, and 4 kGy. Samples were stored at 4 °C and evaluated microbiologically up to 10 days.

Preliminary results of microbial screening showed that total coliforms and E.coli occurred in all samples (2.3 to 10.4 Log10 CFU/g and 1.2 to 8.43 Log10 CFU/g, respectively). Yeasts and molds were detected in nearly all leafy greens, with rocket and basil being the most contaminated. B. cereus was the most common pathogen, present in (39.1%) spinach samples. Staphylococcus aureus was most commonly found in Rocket and lettuce, being present in 28% of rocket samples and in 22% of lettuce samples. Salmonella spp. was prevalent in fresh produce, with rates of 34.7% in spinach samples and 28% in rocket samples. Irradiation treatment of artificially contaminated rocket samples showed an abatement of 4 and 3 Log10 CFU/g for E.coli O157:H7* and Salmonella spp. respectively at a dose of 2kGy. E. coli O157:H7 was more sensitive to electron beam irradiation than Salmonella spp. E-beam irradiation reduced effectively the population of E. coli O157:H7 and Salmonella spp. in rocket samples.

Microbial strains were kindly provided by the USDA-ARS Culture Collection (NRRL).

IAEA-CN-332/481

Radiotracer Measurement in Water Flow Pipe Line System

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Radiotracer technology, a non-intensive technique, can provide rapid information on process parameters. It is widely used for troubleshooting and process optimization in industry.

Water flow system, a semi-open circuit using 60.33 mm diameter (inner diameter 54.79 mm), 48.26 mm diameter (inner diameter 33.96 mm) PVC pipes has been assembled at the laboratory.

The study of the flow-rate and leakage measurement, parallel flow measurement (T-joint) and by-pass measurement (channeling effect) were carried out by four different injection using the radiotracer Tc-99m, activity 50 mCi and volume 4cm3 is injected by a syringe, the gamma rays emitted are detected by four collimated NaI (Tl) (1.5"x 2") scintillation detectors and “CAESAR12” data acquisition system.

The required radiological safety precautions were taken during the transport and released phase of this experiment and all handling was carried out according to prescribed procedures, including the measurement of radiation doses to personnel.

The water flow system and measured data were shown in the figures. This water flow system can support to promote the radiotracer residence time distribution (RTD) method which is extensively used to industries, in order to optimize processes, solve industrial problems, and improve product quality.

Key words; Radiotracer, Tc-99m, Flow Rate, Residence Time Distribution (RTD)

https://drive.google.com/file/d/1thf2Q8g9of7PPMDKPjaHoTXvHoEFr_JF/view?usp=drive_link

IAEA-CN-332/484

Application of Electron Beam Radiation in Natural Polymer Transformation: A Comprehensive Training Program under RLA1029

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The fellowship training conducted at the Thailand Institute of Nuclear Technology (Thailand) encompassed a comprehensive exploration of the electron beam and X-ray facilities. The program provided valuable insights into the diverse applications of these facilities and the dosimetry system employed in electron beam processes. Practical laboratory experiments were conducted to explain the modification of natural polymers through ionizing radiation, which included polymerization, degradation, cross-linking, grafting, and curing. Experiments demonstrated that chain scission can be induced in chitosan molecules, resulting in the formation of smaller particles. The surface of these particles was modified to improve compatibility, facilitating their use as an effective filler in a polylactic acid polymer matrix. Additionally, the use of irradiation for purifying cellulose from sugarcane bagasse was highlighted as a method to create superabsorbent materials with promising applications in agriculture. Overall, the training provided within the framework of the national project RLA1029 provided valuable knowledge on the various applications of electron beam radiation in the modification and purification processes of natural polymers, showing the potential that this technology has for the Argentine industry.

IAEA-CN-332/489

Thermal Stress Analysis and Structural Optimization of Electron Guns for Electron Beam Irradiation Processing

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In the electron beam irradiation process, beam energy and beam spot quality are pivotal to irradiation quality. The reliability and stability of the electron gun, as the source of the electron beam accelerator, are crucial in design. This study utilizes CST and ANSYS for joint simulation of electromagnetic, thermal, and mechanical fields to analyze the deformation behaviors of the electron gun's electrode and filament under thermal stresses and its impact on electromagnetic characteristics. Numerical results reveal that an elevated filament temperature leads to deformation, enlarged beam spot size, and potentially irregular beam spots, significantly affecting irradiation precision and efficacy. Further, electrode deformation weakens the focusing electrode's clamping effect on the current, resulting in an increased electron beam current, enlarged beam waist, and axial position shift. These changes undermine beam focusing performance and may compromise irradiation uniformity and depth control. Therefore, when designing the electron gun structure, the shape of the electrodes should be modified to offset the effects of thermal deformation, and reduce the error between the irradiation preset parameters and the actual parameters. This paper provides feedback for the reliable design of the source of the electron beam accelerator, which can help to improve the structural design of electron guns and enhance their stability and durability.

IAEA-CN-332/492

Experience with Cobalt Gamma Radiation Processing Facilities and Dose Distribution Calculations

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Background : Cobalt-60 source irradiation devices that emit high-energy gamma radiation must be maintained to ensure that the dose distribution is uniform. An unbalanced dose distribution can provide a favorable environment for microorganisms to survive in the irradiated object. Therefore, uniform dose distribution is essential for irradiation devices. On November 23, 2017, a large gamma irradiation facility operated by the Advanced Radiation Research Center of the Korea Atomic Energy Research Institute was loaded with an additional 7.31 X 10^15 Bq (197,632Ci) of cobalt-60, for a total of 1.35 X 10^16 Bq (364,664Ci) of radiation source. An experiment was conducted to determine the spatial dose distribution of the irradiation facility.

Methodology: The dose distribution with distance was measured using 1,026 alanine dosimeters (171×6 points). The beam survey was performed by fixing the alanine dosimeters at 10 cm intervals by installing a radiometer holder made for the measurement. The dosimeters were attached horizontally and vertically at 10 cm intervals in the effective source measurement area, 19 horizontally (1-19) and 9 vertically (A- I), for a total of 171 zones. Measurements were made at six distances from the hull surface: 10, 50, 100, 200, and 300 cm. The dose measurements were performed between November 13 and November 24, 2023.

Results: The dose measured at each distance was calculated as the average of the measurements over a ±5% range, and this value was designated as the average dose rate at each distance, which was plotted on a graph with distance as the x-axis and the average dose rate at each distance as the y-axis. Using measurements taken at random distances within 300 cm of the alanine dosimeter, we derived the dose equation $y = 0.1476x^4 - 0.914x^3 + 1.3758x^2 - 0.7498x + 1.361$ ($R^2 = 0.9997$).

Conclusion : Cobalt-60 sources emit high-energy gamma rays, and if the dose distribution is not uniform, certain areas may be over- or under-irradiated, affecting the effectiveness of the treatment. Therefore, a uniform dose distribution is necessary to ensure that all areas receive the same level of radiation therapy. This results in a uniform dose distribution that can effectively eliminate microorganisms and viruses during the sterilization process of medical devices or food.

IAEA-CN-332/494

Nanocrystalline $CaSO_4$: Eu for Thermoluminescence Dosimetry of Gamma Rays and Carbon Ion Beams

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Background:

Ionization quenching, that is reduction in the thermoluminescence (TL) intensity with an increase in particle linear energy transfer (LET) is a major drawback of all standard TL dosimeters which give a lower estimate of the actual dose of an ion beam. In order to get an accurate assessment of the actual dose, correction factors obtained from Monte Carlo simulations of the radiation field and the ionization chamber measurements need to be applied. This makes the process of passive dosimetry of ion beams become complex and unreliable. However, TL materials with higher saturation doses have a tendency to exhibit lower ionization quenching and therefore an improved LET-independence making them potentially more suitable for ion beam dosimetry. TL materials in their nanocrystalline forms invariably have a higher saturation dose compared to their corresponding conventional microcrystalline forms both for the electromagnetic ionizing radiation as well as for the ion beams suggesting that they have a greater potential for ion beam dosimetry. This has prompted us to study a nanophosphor calcium sulphate doped with europium (CaSO4:Eu) for the purpose of gamma radiation and carbon ion beam dosimetry.

Methodology:

The nanophosphor synthesized using chemical co-precipitation technique was irradiated with gamma rays from a Co-60 source (dose ranging from 10 Gy to 2 kGy) and carbon ion beams (of energies 65 MeV and 85 MeV) with fluence ranging from 1E11 ions/sq.cm to 1E13 ions/sq.cm obtained from a tandem electrostatic accelerator located at Inter-University Accelerator Centre, New Delhi. TL glow curves were recorded on Harshaw TLD Reader-3500.

Results:

For a 10 Gy gamma radiation exposure the nanophosphor displayed its optimized dopant concentration at 0.4 mol% (in a testing range of 0.0 – 0.8 mol%). X-ray diffraction (XRD) spectrum of the sample matched well with the JCPDS card number 96-900-4097 indicating that the nanophosphor had an orthorhombic crystal structure. The nanophosphor upon irradiation with gamma rays showed a wide linear dose response ranging from 10 Gy to 2 kGy with no signs of saturation up to the high dose of 2kGy. TL glow curves showed a single peak at around 158 oC for all different doses of gamma rays in the above mentioned dose range.

A high saturation dose of the nanophosphor further indicated that it may exhibit lower ionization quenching and therefore potentially be more suitable for ion beam dosimetry. The nanophosphor was then tested for its dosimetric features for carbon ion beam of two different energies 65 MeV and 85 MeV. The nanophosphor showed greater sensitivity to the higher energy (85 MeV) of the carbon ion beam but similar glow curve shape and structure for both the energies.

Conclusion:

From this preliminary study, the nanophosphor CaSO4:Eu is found to be potentially suitable for high-dose measurement of gamma radiation of up to 2 kGy. However, a more detailed study of LET-independence is needed in the future to ascertain the nanophosphor’s ability to be used as a passive dosimeter for carbon ion beams. A comparative study with Monte-Carlo simulations of the radiation field is also solicited.

IAEA-CN-332/506

Radiation Effect on Polylactic Acid 3D-Printed Alloplastic Medical Implants for Customized Tissue Repair

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Conventional options for tissue repair in humans often fail to meet desired outcomes, underscoring the urgent need for more efficient and effective customized solutions.

This research specifically aims to produce customized medical devices 3D printed with commercially available polymers and to elucidate the effects of radiation sterilization on their structure, as well as their performance in vitro and as implants in vivo.

Two different medical devices made of polylactic acid (PLA) were tested: a rectangular mesh to be used as an alloplastic to reinforce or repair a myofascial defect in the abdomen; and a hollow parallelepiped used to reconstruct the body of the first lumbar vertebra.

Samples were sealed in nitrogen atmosphere and treated with gamma radiation (12 Gy min-1) or electron beam (10 kGy min-1) up to 100 kGy to test their integrity if further re-sterilizations are needed. The thermogravimetric analysis showed that the irradiation treatment has a marginal effect on the thermal degradation behaviour, and consequently in their structural stability, in both models.

Myoblasts (C2C12) and pre-osteoblasts (MC3T3-E1) cell lines were used for in vitro experiments with the myofascial and vertebra body type devices, respectively. First, cell viability assays where cells were grown in device-conditioned media were aimed to assess if the irradiated devices would release any product to the medium that could inhibit the cells viability and growth. The results suggest that the eventual degradation products arising from the irradiation process do not have a cytotoxic effect. In a second type of experiments, each one of the cell lines was grown directly in contact with the corresponding devices for approximately 7 days to test their viability, attachment and behaviour. The cytochemical staining protocol used to visualize cells nuclei and actin cytoskeleton showed that both cell types did adhere and grow on the respective irradiated device and displayed a normal morphology.

The 3D printed body vertebra device was used in vivo in Wistar rats to confirm its biological functionality and safety. The device was amenable to surgical manipulation, provided sturdy structural support, and presented histological signs of osteointegration at 8 weeks postoperatively. These results are promising and will contribute to establish a complete protocol regarding this type of implant.

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IAEA-CN-332/578

Contribution to the Study of Various Structural Configurations on the UTR Pilot Unit Using Neutron Backscattering Technique Compared with OpenMC Simulation

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In this project, we worked with radiometric techniques, using sealed radioactive sources to inspect the laboratory pilot unit at UTR-CNESTEN, providing methodological aspects and illustrating various experimental configurations.

The work presented in this project contributes to the development of the Neutron Back-Scattering technique using a radioactive source (241Am-Be) of 0.27Ci and a (3He) detector. By demonstrating its effectiveness using different petroleum products (gasoline, benzene.) and other samples with distinct densities and hydrogen contents, to study the impact of these factors on phase separation and the count rate of retro diffused neutrons.

The application of the NBS technique on the UTR-CNESTEN pilot unit allowed us to confirm the validity of our experimental approach for various studied configurations, and the simulation using the Open-MC code on the pilot unit validates the experimental procedure for differents studied configurations.

IAEA-CN-332/633

Calibration Verification and Dosimetry Intercomparison Exercise in the Frame of the RER1021: Enhancing the Use of Radiation Technologies in Industry and Environment, 2020–2023

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Radiation processing is a worldwide applied technology for improving human health, production of advanced materials, preservation of our environment and protection of cultural heritage artefacts. Dosimetry is an essential part of these technologies and the reliability of dosimetry procedures requires verified calibration procedures and traceable dosimetry measurements through the services of standard dosimetry laboratories and regular dosimetry intercomparison exercises. To achieve these goals in the gamma and electron bea m irradiation facilities in operation at the European IAEA TC Member States a calibration verification procedure, followed by a dosimetry intercomparison exercise was carried out through the IAEA RER1021 Regional Project: „Enhancing the Use of Radiation Technologies in Industry and Environment."

11 gamma irradiation facilities and 4 electron irradiation facilities participated in these exercises aiming at to achieve assurance and/or necessary impovements concerning their regular dosimetry procedures.

Calibration verification was performed with reference alanine dosimeters from Risø High Dose Reference Laboratory (HDRL, Roskilde, Denmark), that were irradiated together with the routine dosimeters of the participating irradiation facilities using the gamma or e-beam phantoms, supplied by the IAEA. The alanine dosimeters were measured at HDRL, while the participating laboratories evaluated their own routine dosimeters according to their internal quality management procedures and compared their results with the HDRL reference doses. Results were used to carry out improvement of the calibration functions, if needed.

This exercise was followed by a similar intercomparison exercise, organized by the Dosimetry Laboratory of the Institute of Nuclear Chemistry and Technology (INCT, Warsaw, Poland). The results of this exercise were again compared and analysed.

The results of the these calibration verification exercises showed that the calibration functions in about half of the participating irradiation facilities were acceptable as they were, while in a few facilities smaller adjustment were needed, and in some irradiation facilities new calibration functions must be prepared.

IAEA-CN-332/447

Influence of Low-Energy Electron Treatment on the Crystallization Behavior and Thermal Properties of Polylactic Acid

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Polylactic acid (PLA) is widely used biodegradable thermoplastic polymer due to its favorable processability and relatively low production cost. Its crystallization behavior significantly impacts the mechanical properties and thermal stability. Electron beam (EB) treatment is an efficient and environmentally friendly alternative to traditional modification techniques. The radicals generated during EB treatment can induce a series of different reactions in polymer chains, thereby influencing the molecular structure such as the crystallization behavior. The crystallization behavior of PLA can be modified by mixing Poly (L-lactic acid) PLLA and Poly (D-lactic acid) PDLA too.

In this study, low-energy EB treatment was employed for the modification of PLA, PDLA, and PDLA to investigate the effects on its crystallization behavior including type and structure of crystals, crystallinity and crystallization kinetics. Analytical techniques such as Differential Scanning Calorimetry (DSC), Thermogravimetric Analysis (TG), Polarized Optical Microscopy (POM), and X-ray Diffraction (XRD) were used to study the changes in crystallization behavior and thermal properties before and after low EB treatment.

The results show that low EB treatment significantly affect the crystallization behavior as well as the mechanical and thermal properties of the low EB modified samples. Finally, a structure-property relationship between EB modification, PLA structure, and PLA performance is derived.

IAEA-CN-332/480

Optimization of Alpha Cellulose and N-Cellulose Solubility in Sodium Hydroxide

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Background: Cellulose, the most abundant natural polymer on earth, has been limited in its application to industrial processes due to its low solubility. It is a difficult compound to dissolve largely due to its intra- and intermolecular hydrogen bonding. While not soluble in water, cellulose is soluble in some ionic liquids that have the ability to break the hydrogen bonds that help cellulose retain its crystalline form. However, ionic liquids are not environmentally friendly and are largely made up of organic compounds with high toxicity and low biodegradability. Sodium hydroxide can be used in place of ionic liquids because it fully dissociates, creating ions, that will interfere with hydrogen bonding. Gamma irradiation has been shown to break the 1-4 glycosidic bonds in glucose, providing more available surface area per gram, increasing solubility. The goal of this study is to maximize solubility of cellulose utilizing techniques that have a smaller environmental footprint than ionic liquids. This study examines the effects of two variables on cellulose solubility: sodium hydroxide concentration and irradiation dosage.

Methods: This study adapted the Technical Association of the Paper and Pulp Industry (TAPPI) method T 235 for Alkali solubility of pulp at 25 oC. The TAPPI T 235 was designed for pulp extraction and dissolution of degraded cellulose. This method used a similar concentration scheme but excluded the pulp extraction in favor of comparing cellulose dissolution before and after gamma irradiation. It also used gamma irradiation via Cobalt-60 at the National Institute of Standards and Technology (NIST) to irradiate alpha cellulose (SIGMA-ALDRICH product code: 1002333241, lot number: SLBQ4200V) and medium cellulose fibers (n-cellulose, SIGMA product code: 101809709, lot number: WXBC3692V) to 0, 100, 250, 500, 750, and 1000 kGy at 17 kGy per hour. Samples of 0.5 g of cellulose (alpha and n individually) were dried for 24 hours at 102 oC ± 0.5 oC in a Gallenkamp Microprocessor Controlled Oven (model 1350FM), then soaked in 30 mL of various concentrations of NaOH that included 10%, 18%, 22%, and 25% by weight for 3 hours under constant stirring with a magnetic stir plate (VWR Standard Multi-position Stir Plate). After stirring, the remaining insoluble cellulose was spun down using a Fischer Scientific Centrifuge (Centrific Model 228). The insoluble cellulose was removed and the soluble solution of cellulose was saved to perform carbon analysis using a Shimadzu SSM 5000A Solid Sample Module.

To analyze the carbon content of the NaOH/cellulose solutions, 1 mL of the solution was added to a ceramic boat packed with ceramic fiber to prevent splashing. The Shimadzu SSM was set to 900 oC and the samples were degraded while the carbon was monitored by the Shimadzu SSM. Potassium Hydrogen Phthalate ($C_8H_5O_4K$) was used as a standard to compare the mass of carbon associated with the peak area displayed by the Shimadzu as the sample was degraded.

Results: Results show that cellulose solubility increases until about 500/750 kGy with a drop in the carbon present at 1000 kGy for n-cellulose. Additionally, alpha cellulose solubility increases until 500 kGy then decreases with 750 and 1000 kGy.

Conclusions: From the organic carbon analysis, cellulose irradiated to 500 and 750 kGy contained the most organic carbon. 500 kGy cellulose was most soluble at 18% NaOH for alpha cellulose and 21% NaOH for n-cellulose. 750 kGy was most soluble at 21% NaOH for both alpha and n-cellulose. Because solubility was determined by mass of organic carbon, future work will be focused on determining the degradation products of cellulose at radiation doses above 500 kGy and the molecular weight of any remaining cellulose.

IAEA-CN-332/647

Characterization of Different Composition Artworks Treated by Ionizing Radiation (ENEA, Italy)

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Diagnostic and preservation efforts in Cultural Heritage (CH) are essential for maintaining the longevity and integrity of artifacts and monuments that represent our historical and cultural legacy. Several countries successfully use ionizing radiation processes to preserve and conserve CH artworks of various compositions, including paper, parchment, wood and stone [1]. Despite the benefits of radiation processing over traditional conservation methods, CH professionals often resist its application due to insufficient understanding of the potential physico-chemical modifications (secondary effects) induced by ionizing radiation on treated materials.

In recent years, the Calliope facility (^{60}Co gamma radiation) [2] and REX accelerator (electrons and X-rays) [3] of the ENEA Nuclear Department have conducted extensive research for cultural heritage conservation [4, 5, 6].

The present contribution focuses on the use of various experimental techniques (FTIR, Raman, EPR, viscosimetric and colorimetric analyses), to gather detailed information before and after radiation exposure about the physico-chemical properties of different CH artifacts. Additionally, microbiological analysis of artworks is performed to assess the effectiveness of radiation treatments in eliminating biodeteriogen agents. Results of case studies involving artifacts of historical, cultural, and archival interest are presented.

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IAEA-CN-332/722

Bulk Formation of Zwitterionic Microgel with Additives by Gamma Radiation for Large-Scale Application in Self-Healing Cement

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Microgels are recently being explored as an admixture in the Portland cement as a superplasticiser, adsorbent, air-entraining agent, and also immobilising bacteria or chemicals for self-healing [1-2]. However, a large-scale application of microgels in cement requires bulk production without involving stringent control of conditions during polymerization preferably with water as the solvent. One of the best routes for making large-scale microgel is free radical polymerization of acrylate-based monomers, which are highly water-soluble and easily polymerizable without any additives using gamma-ray irradiation. The choice of zwitterionic microgel was based on the requirement that it should be salt-like with moderate water uptake. Highly water-swelling and fast water-releasing microgels are not preferable in the present case as these may shrink by losing water during the hardening of the cement leaving behind large voids in the cementitious materials, which will be detrimental to the strength and durability [3]. In the present work, the zwitterionic microgel was prepared by using 3-acrylamidopropyl trimethyl ammonium chloride (APMAC) and 2-acrylamido-2-methyl-1-propane sulfonic acid (AMPS). The crosslinker used was methylene bisacrylamide (MBA). The polymerizing solution consisting of 1:1 mol proportion of APMAC and AMPS monomers and 10% MBA were polymerised using 60Co gamma irradiator at two doses i.e. 25 kGy and 75 kGy. The water uptake capacity of microgel gel was found to be moderate (around 200 wt.%). As no functional gain was observed at 75 kGy gamma dose, further studies to prepare composite microgel were carried out at 25 kGy. The composite microgel was prepared by adding Na2HPO4 in a polymerizing solution. This fmicrogel was equilibrated with CaCl2 at pH=12 for the formation of nano-hydroxyapatite as expected from the release of Na2HPO4 from the interior matrix. It is seen from the FESEM image given in Fig.1 that nano-hydroxyapatite particles were formed at the surface and outside also. Thus, it is expected that this microgel particles is promising material for making self-healing cement. The anti-microbial activity of microgel was studied using three bacterial strains such as Staphylococcus aureus, E. coli and Candida albicans. All the Gel samples show good inhibition zones. Microgel samples show promissory anti-microbial growth, especially against Staphylococcus aureus. The actual application of this microgel in cement is being carried out to understand the effects on the mechanical properties of the hardened cementitious materials and its efficacy for the autonomous self-healing of microcracks.

IAEA-CN-332/764

A New Method for Synthesizing Polyvinylpyrrolidone (PVP) Nanogels Initiated by UV Light

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Polymer gels are stable two-component systems composed of a permanent three-dimensional network of polymer chains and a solvent filling its free spaces. Polymeric nanogels are defined as internally crosslinked macromolecules of any shape with a size between 1 and 100 nm. High specific surface area, possible functionalization with ligands, and aqueous stability enable nanogels to be deployed in a broad range of applications. Nanogels are promising carriers in controlled drug delivery systems and gene therapy. The biocompatibility and non-toxicity requirements are fulfilled by selecting the appropriate polymer, such as polyvinylpyrrolidone (PVP).

One of the most suitable synthesis techniques for obtaining nanogels of a biomedical class is preparative pulse radiolysis. It has many advantages but requires expensive equipment. Furthermore, some polymers are sensitive to ionizing radiation. This work aims to develop a new synthesis method for polyvinylpyrrolidone (PVP) nanogels using only H_2O_2 as a photoinitiator and UV light (254 nm) as the source of energy. UV causes photohomolysis of hydrogen peroxide, leading to the emergence of hydroxyl radicals, which induce intramolecular crosslinking of PVP chains.

Deoxidized solutions of PVP and H_2O_2 in various mutual ratios were irradiated with different doses of UV light. The properties of the formed products were determined using static light scattering (SLS), dynamic light scattering (DLS), and viscometric measurements. Analysis of the obtained results led to the conclusion that at a low concentration of monomer units (10 mM) and a large amount of hydroxyl radicals present in the solution (H_2O_2 concentration 11.75 mM), nanogels with a radius of gyration below 20 nm, with no tendency to aggregate, were formed at sufficiently high doses of UV radiation (more than 1 J cm^{-2}).

IAEA-CN-332/776

Sonochemical Synthesis of Antibacterial PEGDA Hydrogels for Biomedical Applications as a Complementary Method to the Radiation Technique

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Hydrogels are used in many applications, e.g. in medicine in aortic grafts, as breast implants, in drug delivery systems, as cell culture scaffolds, contact lenses or wound dressings. Some of these products are synthesised, on the industrial scale, by radiation technique, and the mechanisms of underlying chemical reactions are fairly well known. In contrast, the mechanism of sonochemical synthesis of hydrogels is not yet fully understood. This method, along with radiation technique, can be an alternative to the chemical method – both of these approaches do not require the use of additional substances, such as initiators, are cheap and environmentally friendly.

The action of ultrasonic waves on aqueous solutions of monomers and polymers is, in general, fairly similar to the action of ionising radiation (such as e-beam or gamma radiation). The sonochemical reactions in the liquid lead to the generation of •OH radicals, which in turn act on the dissolved material and result in polymerization and cross-linking (leading to the formation of gels), but also to degradation.

The aim of the work was to use ultrasound as an alternative tool to ionising radiation for the synthesis of macroscopic hydrogels composed of poly(ethylene glycol diacrylate) (PEGDA) matrix and trigonelline as an additive, in order to create non toxic, biocompatible and bioactive material.

The synthesis was carried out in an ultrasonic reactor at 620 kHz, 50 W, with Ar atmosphere and at 20 °C. The swelling kinetics, equilibrium swelling degree of hydrogels and gel fraction content were determined. The cytotoxicity of trigonelline hydrogels was studied using the MTT assay. The biological studies were performed on human endothelial cells EA.hy926 (CRL-2922™ ATCC). The anti-bacterial activity of the hydrogels was done by the incubation of the gel in Escherichia coli bacterial inoculum and subsequently transferring it onto PCA plate.

Based on the obtained results it was concluded that using the sonochemical method, durable hydrogels with appropriate mechanical properties can be acquired. The hydrogels were not cytotoxic, and they were shown to release the active substance through a sufficiently prolonged period of time. Further studies on the application of ultrasonic waves, as a complementary method to the radiation technique, in the synthesis of polymer-based materials are in progress.

IAEA-CN-332/824

A General Approach for the Kinetic Modeling of Gaseous Radiolysis: A Starting Point Toward CO_2 Conversion into Molecules of Interest

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Human activities have significantly increased the emissions of greenhouse gases in the atmosphere. Among those gases is carbon dioxide. In the context of economic growth, as considered by the United Nations Sustainable Development Goals, developing technologies to convert CO2 is of interest, especially for hard-to-abate industries.

Recent studies evaluate the potential of ionising radiation technologies as new candidates (1,2). The decomposition of CO2 under radiations includes many physical and chemical phenomena (3) studied since the beginning of the XX century. Still, developing such technologies has faced several limitations, such as modelling complex mixtures of gases.

In that sense, we propose a zero-dimension kinetic automatic approach for modelling radiation-induced chemistry. This approach is based on curated open-access databases to derive systems of reactions and the FACSIMILE software (MCPA Software Ltd.) (4) for solving differential equations. We perform our simulations for a simple system composed of CO2, O2 and CO for which extensive literature (5) can be used for comparison. Compared to the literature, simulations give good predictions, especially with variations in the concentration of initial gases.

The automatic method can be used to model more complex mixtures of gases for which the number of species involved is often limiting. This enables the exploration of radiation-based technologies to convert and/or synthesise molecules of interest.

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IAEA-CN-332/511

Metabolically Active Yet Non-Viable State of Listeria monocytogenes after Exposure to Sub-Lethal Electron Beam Doses

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Listeria monocytogenes is a significant foodborne pathogen known to cause severe health issues, particularly in immunocompromised individuals, pregnant women, newborns, and the elderly, with notable resilience at refrigerated temperatures. While outbreaks typically involve meat, dairy, and produce, Listeria monocytogenes is most frequently linked to ready-to-eat products. Ionizing technology such as electron beam (eBeam) is known to eliminate this pathogen. However, the metabolic state of this pathogen when exposed to sub-lethal doses is unknown. Sub-lethal exposure to pathogens can occur during phytosanitary treatment of fresh produce. We hypothesize that surviving cells of Listeria monocytogenes exposed to sub-lethal eBeam doses will exhibit increased virulence due to enhanced stress responses. This study investigates the impact of sub-lethal irradiation on Listeria monocytogenes.

Among the 13 serotypes of Listeria monocytogenes, three- 1/2a, 1/2b, and 4b- account for 90% of human infections. Inactivation studies have been performed to determine the D10 value, which tells us the dose at which a bacterial population is reduced by 90%. The D10 values for strains of Listeria monocytogenes are 0.3 kGy ± 0.06 for serotype 1/2b (ATCC BAA-839) and 0.4 kGy ± 0.09 for serotype 4b (ATCC 19115). Metabolic activity, indicative of nutrient consumption and potential virulence, remains positive after irradiation. Previous studies have shown that ionizing radiation affects gene expression, particularly in relation to stress response and virulence. We propose to study the gene expression in this pathogen after exposure to sub-lethal eBeam doses and also study virulence using cell culture and animal models. These studies will be performed at 1 kGy and 7 kGy doses.

Understanding the effects of sub-lethal irradiation on Listeria monocytogenes is crucial for ensuring the safety of eBeam or gamma processed foods. Although ionizing radiation significantly reduces bacterial populations, it is extremely important to calibrate the treatment dose such that there are no surviving pathogens. Ultimately, these insights will help enhance food safety protocols and improve public health outcomes.

IAEA-CN-332/518

Electron-Induced Sorting of Mixed Polyolefin Waste

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The use of mixed plastic waste for the preparation of plastic products will lead to low performance products due to incompatibility of different types of polymers. Thus, mixed plastics such as polypropylene (PP) and polyethylene (PE) has to be separated into polymer fractions. It is not possible to separate PP and PE using the sink-float method as the density of both polymers is comparable.

The electrostatic separation bases on the electrostatic charging of polymers that in turn based on the triboelectric series and the chemical structure of polymers. PE and PP are not separable as both are close to each other in the triboelectric series due o similar chemical structure.

In order to achieve a charging through a triboelectric impact, a defined pre-treatment of the polymers is necessary. When polymers are pre-treated with electrons, uncompensated negative charges are transferred to the polymers. The lifetime of these negative charges transferred depends on environmental conditions such as humidity as well as on the material properties such as the degree of crystallinity, glass transition temperature, and water content of polymer.

In this work, plastic waste was shredded, sink-float separated, dried, purified and per-treated with low energy electron to be finally electro-separated.

IAEA-CN-332/592

Thermoluminescence Study: Effect of Nutritional Supplements in Salts on Thermoluminescent Characteristics

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Extensive research was conducted on various emergency dosimetry techniques for triage, prompted by the potential risks of radiological and nuclear incidents that may expose the general public to radiation. The objective of this study was to examine the feasibility of utilizing fortified nutrient salts for retrospective dosimetry within the dose range associated with triage scenarios. Our investigation focused on the thermal stimulated luminescence (TL) signal present in the samples, including the limit of detection, dose response, reproducibility and fading. Kinetic parameters of the salts deconvoluted by general order kinetics (GOK) using the TolAnal: TL/OSL Glow Curve Deconvolution Program are presented.

Four distinct types of sea salts produced by Solana Pag Croatia, were subjected of examination. The sample set encompassed fine sea salt and three distinct fortified sea salts: one with a 50% reduction in sodium compared to regular salt, one fortified with potassium and one fortified with calcium and magnesium. The measurements were carried out utilizing a Riso TL/OSL DA-20 reader. TL was performed using BG39 and U340 optical filters.

Significant radiation-induced TL were observed. The dose response analysis demonstrated a linear relationship, indicating consistent and predictable behavior in response to varying radiation doses. The ratios of the measured doses to the given doses were comperable. Thermoluminescent peaks are observed at about 120 °C, 210 °C, and 280 °C. The most stable in time is the peak at 280 °C with very low fading rates after 14 days while the other peaks have half-lives of several days. TL intensity strongly depends on optical filters.

IAEA-CN-332/620

NV Center Doping of Laboratory Diamonds by Electron Beam

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This work focuses on creating diamonds with structural defect in order to generate interesting properties for applications such as magnetometry, radar detection, dosimetry, and jewelry. In particular, we focused on optimizing colored center for high-end jewelry. Extensive work on the diamond growth, electron beam irradiation, and post-irradiation annealing at high temperature has been done to better understand and control the creation of colored centers.

Diamond layers were grown with varying nitrogen concentrations (0-70 ppm), the formed diamond were irradiated with 10 MeV electron beams to create NV0 or NV- (Nitrogen vacancy) centers. Annealing, at temperatures ranging from 850°C to 1600°C, was conducted and ODMR (Optically Detected Magnetic Resonance) or photoluminescence was used to characterize diamond before and after treatment.

Our findings demonstrate that colored center density decreases with reduced nitrogen plasma concentration, and lower irradiation doses. High-temperature annealing significantly decreases NV center concentration due to vacancy diffusion, transforming some centers into H3 centers. The consecutive treatment of electron irradiation and annealing plays a crucial role, where irradiation introduces vacancies forming NV centers, and annealing adjusts the concentration and distribution of these centers. This dual approach enables precise tuning of diamond's properties, ensuring optimal performance for both quantum technologies and high-end jewelry applications.

Based on first promising results, a new irradiation apparatus has been designed and developed in order to control, dose rate, temperature up to several hundred degrees Celsius in an inert atmosphere. This aims at controlling simultaneously irradiation and annealing.

IAEA-CN-332/640

Reducing Energy in Super Water-Absorbent Production by Remodeling Hydrogels into Microbeads for Water Reservoirs in Agricultural Soil

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Previously, we faced challenges in scaling up the production of starch-based super water absorbent (SWA) hydrogels due to their high energy and time requirements. The traditional process involved labor-intensive steps such as cutting, drying, and grinding, which negatively impacted the SWA's properties, particularly its swelling capacity and gel fraction. To address these issues, we developed a new method for synthesizing SWA in the form of microbeads. This approach reduces both energy consumption and production time, shortening the production period for 1,000 kg of SWA from 105 days to just 7 days. Furthermore, the SWA beads produced are uniform in shape and size, with a swelling capacity of approximately 360 g/g of their original dry weight. SWA beads can also undergo re-swelling for more than five cycles while maintaining their swelling ratio, demonstrating significant potential as water reservoirs in agricultural soil.

IAEA-CN-332/645

Efficiency of Electron Beam Irradiation for Wastewater Treatment

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Background: Water has long served as a convenient repository for human waste, but the exponential growth of the human population and the increasing variety and quantity of chemicals have outpaced nature's ability to dilute and degrade them. With over 50,000 chemicals in commerce in the US alone, along with their degradation products and metabolites, the potential for pollution is vast. Many of these chemicals are uncharacterized but are predicted to be persistent and bioaccumulative. As only a small fraction of Earth's water is easily accessible for human use, the contamination of lakes and rivers becomes a significant concern. Conventional wastewater treatment methods effectively remove traditional pollutants like bacteria, nitrate, phosphate, hydrocarbons, and heavy metals but are less effective against emerging contaminants such as pharmaceuticals, pesticides, plasticizers, and surfactants. This study aims to address this issue by removing pollutants from wastewater effluent using high-energy electrons through electron beam irradiation (EB). This method generates highly reactive species that can rapidly break down organic pollutants into smaller, more biodegradable products. By focusing on the effectiveness of EB irradiation in degrading a wide range of contaminants, rather than identifying them individually, this research seeks to advance water purification technologies and ensure a cleaner and safer water supply.

Methods: Two batches of wastewater samples were irradiated at various doses at the National Institute of Standards and Technology (NIST) in Maryland, USA. The treated samples were analyzed using a Thermo Scientific Orbitrap LC-MS with an EQuan autosampler for large volume injections, ensuring precise, high-resolution data with increased sensitivity for detecting, characterizing, and quantifying trace analytes. The first batch was irradiated at doses of 0.1, 0.5, 2, 5, 15, and 25 kGy, while the second batch received doses of 0.05, 0.1, 0.2, 0.5, 1, and 50 kGy. All samples were analyzed in full scan mode, with spectra recorded over the m/z range of 100-1200 in both positive and negative modes using an electrospray ionization (ESI) probe. In negative ion mode, analytes are charged through deprotonation, while in positive ion mode, they are charged through protonation. The obtained results indicated the presence and absence of corresponding masses in the wastewater samples. The recorded data was processed using MZmine 2 software, a widely used, free tool for preprocessing untargeted LC/MS raw data.

Results: The results demonstrated that EB treatment significantly degraded contaminants, with reductions of up to 84.52% for individual pollutants. Specifically, approximately 72% degradation was observed at 0.5 kGy, increasing to 92% at 2 kGy. Figure 1 (given as an attachment) illustrates the degradation percentage of contaminants with increasing irradiation doses, showing a clear trend of higher degradation at higher doses.

Conclusion: These findings indicate that electron beam (EB) irradiation is a promising technology for improving the effectiveness of wastewater treatment. This study highlights the potential of incorporating EB technology into wastewater treatment protocols to achieve superior contaminant removal and enhance environmental sustainability.

IAEA-CN-332/669

Monte Carlo Simulations of Electrostatic Field Effects on Dose Distributions: A Predictive Framework

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Background: E-beam irradiation is frequently used for sterilization of medical devices. During this process, electrons can become immobilized in non-conductive materials like polymethyl methacrylate (PMMA), resulting in a stored charge distribution. High doses used in industrial sterilization can thereby generate significant electrostatic fields in the material, potentially affecting the dose distribution.

Methodology: This study employs TOPAS MC/Geant4 simulations to examine the impact on dose distributions of these electrostatic fields within a PMMA cylinder. We developed a framework to calculate the electrostatic field based on simulated electron deposition, and implemented this non-homogeneous field in TOPAS. The absorbed doses within simulated alanine pellets on the cylinder surface were analyzed under varying electrostatic field strengths. Computational results were validated against experiments conducted at an industrial irradiation facility.

Results: The results from the simulations showed good agreement with dosimetric measurements. The results indicate that electrostatic fields within a PMMA cylinder significantly impact the dose to surface-mounted alanine pellets, particularly those positioned from 45 to 90 degrees around the cylinder as field strength increases.

Conclusion: This study indicates that electrostatic fields arising from stored charges can have a significant influence on the dose distributions during e-beam sterilization of medical devices. This framework could form the basis for a tool for predicting the effects of stored charge distributions in polymer-based products.

IAEA-CN-332/380

Application of Non-Destructive Testing in the Preservation of Cultural Heritage Buildings

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The application of Non-Destructive Testing in the preservation and restoration of built heritage provides a thorough understanding of the buildings condition by gathering relevant information about the materials and construction techniques of historical buildings and structures.

Radar, Ultrasonic Testing, Pulse Echo Scans as well as Infrared Thermography are all well qualified investigations suitable to diagnose in an accurate way existing problems, variations and degradations, and assess the feasibility of materials and intervention strategies in a non-invasive or minimally invasive way.

These procedures have been applied to some buildings located in the Valtellina region of Italy, affected and characterized by major structural damages, including Palazzetto Besta in Bianzone, where the evaluation of the condition of the building was essential to carrying out the restoration intervention in a more consistent and respectful manner.

The potential and effectiveness of these technologies, in dealing with extremely valuable and delicate situations, has been demonstrated, and as the field continues to grow and innovate, it allows for increasingly accurate results in the investigation of historic building characterization, and for facing with the relevant structural damages often due to natural and non-natural disasters, as well as to change mechanism caused by decay processes.

Keywords: Radiation Science and Technology; Built Heritage; Valtellina Region.

IAEA-CN-332/562

Studying and Developing a New Computed Tomography Method for Investigating Distillation Columns

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Abstract: Distillation columns are essential components in refineries, playing a crucial role in separating and purifying crude oil mixtures for production. However, due to extreme processing conditions, such as high temperatures, pressures, and the flow of liquids and vapors, these columns are prone to malfunctions. Gamma scanning is a widely used technique in petrochemical refineries to investigate the condition of trays and the distribution of liquids within these columns. This technique generates a one-dimensional graph that displays recorded radiation counts and column elevation, providing generally qualitative results. To enhance the diagnostic capabilities of gamma scanning, a new method called Laminography (or 2D gamma scanning) is being developed in our laboratory. This report introduces the 2D gamma scanning technique, which is applied to assess the condition of trays in a laboratory-scale distillation column model. The new technique is expected to improve the detection of tray or liquid flow malfunctions, which can significantly reduce the efficiency of the distillation process. Additionally, it has shown potential in our laboratory for detecting issues such as tray bending, tray collapsing, flooding, and foaming. In our upcoming research, we will explore ways to adapt this technique for industrial applications.

IAEA-CN-332/649

A Trade-Off Between Quality and Speed in Neutron Tomography by Multi-Objective Optimization

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Background of the study:

Neutron tomography is a powerful tool for non-destructive imaging and analysis of materials and structures. However, achieving high quality in neutron tomography is crucial for observing the details of the structure inside the investigated object. Increasing the number of projections correlates with increasing the quality of the reconstructed volume, but this also reduces the speed of tomography.

Methodology:

To address this challenge, we have developed a novel method that enables a trade-off between quality and speed of tomography by using a multi-objective optimization algorithm. This approach allows us to find the optimal balance between quality and speed, rather than just basing our choice on the Nyquist-Shannon rate.

Results:

Our optimization results show that for a desired level of quality (e.g., above 70%), it is possible to reduce the number of projections to half of the Nyquist-Shannon rate. This reduction in the number of projections significantly increases the speed of tomography, making it more practical for widespread applications.

Conclusion:

In conclusion, our novel method offers a promising approach to achieving a balance between quality and speed in neutron tomography. By using a multi-objective optimization algorithm, we can find the optimal trade-off between these two competing objectives, enabling faster and more efficient imaging and analysis.

IAEA-CN-332/394

Optimization of the synthesis of acrylamide-grafted-Polypropylene-non-woven fabric using electron beam induced irradiation

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Electron beam induced grafting is a technique used to modify the surface of polymers, with applications across various fields. The pre-irradiation method involves exposing the backbone polymer to irradiation, generating surface free radicals that can subsequently react with a monomer forming a covalent bond on the surface.

The scope of this study is to investigate the impact of different parameters on the degree of grafting using the pre-irradiation method with electron beam (1,65 MeV) in air. Polypropylene non-woven fabric (PP-NWF) serves as the backbone polymer and Acrylamide (AA) was used as monomer.

Different pre-irradiation doses (40 – 120 kGy), and different grafting parameters: monomer concentration, solvent composition, grafting temperature, anti-homopolymerization agent, concentration, and reaction time were examined.

The results indicated optimal conditions for maximizing the degree of grafting with 80 kGy pre-irradiation dose, 40% monomer concentration , temperature between 60-62°C, and 3 mg of $CuCl_2$ as the anti-homopolymerization agent. These conditions enabled achieving an average degree of grafting of 68% while preventing the formation of homopolymers.

This research highlights the potential of electron beam induced grafting as a customizable technique for enhancing polymer surface properties. Future studies could further explore additional parameters to refine and expand upon these results.

IAEA-CN-332/374

Assessment of Shielding Properties of Concrete Slabs using Gamma Computed Tomography

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Shielding materials are very important in the construction of nuclear installations and facilities. This ensures the containment structures are not easily destroyed by radiation damage and also to protected people and the environment in the case of unexpected release of radiological materials. This study investigated the shielding properties of four pieces of concrete slabs of varying composition of pozzolana and Portland cements using portable gamma computed tomography (CT) equipment which employs gamma rays from Cs-137 source of activity 48 mCi and NaI detector. The objectives were to determine the relative shielding properties of the concrete sample and also to assess the CT equipment for its capability in discrimination of our concrete materials of different compositions. Four samples labelled A, B, C, and D was mounted one after the other and centred as much as possible in the gantry of the CT equipment. Both linear and rotational resolutions were set at 70 and the counting time of 5 seconds was used in the collection of the scan data. The reconstructed image of each sample was generated using filtered back algorithm. Analysis of the reconstructed images revealed that, sample C has the best shielding property followed by B and D. Sample A has the lowest shielding property. The implications of the results were discussed and recommendations given.

IAEA-CN-332/842

Diagnostic Methods for Cultural Heritage

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Stable isotopes are used to study the environment, major natural physico-chemical cycles, the geological history of our planet and, increasingly, cultural objects (the origins and diets of past populations, for example).

This democratization is based, on the one hand, on the study of the bio-physico-chemical mechanisms by which various isotopic "archives" record the paleo-environment (temperature, hydrology...). But also, technical advances enabling us to design increasingly sensitive/precise/selective observation/characterization instruments, while offering increasingly inexpensive measurements. The arrival of laser instruments has enabled many laboratories to equip themselves with high-performance machines at a lower price than mass spectrometers, while enabling faster measurements.

At LSCE, CEA DRF (France) has been developing new-generation optical instruments for the past 10 years. The aim is to offer instruments with the advantages of lasers (low cost, rapid measurements, etc.) with performance comparable to or even exceeding that of state-of-the-art IRMS. Examples include demonstrations of isotope 17 anomaly (Δ17O) measurements in water and CO_2, and the development of an instrument capable of measuring both Δ 17O and dual-clumped (Δ47; Δ48) in the CO_2 simultaneously, at least as well as the best IRMS.

IAEA-CN-332/119

Autologous NK Cell Culture Medium Gamma-Irradiated with 10 kGy Promotes Wound Healing by Inhibiting Heat Stress-Induced Skin Cell Death and Enhancing Proliferation Through Activation of the PI3K/Akt Signaling Pathway

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Skin is considered one of the most vital organs in the body due to its important functions such as an outer protective barrier against various external agents and a temperature regulator. With a high rate of morbidity and mortality, skin burn is not only difficult to treat, but also poses a major public health burden worldwide.

Natural killer (NK) cells are innate lymphocytes critical for controlling viral infections and eliminating malignant cells, originally identified by their ability to kill target cells without prior sensitization. Especially, increasing evidence has shown that NK cell culture broth (NK-CM) yields a favorable therapeutic benefit for skin diseases.

We conducted research to develop skin wound treatment materials by using radiation technology to improvement the sterilization and function of NK cell culture medium, a by-product of cell and gene therapy.

Our results showed that NK-CM expressed various markers of NK cells (Fig. 1). NK-CM gamma-irradiated with 10 kGy significantly promotes thermal burn wound healing by increasing expression of Nrf2/HO-1/PI3K/Akt and inhibiting heat stress-induced cell death (Fig. 2). As well, NK-CM accelerated re-epithelialization with increased expression of CK19 and PCNA. It suggesting that NK-CM may contribute to the improvement of the wound healing through activating Nrf2/HO-1/PI3K/Akt signaling pathway.

IAEA-CN-332/120

Gamma-Irradiated Eucommia ulmoides Extract Protects Skin Cells by Regulating Nrf2 and NF-κB Signals to Enhance Antioxidant and Anti-Inflammatory Activities

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Skin being the first defense mechanism of the immune system allows itself to respond and resist to the hostile environment of temperature, humidity, and radiations. The skin is the largest organ of the human body, accounting for about 14~17% of the human body weight, and has a series of physiological functions such as breathing, sensation, protection, absoption, secretion, excretion, temperature regulation, and metabolism, and it is also an important barrier to protect the homeostasis.

Eucommia ulmoides (EU) has been widely used in Korea, Japan, and China. It has also pharmacological effects on coronary blood flow, pain relief, diuresis, and lipid metabolis. Recently, a water extract from Eucommia ulmoides leaves was reported to possess a potential antioxidant effect and to prevent oxidative DNA damage and lipid peroxidation.

In this study, we found that 10 kGy gamma-irradiated EU significantly reduced the expression of IL-6 and IL-1β (Fig. 1), reduced NF-kB phosphorylation, and repaired and/or increased Nrf2/HO-1 expression, thereby promoted anti-oxidant enzyme gene expression (Fig. 2). It suggesting that 10 kGy gamma-irradiated EU has antioxidant and anti-inflammatory activities, which makes it suitable for treating skin wounds. What is more interesting is that the effect is even better when the EU extract is gamma-irradiated, which means that there is a need to identify the optimal antioxidant and anti-inflammatory active substances according to gamma irradiation.

IAEA-CN-332/476

Study of Side-effects on Cellulose Based Materials Induced by MeV Proton Irradiation

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The use of Ion Beam Analysis (IBA) for cultural heritage characterization is a well-known method for determining the concentration and distribution of elements present in the artefact. These IBA techniques employ high-energy ion particles, typically protons with energies in the MeV range. They are generally considered non-destructive when proper experimental conditions are applied. However, recent concerns have emerged regarding potential side effects on the analyzed materials. These effects, even if not immediately noticeable, may become visible over time, posing a risk to the integrity of these artifacts.

To investigate the possible origin of side effects on cellulosic-based materials induced by a 2 MeV proton beam, several samples were irradiated in both open air and vacuum conditions, applying different fluences (deposited charge per unit area) within and beyond usual analytical practices: 0.1, 1, and 4 $\mu C/cm^2$. Due to the variability of historic materials, several types of cellulose-based materials were tested, including Whatman filter paper, used as a reference sample.

To comprehensively assess the side effects, we employed a set of techniques, including colorimetry, X-ray Diffraction (XRD), Attenuated Total Reflection Fourier Transform Infrared Spectroscopy (FTIR-ATR), Thermogravimetric Analysis (TGA), and Differential Scanning Calorimetry (DSC). Preliminary results revealed that when the deposited charge exceeds the typical values for characterizing these materials (0.1 $\mu C/cm^2$ or less), visible colour changes were detected, along with a loss of crystallinity and a decrease in degradation temperature.

This work highlights the critical balance between using IBA techniques for cultural heritage artefact characterization and the need to preserve these materials for future generations. By identifying and understanding the potential side effects of such analytical techniques, we can refine our methodologies to ensure their effectiveness while safeguarding the integrity of the artefacts.

IAEA-CN-332/502

Enhancing Industrial Performance and Troubleshooting Capabilities: Angola's Journey with IAEA and Moroccan Support

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Optimizing industrial processes is crucial for developing nations that seek to improve the performance and efficiency of their production systems, as in the case of Angola, the ANG 1005 Project, promoted and financed by the International Atomic Energy Agency (IAEA) and in collaboration with Morocco, entitled "Using Radiation Technologies as Diagnostic Tools for Optimizing Industrial Plant Process Performance and Troubleshooting," is an example of how radiation technologies for industrial use can accelerate countries' industrial development processes. This project is transforming Angola's industrial sector in matters of diagnosis and process optimization. This work aims to explore Angola's transformative journey under the ANG 1005 Project, highlighting key milestones achieved, including the integration of specific radiation technologies, the upgrade of the Isotopic Laboratory and observable benefits in industrial plant operations. To carry out this project, investment was made in training technicians through cooperation between African countries, supplying equipment and radiation techniques for diagnosis and optimization of industrial processes, certification of technicians to enable them to provide services in the industrial sector. The results of this project sound for themselves, as the CNIC Isotopes laboratory was equipped, 3 technicians were certified in 2 different techniques (gamma scan and Radiotracer industrial applications), placement of student interns and the application of the gamma technique scan at the Luanda oil refinery, which is in the execution phase. By highlighting Angola's progress and the success of this project, we emphasize the role of advanced technologies in driving industrial growth and sustainability and international south-south cooperation. The potential and success of this project suggests that we recommend this same model be replicated in other developing countries.

Keywords: Radiation technologies. Industrial efficiency. Industrial process optimization. Diagnostic tools.

IAEA-CN-332/503

Luminescence Study of Nano-Phosphor $CaNa_2(SO_4)_2$: Eu for Gamma Rays and Ion Beams

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1. Background of the study:

Heavy-charged particle beams, such as protons and carbon ions, are increasingly recognized as optimal tools for treating deep-seated, inoperable tumors. Unlike traditional photon therapy, the dose from these particles intensifies with penetration depth, peaking sharply at the end of their range, which allows for precise targeting of the tumor. Carbon ion therapy stands out due to its high precision in dose application and significant biological effectiveness against malignant tissues. The precise measurement of the dose delivered by these energetic ions is crucial, particularly in the context of human treatment. Thermoluminescent dosimeters (TL dosimeters) are considered suitable for verifying doses in heavy ion irradiation, especially for carbon ions. This study focuses on the luminescence properties of nano-phosphor $CaNa_2(SO_4)_2$: Eu under gamma rays and carbon ion beam to explore their potential use in accurate dosimetry.

2. Methodology:

$CaNa_2(SO_4)_2$: Eu was prepared with the combustion method. Different concentrations of Eu ranging from 0 to 0.5 mol% were added to the compound and the optimized concentration was found to be 0.1 mol % Eu after irradiation with 10Gy gamma dose. Annealing study showed that the optimized temperature is 500^{o}C for 1h. TL measurements were recorded using the Harshaw TLD reader 3500. The pellets produced were exposed to 80 MeV of carbon ion in the fluence range of 1e10 to 1e13 ions/cm2 by means of a 16 MV Tandem Van de Graaff type electrostatic Pelletron accelerator situated at the Inter-University Accelerator Center (IUAC), New Delhi, India.

3. Results:

The intensity of $CaNa_2(SO_4)_2$: Eu increased with the increasing dose from 10 Gy to 7 kGy of gamma radiation. XRD showed that the data matches well with the JCPDS card number 96-900-0155 with a monoclinic crystal structure. The average crystallite size was found to be 23 nm. FESEM showed the formation of slab like structures. As compared to the standard phosphor TLD-100, $CaNa_2(SO_4)_2$: Eu is more sensitive to gamma rays of dose 10Gy. It was irradiated with 80 MeV carbon ion beam and It showed a linear response from in the fluence range of 1e10 to 1e12 ions/cm2. Even though it is less sensitive than CaSO4: Dy for ion beam, it shows a wide linear dose response and a simple glow curve structure. It shows a potential to be used as a dosimeter for gamma rays and carbon ion beams.

4. Conclusion:

The study successfully synthesized and optimized the luminescence properties of nano-phosphor $CaNa_2(SO_4)_2$: Eu for dosimetry applications under both gamma rays and carbon ion beams. The results demonstrate that $CaNa_2(SO_4)_2$: Eu exhibits a linear dose response and high sensitivity to gamma radiation. It is also a viable candidate for dosimetry in carbon ion therapy. Future research could explore the long-term stability and repeatability of the luminescent response, as well as the potential integration of this material into clinical dosimetry systems, thereby advancing the precision and effectiveness of cancer therapies involving heavy ion irradiation.

IAEA-CN-332/508

Enhancing TPS Composites through Ionizing Radiation for Valorizing Yerba Mate Production Waste

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Natural waste generation is an important issue in agricultural activities, especially in the production of yerba mate (YM) in Argentina. This study investigates the use of ionizing radiation to modify YM stems, offering a sustainable alternative to traditional chemical modifications.

The YM ground stems were irradiated, using a Co60 (~750 kCi) source (10, 50, and 75 kGy). Studies on physical and chemical characterization were conducted. The irradiated powder was then incorporated at 10% w/w into thermoplastic starch (TPS) composites using an extruder, and their properties were compared to those of composites made with non-irradiated filler.

As the irradiation dose increased, the powder increased water solubility and decreased thermal stability, indicating degradation. The FTIR spectra showed changes in functional groups, indicating oxidation. Electron microscopy showed that radiation caused modifications in the fiber morphology, resulting in a rougher surface texture. These changes led to a new set of fillers, more compatible with TPS matrices. TPS composites containing irradiated fillers showed superior mechanical properties compared to those with non-irradiated fillers, with improvements of up to 30% in Young's modulus and strain at break.

Ionizing radiation effectively modifies YM stems, improving their compatibility with TPS matrices and enhancing their mechanical performance. This method provides a sustainable approach to the valorization of natural polymer wastes, promoting environmentally friendly composites.

IAEA-CN-332/513

Gamma-Ray Scanning Technique to Evaluate the Performance of Absorber Column on Offshores Natural Gas Production, Indonesia

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A gas treatment unit (GTU) absorber was suspected of having a problem that caused a decrease in natural gas production by 42% (from 250 to 145 MMSCFD). It is a structured packing column that functions to remove H2S gas from the natural gas stream on a floating production, storage and offloading (FPSO) in Madura Strait, Indonesia. The gamma-ray scanning technique was proposed to evaluate the performance of the column. The scanning was carried out in four parts over twenty months. There are six scan lines for each scanning part that gridded the column to map density distribution on the packing bed. A gamma radiation source (Co-60) with an activity of 1.85 GBq was used as the transmitter, while a NaI(Tl) scintillation detector was the receiver. They flanked the column and moved in parallel from the bottom to the top of the column. The first scanning part aimed to check the condition of the bed packing after the suspected problem. The second was performed five days later and aimed to study the effect of jet cleaning treatment on the column. The third was to monitor the condition of the column after it had been operating for five months. The final scanning part aimed to evaluate the performance of the column after the packing bed replacement. The first part of the scanning data showed inhomogeneous density distribution conditions on the packing bed. The second part showed that the jet cleaning treatment affected the density distribution on the packing bed. The third part results showed worse bed conditions than before. The fourth part results (after packing bed replacement) showed that the density distribution on the bed was much better than the previous conditions. At that time, the used packing bed that had been dismantled from the column can be witnessed. The condition of the packing bed was in accordance with the data from the three previous scanning parts. There were crushed packing bed materials in several areas so that there were cavities, and then debris from the crushed material became new solids in other parts of the packing bed that led to blockages. These results prove that the gamma-ray scanning technique contributes significantly to evaluating the performance of the absorber column.

IAEA-CN-332/519

Assessing the Risk of Incorporating a Radioactive Source into Rhinoceros Horns Using the Monte Carlo Calculation Code RayXpert® to Combat Poaching as Part of the Rhisotope Project

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The Rhisotope Project, founded in 2021 by Prof. James Larkin, aims to save rhinos from the threat of extinction by implanting radioisotope into their horns using advanced nuclear science. The dose distribution study has been performed using Monte Carlo simulations in order to assess the safety of this innovative approach.

RayXpert® is a 3D Monte Carlo calculation code developed by TRAD Tests & Radiations and dedicated to various applications encountered in the nuclear field. In the context of the Rhisotope Project, it has provided a comprehensive risk analysis by calculating the dose distribution within the rhinoceros' head.

This study included an initial step of translation of a DICOM file into a STEP file, readable by the software. Thereafter, simulations were conducted in order to consider a radioactive activity detectable by current detection infrastructures at international borders. Results lead to the choice of a radioisotope activity and placement that does not pose a significant health risk to the rhinoceros.

The relevance of Monte Carlo simulations provides a solid foundation for the first phases of the Rhisotope Project. The current step of the Rhisotope project is a trial phase, where several rhinoceros have been implanted with a radioactive tracer.

IAEA-CN-332/521

Field Application Study of an Electron Beam Treatment System for the Reduction of NO_x and SO_2 in Flue Gas Emitted from a Waste Incineration Plant

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The reduction of nitrogen oxides (NOx) and sulfur dioxide (SO2) in flue gas emitted from waste incineration plant was investigated using an electron beam (EB) treatment system. This treatment system developed in this study simultaneously sprays additive solution (0.2 M NaOH) while irradiating EB to covert NOx and SO2 into aerosol (NaNO3 and Na2SO4) through oxidation reactions of radicals and active species generated by EB. An on-site study was conducted at a waste incineration plant located in South Korea. Approximately 120 ppm of NOx and 100 ppm of SO2 from the flue gas were supplied to the EB treatment system at a flow rate of 20 m3/hr. The performance of the EB treatment system was evaluated under two conditions: (1) EB irradiation only (EB only) and (2) EB irradiation with NaOH additive spraying (EB+NaOH). In the EB only process, the highest removal efficiencies were achieved at 5 kGy for NOx (85.2%) and 10 kGy for SO2 (77.0%). In contrast, the EB+NaOH process showed the highest removal efficiencies at 3 kGy for NOx (88.0%) and 3 kGy for SO2 (99.0%). The EB+NaOH process improved the removal performance of NOx and SO2 compared to the EB only and allowed for a decrease in the absorbed dose (EB irradiation energy). The EB treatment system developed in this study has been demonstrated to efficiently remove NOx and SO2 in the flue gas.

IAEA-CN-332/523

Effect of Gamma Irradiation on the Sustainable Use of Recycled Pre-Consumed Polypropylene-Based Medical Waste

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In view of minimizing the environmental impact associated with plastic production and consumption, the use of polymeric waste in new valuable performance products through sustainable processes offers cost-effective benefits as it reduces the consumption of high costs virgin materials. Polyolefins, especially polypropylene (PP) are among the main polymers with high consumption and easy recyclability. A viable solution to the current needs of reducing the amount of incinerated medical waste is the reuse of recycled PP in new composites incorporating biomass. In this context, ionizing radiation serves as a microbial decontamination technique, simultaneously used for modification of recycled PP-based polymeric materials in order to enhance their performance. This study aims to evaluate the effect of different gamma irradiation absorbed doses on the structural, thermal, rheological and mechanical properties of newly developed materials based on pre-consumed recycled PP resulted from medical syringes and celandine (Chelidonium majus), obtained by melt compounding and compression molding.

IAEA-CN-332/535

Functionalization of Food Packaging Films by Radiation-Induced Grafting

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The development of novel materials with enhanced surface properties has attracted researchers globally, with numerous studies conducted at leading scientific institutions. Radiation-induced grafting have emerged as methods to modify a broad spectrum of polymers for applications in biomedicine, food packaging, and tissue engineering scaffolds. Despite some initial attempts, there is still a limited presence of products on the market that are activated through grafting methods. One of the most dynamically developing segments of the economy is packaging market. Manufacturers are looking for new and innovative packaging types and technologies to produce more cost-effective, practical and of higher performance items. Bioactive food packaging is a novel concept of technologies intended to extend food product shelf-life, reduce the risk of spreading communicable diseases, improve food safety and minimize food spoilage.

This study focuses on the design and characterization of active food packaging films with surface-bound antimicrobial proteins and/or peptides that can extend food shelf life, improve food safety, and minimize food spoilage. To achieve this goal, it is first necessary to functionalize the surface of the packaging with appropriate functional groups and then attach bioactive molecules to the modified surface. The method which can be used for surface modification is radiation induced grafting.

In this work packaging foils, composed of three layers: PP, PP/PE and internal layer, known as DCL-B and DCL-BD (supplied by Dekofilm Polska) were used as a matrices for radiation-induced grafting. Two monomers: acrylic acid (AAc) and acrylamide (AAm) were used as a grafting agents to introduce carboxyl or amine groups on the surface, respectively. Different parameters affecting the grafting yield, such as effect of absorbed dose, dose rate, time of irradiation, monomer and hompolymer suppresor concentration, were investigated. The radiation-induced grafting was carried out using an electron accelerator ILU-6 (electron energy 1.65 MeV, pulsing frequency 2 and 10 Hz, beam current 50 mA). Physicochemical properties of the control and grafted food packaging films were studied using infrared spectroscopy (ATR-FTIR), electron paramagnetic resonance spectroscopy (EPR), thermogravimetric analysis (TGA) and scanning electron microscopy (SEM).

Satisfactory results of surface functionalization with the direct method were obtained, both for acrylic acid and acrylamide grafting. Optimization of EB irradiation parameters (absorbed dose, dose rate, time of irradiation) for functionalization of food packaging films were achieved and films with three levels of grafting degree (DG = 20 - 80%) were produced and characterized. Basing on a comparative analysis of the spectra of pristine and grafted samples using spectroscopic techniques (EPR, FTIR) showing new bands that might be attributed to grafted polymers. TGA thermograms of the pristine films and grafted one shown in an additional step of thermal decay at around 300oC that can be attributed to the degradation of the grafted layers. SEM demonstrated that grafting results in topographic changes due to the presence of covalently bound poly(acrylic acid) and polyacrylamide.

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IAEA-CN-332/539

Investigating Subsurface Flow Constructed Wetlands using Electrical Resistivity Tomography (Case study: Chorfech Constructed Wetland)

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Cities in Tunisia with a population of more than 5,000 already have sewage treatment facilities. However, the environment and public health are seriously endangered by poor sanitation in rural areas and small settlements. The majority of the 40% of Tunisians who live in rural regions have access to drinking water. Poor sanitation services are provided to 83% of this population, and their effluent is dumped into the environment untreated.

The constructed wetland at Chorfech is made up of 3 types of flow (2 horizontal and 1 vertical). The waste water treatment in this locality consists of one Imhoff tank for pre-treatment and three stages in series: a horizontal subsurface flow CW system as the first stage; a subsurface vertical flow CW system as the second stage; and a horizontal flow CW as the third. We investigated and measured the physical characteristics of the materials in Chorfech's constructed wetland. The 1st stage HF beds are filled with siliceous gravel Ø 8–12 mm, while the 3rd stage ones with siliceous gravel Ø 5–10 mm with an average medium height of 0.8 m. The 2nd stage VF CWs are filled with four layers, from bottom to top: 0.15 m of gravel Ø 40–70 mm, 0.10 m of gravel Ø 5–10 mm, 0.50 m of coarse sand Ø 0.02–0.1 mm, and 0.20 m of gravel Ø 5–10 mm.

Improving the efficiency of the wetland necessitates meticulous management of its structural elements and wastewater flow pathways. Numerous factors have the potential to influence the system's operational efficacy of the system, including subsurface infiltration and the accumulation of sludge within the flow beds.

To evaluate the internal water fluxes of, the electrical resistivity tomography (ERT) technique serves as a highly effective tool for modeling hydrodynamic environments.

This study examines the potential of the electrical resistivity (ER) method as a non-invasive technique to identify malfunctions in full-scale tertiary wastewater treatment wetlands, such as clogging and the pathway, which can ultimately shorten the system's lifespan and diminish its performance.

Electrical resistivity (ER) measurements were conducted using the Wenner method on two overloaded horizontal subsurface wetlands (HSF-CW1 and HSF-CW2). The detailed 2D data from the electrical resistivity tomography profiles obtained reveals that the gravel filter's thickness varies between 0.5 to 1.5 meters, demonstrating a consistent pattern that promotes wastewater flow within the facility. The electrical resistivity of the gravel filter layer falls within the range of 10 to 40 ohm·m. The crucial outcomes of this investigation suggest that utilizing electrical resistivity tomography represents a significantly beneficial approach for analyzing subsurface flow constructed wetlands and elucidating their internal configuration. The detailed two-dimensional data secured via electrical resistivity tomography emerges as the favored technique for acquiring detailed spatial information about the subsurface dynamics within this setting. Notably, when evaluating the High-Surface-Flow-System Constructed Wetland, the electrical tomography profiles distinctly outline the vertical extents of the gravel layer and unveil horizontal fluctuations in electrical resistivity within the gravel filter, reflecting areas experiencing heightened surface ponding as a consequence of blockages.

IAEA-CN-332/541

Investigation of Using Radiotracers for RTD Determination in CSTR with Aeration for Poly(3-Hydroxybutyrate) Production

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Due to the increasing importance of biodegradable Polyhydroxyalkanoates (PHA) biopolymers, including Poly(3-Hydroxybutyrate for the production of packaging and medical applications, investigation in these fields is crucial to meet the requirements of "green industrial production". Research was conducted to optimize the bacterial culture of genetically modified Escherichia coli, commonly used for biosynthesis of Poly(3-Hydroxybutyrate) in Continuous Stirred-Tank Reactor (CSTR) with aeration. Optimization of the process involved:

(i) research of the possibility for selection of radiotracers to determine the Residence Time Distribution RTD in a CSTR with aeration,

(ii) investigation of an aeration of microorganism cultures which were carried out in the BioFlow 310 bioreactor by determination of the oxygen volumetric mass transfer coefficients.

The substrate applied for the microorganisms was either pure glucose or the waste carbon sources. The bioreactor applied in the current research was equipped with a Rusthon-type double turbine and a gas sparger. The oxygen volumetric mass transfer coefficients were determined for the air-water system at a temperature of 37 oC, in an active volume of 5 dm3 and with aeration set to 5 dm3/min. The experiments were carried out for three values of rotational speeds of the stirrer: (i) 150 rpm; (ii) 250 rpm; (iii) 350 rpm. The experimentally determined values of the volumetric mass transfer coefficients were then compared with the values predicted with the modified van't Riet correlations. Studies were undertaken on the selection of radiotracers to determine RTD in CSTR with aeration and on the development of a measurement method. The obtained results of the oxygen volumetric mass transfer coefficients and research on selection of radiotracers for RTD will be used to determine (i) flow rate in relation to the kinetics of microorganism growth, (ii) mass balance in the gas-liquid system of the genetically modified Escherichia coli culture based process to produce Poly(3-Hydroxybutyrate) in CSTR with aeration.

IAEA-CN-332/542

Joint Multi-Optimization of Radiation Treatment of Plant Materials for Enhancing Bioethanol Production

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Bioethanol production from lignocellulosic biomass fits into the strategy of a circular economy and zero waste plans. Additionally, employing ethanol as an alternative fuel offers the possibility for the global economy to break free from the petrochemical sector, ensuring both energy security and environmental safety. However, the conversion of biomass into ethanol is a challenging and multi-stage process because of the variation in the biochemical composition of biomass and the recalcitrance of lignin, the aromatic component of lignocellulose. Due to the high expenses of research and manufacturing, cellulosic ethanol production has not yet found significant commercial success. As a result, much work needs to be done to make it more successful and widespread. For efficient conversion to bioethanol, it is important to study the composition of the raw lignocellulosic biomass and devise appropriate delignification and saccharification strategies. In this study we propose to optimize radiation processing of the use of ionizing radiation to break down cellulose from Peganum harmala. The main goal was to understand the interplay between the irradiation dose, the physical aspect of the plant (powder, fragmented, not fragmented), and its level of humidity, and how these factors increase the removal of lignin, the breakdown of cellulose, and the release of monomer sugar. To this end, sixteen experiments were designed using a Box-Behnken matrix and response surface methodology to understand concomitant interactions between different factors. The optimal levels were predicted by NemrodW software and were experimentally validated. We expect that such approach enhances the saccharification yields by producing more ethanol precursors, and lowered costs compared to enzymatic or acid hydrolysis techniques.

Keywords: Radiation-chemical treatment; bioethanol; lignocellulosic biomass; fermentation; biofuel; Box-Behnken matrix; response surface methodology

IAEA-CN-332/543

Investigation of Electron Beam Calibration Using Depth-Dose Channel Ratio Methodology

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Background of the study:

Electron beam calibration dosimetry traditionally requires the sequential use of depth-dose packs to tune the voltage for accuracy. Once the dose pack is irradiated and the dose established, the potentiometer is adjusted based on the results. While this is considered an acceptable industry practice, the process lacks an accurate performance curve based on computational dosimetry to serve as a reference. This is particularly useful for quantifying absorbed dose in surface layers, where sterilization requires high confidence.

Methodology:

The PENELOPE Monte Carlo code for radiation transport is used to calculate a channel ratio between the alanine dosimeter and stepped polyethylene absorber layers.

Results:

50 KeV increments ranging from 100 KeV to 300 Kev are examined for use as a reference curve during electron beam calibration. A process for using this to assess surface dose is also considered.

Conclusion:

Accuracy of these calculations and possible sources of process error are discussed.

IAEA-CN-332/544

Post-Earthquake Structural Damage Assessment and Disaster Response in Ecuador: Insights from NDT-CE and International Technical Cooperation Mission

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On March 18, 2023, a 6.6 Mw earthquake occurred in the Guayas province of the Republic of Ecuador, primarily affecting the central-southern region of the country and, to a lesser extent, the northeast of the Republic of Peru. The epicenter was located off the coast of Balao Canton in the Gulf of Guayaquil area, with its hypocenter approximately 63 km deep.

Immediately following the seismic event, disaster response protocols were activated, particularly those related to housing and infrastructure, to conduct rapid visual screening (RVS) inspections according to the methodology of Ecuador's Design Guide 5. The purpose of these RVS inspections was to verify and categorize the damage status of affected constructions, with labels indicating their risk level to the population.

According to the survey conducted by public entities, the earthquake caused significant damage in the Ecuadorian provinces of Azuay, El Oro, and Guayas, resulting in 14 deaths, 500 injuries, and 3700 affected individuals. Regarding infrastructure and housing, damages were reported in 331 educational units, 57 health centers, 61 public properties, 77 private properties, and 1030 homes. Additionally, 277 homes and 8 public properties were destroyed. Based on the RVS inspection results, Machala Canton in El Oro province was identified as the most affected area.

Simultaneously, an international technical cooperation mission organized and promoted by the IAEA was activated to provide technological assistance in the field of Non-Destructive Testing applied to the civil engineering (NDT-CE) in Machala. The mission aimed to train university professionals and responders in the use of these methods to enhance the understanding of the state of reinforced concrete structures post-earthquake and to increase confidence in the evaluations.

This work presents and discusses some of the damages to buildings caused by the earthquake and results of the technical cooperation mission, which are of interest for their application in other countries in the region and around the world.

IAEA-CN-332/546

Enhancement of Interfacial Interaction Between Pineapple Leaf Fibers and Polypropylene Resins Assisted by Ionizing Radiation

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The generation of plastic waste has been constantly increasing over the years worldwide. Approximately 60 % of total polyolefin production, such as polypropylene and polyethylene, are discharged in landfills and only nearly 5 % are recycled. On the other hand, the use of Pineapple leaf fiber (PALF) obtained from agricultural biomass; very abundant in Costa Rica, might replace partially plastic resins with cellulosic materials to form composites that may reduce the cost and improve mechanical properties. However, in order to perform fiber reinforcement, it is necessary to enhance thermoplastic matrix and lignocellulose fiber interface interactions. Several strategies have been reported, that involve chemical surface treatment to the fibers, and compatibilizer methods that provide suitable adhesion between natural fiber-polymer matrices. Therefore, the objective of the present work is to prepare composites of recycled polypropylene resin, Pineapple leaf fibers (PALF) and PP resins pretreated using ionization radiation (at a dose of 200 kGy). In this investigation, PP/PALF/ɣ-PP composites are fabricated using a Brabender Mixer followed by heat compression. The mechanical properties of the composites are evaluated by adding different percentages of PALF. Moreover, Fourier Transformed Infrared Spectroscopy (FT-IR), Differential Scanning Calorimetry (DSC), Thermal Gravimetric Analysis (TGA), and X-ray diffraction (XRD) is presented. The formulated mixture might be a good candidate for the preparation of composites that can be used as construction material.

IAEA-CN-332/552

Next-Generation Superconducting Electron Accelerators: A High-Efficiency and High-Power Tool for Radiation Science and Industrial Applications

J. Thangaraj (Fermi National Accelerator Lab (Fermilab)) – USA

In the rapidly evolving landscape of radiation processing, the demand for more efficient and sustainable technologies is at an all-time high. This talk will expose the ICARST audience to the groundbreaking advancements in superconducting compact accelerator technology and its transformative potential within the electron beam processing market. From treating contaminants in water to revolutionizing surface treatments and sterilization processes, the potential applications are as vast as they are revolutionary. In this presentation, we will highlight the current status and the key innovations driving the development of superconducting compact accelerators. We will briefly delve into the technical aspects of these high-efficiency accelerators, showcasing their ability to be used as a high-power e-beam/x-ray source at negligible thermal loss compared to conventional counterparts.

Using the Fermilab Compact SRF (Superconducting Radio Frequency) accelerators as a pioneering model, we will explore how compact SRF accelerators provide new opportunities for high-efficiency radiation applications. From enhanced productivity in industrial applications to the potential for novel processes, we anticipate this work will present a compelling case for industry stakeholders to embrace this transformative technology for radiation science and application.

IAEA-CN-332/559

Gamma Irradiation on Silybin: Enhancement of Tyrosinase Inhibitory Activity Through Structural Modification

A. R. Han, C. Hyun Jin (Korea Atomic Energy Research Institute) – Republic of Korea

Ionizing radiation technology is an eco-friendly chemical technique that can be applied to modify chemical structures of bioactive compounds, contributing to an enhancement of their biological activities. In this study, silybin (1), the major component of the fruit extract of Silybum marianum (common name: milk thistle), was exposed to 300 kGy of gamma ray, resulting in the production of two radiolytic flavonolignan derivatives. Their structures were identified as 3-deoxysilybin (2) and 2,3-dehydrosilybin (3) via the analysis of nuclear magnetic resonance and high-resolution electron ionization mass spectroscopy data. Radiolytic products 2 and 3 exhibited improved tyrosinase inhibitory capacity with IC50 values of 274.6 and 109.5 μM, respectively, compared to the original compound, silybin (1; IC50 >500 μM). Therefore, our results suggest that γ-irradiation is an effective method for structural modification of silybin and it derivatives 2 and 3 may be potential tyrosinase inhibitors.

IAEA-CN-332/561

Gamma Irradiation-Induced Degradation of Sulfadimethoxine in Aqueous Solution: Kinetics, Influence of Additives, and Degradation Pathway

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Sulfadimethoxine (SDM), an antimicrobial drug within sulfonamide antibiotics, is widely used in veterinary medicine and approved for use in humans in some countries. Because of its high mobility, SDM has been reported to be detected in surface water, groundwater and wastewater. It was classified among the pharmaceuticals assessed to be at high risk due to its capacity to induce microbial resistance and the potential adverse effects on aquatic organisms. Conventional water treatment techniques were ineffective to degrade SDM dissolved in water. Alternatively, Advanced Oxidation Processes (AOPs) such us, photocatalytic method, ozonation and ultraviolet radiation proved to be efficient to remove SDM from water. Among AOPs, gamma radiation has emerged as a promising treatment for effective degradation of antibiotics in water. In this study we investigated, for the first time, the gamma radiolysis of SDM in aqueous solution. Various influencing factors such as, absorbed dose, initial concentration, pH, inorganic anions and organic matter, on the removal efficiency of SDM were examined using HPLC technique. A kinetic study was performed and the by-products were identified by LC-MS/MS. Synergistic effects of MnO4- and S2O82- in the gamma radiation degradation of SDM were also evaluated. The experimental results showed that gamma-ray irradiation was efficient for removing 99.5% of SDM from water with an initial concentration of 20 mg/L under an absorbed dose of 5 kGy. The removal efficiency increased with increase of the absorbed dose and the degradation process fitted a pseudo-first order. When SDM concentration was in the range of 10-30 mg/L, the dose constant decreased with an increasing initial SDM concentration. The removal process was inhibited in both alkaline (pH=9 and pH=11) and acidic media (pH= 3) and the degradation was optimal under neutral conditions. The presence of inorganic anions had obvious influence on the degradation of SDM, which decreased from 99.5% to 99.3%, 91.2%, 98%, 97.8, 93.5% and 67.2% in the presence of 2 mmol/L CO32-, HCO3-, HPO42-, H2PO4-, NO3- and NO2-, respectively at 5 kGy. The addition of 35 mg/L humic acid only had a minimal effect on SDM degradation and the total degradation rate after adding humic acid was 96%. The mineralization of SDM was monitored measuring the chemical oxygen demand (COD). It appeared that the COD of the solution decreased substantially at 5 kGy. Antimicrobial experiments conducted using Escherichia coli bacteria confirmed the disappearance of any antimicrobial activity in the irradiated solution of SDM at 5 kGy. SDM was significantly degraded by gamma radiation at the absorbed dose of 5 kGy, however, addition of 2 mmol/L MnO4- and S2O82- promoted degradation of SDM to 100% and 99.6% only at 3 kGy and 2 kGy absorbed doses, respectively. Based on the identification of intermediate products during gamma irradiation using LC-MS/MS technique, a plausible degradation pathway of SDM was proposed. Our investigation confirmed that gamma radiation treatment could be an effective method for removal of recalcitrant antibiotics such as sulfonamides.

IAEA-CN-332/573

Receptor Binding Assay for Saxitoxin Detection and Electron Beam Technology for Its Degradation

A. Ben Mansour, M. Abdennadher, M. Samaali, K. Nasr, Z. Azzouz Berriche, A. Bellaaj Zouari (National Center for Nuclear Sciences and Technology) – Tunisia

Occurance of harmful algal blooms (HABs) has become a major concern for several threatened regions in North Africa. Due to climate change and eutrophication, the frequency and the geographic distribution of toxin –producing algea are increasing. The produced emergents marine toxins in water and seafood may have a considerable impact on public health, environmental preservation and economic challenges. Thus, effective monitoring programmes are required to manage and mitigate their detrimental global effect. With this purpose, several analysis methods have been developed for their detection. Paralytic Shellfish Toxins (PST) are one of the main toxins detected in Tunisian coasts. To enhance the sustainabe development a new laboratory is implemented adopting the rapid and sensitive receptor binding asssay(RBA) for saxitoxins detection in the frame of an IAEA regional TC project. During the implementation process, shellfish and sea waters samples were collected from selected production sites from Tunisian Southern coasts before being analysed. In addition, shelfish samples obtained in the frame of Proficiency Testing Scheme, were analysed with the radiometric RBA technology and evaluated positively. This in vitro transferred technology is rapid, reliable, cost effective and particulaly suitable for determination of integrated toxic potency of seafood samples. It is also an additional option avoiding the use of live animal bioassays for regulatory applications.

Due the growing populations, unequally distributed freshwater and increasing drought linked to climate change, desalination is increasingly being used to provide drinking water around the globe.

Alexandrium minitum is one of the common bloom-forming dinoflagelate in the Medeterranian Sea. This genus is producing potent paralytic saxitoxines. As the red tide blooms are increasingly appearing, treatment technologies are needed to address not only these saxitoxines, but also the toxin-producing dinoflagelates cells in the water desalination plants.

In the few published studies, high energy electron beam (eBeam) irradiation technology presents a promising strategy for the mitigation of both harmful algea cells and dispersed toxins in surface water.

In vitro Alexandrium minitum cultures and saxitoxin standard solutions were prepared. Selected eBeam irradiation varying doses were applied on the cultivated strains and toxin solutions. The analysis of the irrdiated solutions are in progress. The present study is devoted to the effect of varying electron beam irradiation doses on the development of the Alexandrium minitun cells and the stability of the paralytic saxitoxin. The lethal dose for cells as well as the degradation dose for saxitoxin to be evaluated represent the basis for further studies on real sea water samples to ensure efficient eBeam irradiation traitement.

Keywords: Harmful algal blooms, Paralytic Shellfish Toxins, receptor binding assay, Alexandrium minitum, saxitoxin, eBeam irradiation, water

IAEA-CN-332/577

Gamma Radiation Effects on the Physicochemical Properties of Organic Fruits

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Different methods are nowadays employed for the preservation of postharvest fruits quality, such as chemical treatments, heating and freezing. However, the application of these methodologies often causes heavy losses during storage, due to pathogenic microorganisms' and insects' activity. In addition, physical and chemical techniques can leave dangerous residues on treated fruits, resulting in risks to human health. Gamma radiation, which is characterized by high penetration power, is a safe technology used for the postharvest food preservation. Despite the use of ionizing radiation is widespread in many countries, the potential physicochemical changes induced by radiation still represent topical issues for the agri-food supply chain. The present contribution focuses on the characterization of food matrices by using spectroscopic techniques not conventionally used in this sector [1,2]. In particular, simple and effective protocols based on non- or minimally destructive techniques, such as Electron Spin Resonance Spectroscopy (ESR), Micro Raman Spectroscopy, Fourier-Transform Infrared Spectroscopy (FTIR), were developed. Organic pistachio and blueberries were irradiated at the Calliope Co-60 irradiation facility at ENEA Casaccia Research Center (Rome, Italy) [3]. The influence of gamma irradiation was evaluated at different conditions, in terms of absorbed dose and dose rate values, comparing the results obtained before and after exposure. This study validates the use of these spectroscopic analyses for the morphological, structural and compositional characterization of complex food matrices with different constituents.

[1] Golding, John B., et al. "Low dose gamma irradiation does not affect the quality, proximate or nutritional profile of 'Brigitta'blueberry and 'Maravilla'raspberry fruit." Postharvest Biology and Technology 96 (2014): 49-52.

[2] Alinezhad, Masoumeh, et al. "Effect of gamma irradiation on the physicochemical properties of pistachio (Pistacia vera L.) nuts." Journal of Food Measurement and Characterization 15 (2021): 199-209.

[3] A. Cemmi, I. Di Sarcina, G. Ferrara, ENEA Technical Report RT/2020/1/ENEA.

IAEA-CN-332/581

Use of the Neutron Backscattering Technique for Humidity Analysis in the Cardboard Recycling Industry: Experimental Study

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A significant portion of the used cardboard supplied to the recycling industry may contain water within its internal voids. Presently, the price of used cardboard is determined based on its weight, and suppliers have significant potential to add water to increase its price. The methods currently used to detect moisture content in cardboard are limited to thin cardboard sheets only.

This project presents a nuclear gauge based on neutron backscattering containing a 0.27 Ci source of 241Am-Be to detect moisture in raw materials for the cardboard industry.

The results obtained showed that this technique can be used by the cardboard recycling industry for rapid and non-destructive detection of water in the majority of used papers by measuring the maximum neutron path in the cardboard. Subsequently, by establishing a calibration curve correlating the quantity of backscattered neutrons and the water content, and insering an additional parameter to be applied to the measured water content values.

The count of thermal neutrons detected increases significantly with the addition of even a small fraction of material containing hydrogen, such as water. In used cardboard with a non-uniform distribution of water, the relationship between the count of thermal neutrons detected and the water content deviates from a linear curve.

IAEA-CN-332/584

Degradation of Chlorinated Organic and Pyrethroid Pesticides Induced by Gamma Irradiation in Cultural Heritage

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Background of the study:

The presence of pesticides in cultural heritage items poses health risks to museum workers and others who come into direct contact with contaminated objects. Mitigation measures are necessary, and in this context, ionizing radiation emerges as a promising technique for application to cultural heritage, as previous studies have demonstrated its potential for degrading organic pesticides in soil, food, aqueous waste, and other substrates. This presentation aims to explore the application of gamma radiation for the degradation of DDT, lindane, hexachlorobenzene, and permethrin, pesticides historically used for the preservation of cultural heritage objects.

Methodology:

A Cobalt-60 gamma-ray source was used for irradiation experiments at IPEN's Multipurpose Cobalt-60 Irradiator facility at the Radiation Technology Center (CTER) of the Nuclear and Energy Research Institute, IPEN–CNEN/SP. Standard pesticide solutions at 1, 5, and 10 ppm concentrations were irradiated with doses of 0, 1, 3, 6, 10, 25, 50, and 100 kGy. Pesticide concentrations were analyzed before and after irradiation using GC-MS, and to validate the analytical method, parameters including selectivity/specificity, linearity/working range, limit of detection (LOD), limit of quantification (LOQ), precision, and accuracy were evaluated.

Results:

The results indicated that 25 kGy doses degraded DDT by 93.07%-98.25%, lindane by 58.25%-78.45%, hexachlorobenzene by 27.56%-83.26%, and permethrin by 31.51%-71.42%. Increasing the absorbed doses resulted in greater degradation of the target pesticides.

Conclusion:

The pesticides selected for this research are persistent and were significantly reduced by ionizing radiation processing. Future studies are needed to determine if degradation efficiency remains in samples simulating museum objects and if different substrates can influence pesticide degradation results. The application of ionizing radiation on cultural heritage items must be conducted within limits to avoid undesirable side effects. Therefore, future investigations should consider whether absorbed doses capable of degrading pesticides in solutions are safe for application on cultural heritage items.

IAEA-CN-332/587

Electrical Pollutions and Perturbations in an Electron Accelerator Facility

M. Trabelsi, M. Kraeim (CNSTN-Centre National des Sciences et Technologies Nucléaires) – Tunisia

Radiation processing technology started in Tunisia by the installation of a pilot plant gamma irradiator in 1999 and an electrons beam accelerator in 2009 at the National Centre for Nuclear Science and Technology (CNSTN). These facilities are established with the support of the International Atomic Energy Agency (IAEA) in the frame of the technical co-operation assistance program. The electrons-beam facility is equipped with Circe III Linac accelerator and a conveyor roller system for industrial applications like sterilization of pharmaceutical single use products.

This work objects is to explore and study different electrical pollutions and perturbations in the electrical networks of the accelerator and to study possible solutions.

We will present electrical measurement for pollution generated by the accelerator and his peripherals.

Then, a study has been elaborated reinforced by simulation for the filtering solutions to be adopted.

IAEA-CN-332/590

The Italian Certification of Non-Destructive Testing Personnel in Civil Engineering

D. Ranalli, E. Tuberosa, M. Reggiani (AIPnD – Italian Assocation of Non Destructive Testings) – Italy

In industrial diagnostics, the certification of non-destructive testing personnel has followed a continuous evolution over the course of approximately 60 years.

On the contrary, in the international fields of diagnostics in civil structures and infrastructures has not been considered necessary to globally standardise the training and qualification personnel in construction materials testing.

Since 2000, Italy has been one of the first countries to undertake a process of qualification of personnel on essential to NDT in civil engineering, producing in 2024 the national standard UNI 11931 "Certification of technical personnel in charge of the execution of non-destructive testing in civil engineering".

Why do we create this professional figure?

Italy has an important building heritage: almost half of the structures built on the national territory are subject to historical and architectural bonds. The growth of living standards to effectively counteract natural phenomena and to adapt to technological innovations involves the need to know the state of conservation of structures, past and contemporary. In this context, it is important to verify the mechanical and constructive characteristics of the structures that are in the operating status.

Currently in Italy, more than 8000 certificates of NDT operators in civil engineering have been issued.

La certificazione in Italia del personale addetto ai controlli non distruttivi in ambito civile

Nella diagnostica industriale, la certificazione del personale addetto ai controlli non distruttivi ha seguito una continua evoluzione nel tempo di circa 60 anni.

Al contrario, nei settori internazionali della diagnostica delle strutture e delle infrastrutture civili non si è ritenuto finora necessario standardizzare la formazione e la qualificazione del personale per le prove sui materiali da costruzione.

Dagli inizi degli anni 2000 l'Italia è stato uno dei primi paesi ad intraprendere il percorso di qualificazione del personale addetto ai Controlli Non Distruttivi in ingegneria civile, producendo nel 2024 la norma UNI 11931 "Certificazione del personale tecnico addetto all'esecuzione delle prove non distruttive nel campo dell'ingegneria civile e dei beni culturali ed architettonici".

Perché creare questa figura professionale?

Lo stato italiano possiede un patrimonio edilizio importante: quasi la metà (~47 %) delle strutture realizzate sul territorio nazionale è sottoposta a vincolo di tutela storico ed architettonico.

La crescita dello standard di vita per contrastare efficacemente i fenomeni naturali ed adeguarsi alle innovazioni tecnologiche comporta la necessità di conoscere lo stato di conservazione delle strutture, passate e contemporanee. In questo ambito, è importante verificare le caratteristiche meccaniche e costruttive delle strutture che si trovano nello stato di esercizio.

Attualmente in Italia sono stati emessi oltre 8000 certificati di operatori NDT in ingegneria civile.

IAEA-CN-332/596

The Use of Non-Destructive Techniques to Detect the Presence of Cracks in Gargoyles of the Monastery of Santes Creus in Tarragona (Catalonia)

A. Domato, L. Aranda (Private company – SOCOTEC) – Spain

The Monastery of Santes Creus is in the province of Tarragona, Spain. It was founded in 1160 and reached its greatest splendor during the 13th and 14th centuries under the reigns of Peter the Great and James II the Just. The Monastery features solid, austere, and grave architecture, like other Cistercian monasteries in the area: Poblet and Vallbona de les Monges. This sobriety contrasts with its cloister from the 14th century, which was the first Gothic-style cloister in the Crown of Aragon. This cloister was built over the space of an older, more sober Cistercian cloister, of which only traces of a small temple remain. In contrast, the new cloister was constructed with the light and forms characteristic of Gothic architecture of the time: pointed arches, decorated capitals, etc. Among the elements remodeled by the new architecture are the gargoyles.

Gargoyles are protruding parts of the facade used to drain water from roofs and terraces, and in medieval architecture, especially Gothic, they were widely used in churches, cathedrals, and monasteries. They have forms of animals or people in grotesque shapes, according to some traditions, to scare away evil spirits and sinners. The cloister of the Monastery of Santes Creus has a total of twenty-eight gargoyles, which allow the expulsion of water collected on the terrace that covers its galleries. The pass of time and exposure to the varying weather conditions of the area have caused the limestone from which they are made to deteriorate, especially in the form of cracks.

To detect possible cracking in these pieces, a double campaign of non-destructive testing (NDT) was planned to identify their presence for a subsequent more detailed study of each piece and its treatment, either recovery or replacement, given that they are elements in a dangerous position for visitors.

Firstly, an inspection campaign was carried out using ground-penetrating radar on all the pieces, comparing the results obtained with previously known results from pieces without defects.

Subsequently, on all pieces where it was possible, a test measuring the velocity of ultrasonic pulse transmission was conducted directly, using exponential transducers that allow measurement on irregular surfaces without alteration from chemical contact agents.

The combination of the two non-destructive methods mentioned and visual inspection allowed the identification of the pieces that needed to be repaired.

IAEA-CN-332/597

The Role of the IAEA in Enhancing Nuclear Education in Sudan

A. Hassan (Sudan Atomic Energy Commission) – Sudan

Nuclear education in Sudan was introduced recently, before that there were many programs that are relevant to medical applications. Many national universities offer degrees that are relevant to peaceful applications of nuclear technology, these include but not limited to: Bachelor of Radiology, Bachelor of Radiotherapy Technology, Bachelor of Nuclear Medicine, Bachelor of Nuclear Engineering, Master of Science in Medical Physics, Master of Science in Radiation and Environment Protection, Master of Nuclear Sciences, Master of Nuclear Medicine Technology, Master of Radiotherapy Technology, Master of Radiation Chemistry, Master of Nuclear Chemistry, Master of Nuclear Physics. In addition to Master and Ph. D degrees in the previous subjects by research.

Atomic Energy Council (AEC) of Sudan Academy of Sciences (SAS) was founded in 2004 under the umbrella of the Ministry of Science and Technology at that time and is now under the umbrella of the Ministry of Higher Education and Scientific Research. SAS is a public university with privacy stemmed from being the first university dedicated only for postgraduate studies in Africa and the Arab world, according to the available information. AEC adopt three master programmes from the harmonized syllabus under the AFRA regional agreement.

AEC plays important roles in promoting nuclear knowledge and supplying the labour market with number of qualified cadres.

The IAEA played and continue to play big roles in enhancing the nuclear education through provision of equipment, tools, references, teaching materials, experts and lecturers, the support is usually provided through the IAEA technical cooperation projects.

This paper will reflect the nuclear education in Sudan, the estimated number of graduates, the support received from the IAEA.

IAEA-CN-332/599

Application of High-Power Electron Linear Accelerator in the Medical Supplies Industry

Peng Cheng, Y. Liu (CGN Dasheng Electron Accelerator Technology Co.,Ltd.) – China

Electron accelerator is a kind of modern advanced high-tech equipment suitable for comprehensive irradiation processing. Under the high-energy electron beam produced by electron accelerator, some substances will produce physical, chemical and biological effects, which can be widely used in food preservation, killing pests, disinfection and sterilization and material modification, etc., with the advantages of green, sustainable and efficiency.

In China, with the continuous establishment, enrichment and implementation of relevant standards for irradiation equipment and irradiation sterilization, newly built irradiation equipment is developing towards standardization, standardization, intelligence and scale, and the application of irradiation sterilization is rapidly expanding from traditional food irradiation to medical consumables sterilization. Including medical dressing, intramuscular injection consumables, intravenous infusion consumables, trauma care dressing consumables and surgical hygiene instruments, etc., as shown in Figure 1.

With the increasing demand for food safety and disinfection and sterilization of medical and health products, the market scale of 10MeV electron irradiation accelerator is also expanding. By 2025, China will have more than 200 sets of 10MeV industrial electron irradiation accelerators in operation, of which more than 90% are electronic linear accelerator models of 20kW and below. With the increasing demand for radiation processing of medical and health products, 10MeV/20kW models will be difficult to meet the processing production requirements of some high-dose processing products, and there is an urgent need for higher-power models. According to market demand, CGN Dacheng has developed 10MeV/32kW electron linear accelerator in 2024.

IAEA-CN-332/607

Implementation of Radiation Safety Measures for Sealed and Unsealed Sources at the National Centre for Scientific Research (CNIC)

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Ensuring the safety and protection of personnel from radiation exposure is a critical aspect of managing irradiation facilities. This study focuses on the implementation of effective radiation safety measures at the National Centre for Scientific Research (CNIC) under the Ministry of Higher Education, Science, Technology and Innovation (MESCTI) in the Republic of Angola. The facility houses laboratories dedicated to Isotopic Hydrology, Non-Destructive Testing (NDT), and Radiometric Techniques, utilizing sealed sources such as Cs-137 (50 mCi) and unsealed sources like Technetium-99m (Tc-99m), which is generated on-site. The comprehensive safety strategy includes dosimetry, adherence to international standards, and rigorous quality management protocols. Special emphasis is placed on the training and expertise of personnel, including level 2 certification in Gamma Scanning and Residence Time Distribution techniques, to minimize exposure risks. This publication provides detailed insights into the operational procedures and protective measures designed to maintain a safe working environment.

Keywords: Radiation safety, dosimetry, Radiation techniques, quality management, irradiation facilities.

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Dutch Papers Irradiated with Gamma Rays in 1993: Comparison of Their Condition After 30 Years of Natural and Artificial Ageing

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The use of ionising radiation to disinfect cultural heritage paper-based materials has a long history of practice and research. In the Netherlands, gamma radiation was adopted in the early 1990s to treat objects suffering from microbiological attack, including archival materials. Research initiated in 1993 by the Cultural Heritage Agency of the Netherlands in Amsterdam aimed to study the long-term effects of gamma radiation treatment in five different types of paper by applying artificial ageing after a 10 kGy irradiation [1]. Since the results of that research were published and some samples are still available, it is possible to compare the 30-year-old data with the current condition. Although mechanical testing could not be reproduced due to a lack of large enough samples, comparing the extraction pH of the papers made in 1993 and at the present date was possible. Other methods, such as colourimetry, X-ray Diffraction (XRD), and Thermogravimetric Analysis (TGA) were also applied, to indicate chemical alterations in the cellulose matrix of these papers.

Relevant data obtained so far show that the pH of gamma-irradiated samples is similar to untreated samples after these 30 years, except for datacopy paper, where we observe a c. 1 unit lower pH on irradiated samples. Colorimetry (in CIELAB colour space, Lab*), showed that papers gamma irradiated have an overall higher ΔE (c. 1 to 12 units higher) when compared with non-irradiated papers. The higher differences were observed for Archival rosin-sized rag paper from the late 19th century (ARA paper).

XRD technique was used to calculate the index of crystallinity of the samples, following the methodology used by Segal [2]. In general, slight differences were recorded in the samples, independently of the irradiation or ageing process. Among the samples, the ARA papers are those with a higher loss of crystallinity.

The degradation profiles obtained by TGA were similar for each type of paper, regardless of the irradiation treatment and the ageing process, except for the ARA paper. In this case, a nearly 40 °C drop in the degradation temperature was observed only for samples artificially aged without radiation treatment. This observation points out that gamma radiation did not affect significantly the papers' degradation profile.

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Empowering School Educators with Comprehensive Radiation Science and Technology Knowledge

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In an era marked by rapid technological advancement and increasing societal reliance on nuclear science and technology, equipping school educators with comprehensive knowledge in these fields is crucial for fostering informed future generations. This paper explores the imperative of integrating robust radiation science and technology curricula into a two-week teacher training course organized by the IAEA/RAS0079: Educating Secondary Students and Science Teachers on Nuclear Science and Technology. A total of 11 training courses were conducted in different countries, co-hosted by nuclear research and development (R&D) agencies. The purpose of the program is to train school educators on essential and appropriate information about nuclear sciences and how to communicate such knowledge to the schools. By enhancing educators' understanding of nuclear principles, applications, and safety, schools can significantly improve science literacy among students. Good teaching skills are fundamental in this endeavor, enabling educators to convey complex concepts, inspire curiosity, and stimulate critical thinking. Effective teaching not only facilitates students' grasp of intricate subject matter but also cultivates a positive attitude toward science and technology careers. The paper underscores the necessity of continuous professional development and targeted educational resources to support educators in delivering high-quality radiation science and technology education. Ultimately, empowering teachers with specialized knowledge and pedagogical skills will ensure a well-rounded education that prepares students for the scientific and technological challenges of the future.

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Gamma Scan for a Triethylene Glycol (TEG) Natural Gas Dehydration Column: Indirect Detection of Failure Mechanisms on the Bed

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The "Column Gamma Scan" is a nuclear diagnostic technique that enables visualization of the interior of industrial structures without halting their operation. Applied to a natural gas dehydration column using TRIETHYLENE GLYCOL (TEG) in a cryogenic plant, the main objective is to reduce the water content in the natural gas to acceptable limits. This is crucial as hydrates can cause serious transportation problems and affect the subsequent cryogenic column.

In the case of the TEG dehydration column, significant operational issues were noted. Plant personnel spent considerable time adjusting parameters to achieve proper operation without success. Consequently, a Gamma Scan was conducted to evaluate the condition of the column's internal components. The inspection included three cross-sectional scans in a triangular pattern to analyze the column's fluid dynamic behavior.

The Gamma Scan results revealed several internal component problems, including fouling in the demister, unevenness in the distributor, and channeling in the bed. These issues explained the column's improper operation and its negative impact on downstream processes. Identifying these anomalies precisely allowed for a deeper understanding of the malfunction, which had plagued the personnel for a long time.

This study highlights that Gamma Scan is useful not only for detecting immediate failures but also as a preventive and predictive tool. By indirectly identifying failure mechanisms in the column's internal components, the technique provides valuable information to anticipate problems and plan effective maintenance. This proactive approach improves the reliability and operational continuity of the natural gas dehydration plant, optimizing operations, reducing unscheduled downtime, and enhancing overall efficiency.

Keywords: Column Gamma Scanning, nuclear diagnostics, dehydration column, natural gas, triethylene glycol (TEG), cryogenic plant, gamma radiation, density profile, fluid dynamic behavior, demister, distributor, bed, failure mechanisms, preventive/predictive approach, operational reliability, scheduled maintenance, hydrocarbon processing.

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Characterization of the ^{252}Cf Neutron Source at the Jordanian Neutron Calibration Laboratory Using Gamma-Ray Spectroscopy

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The neutron laboratory implements a 252Cf neutron source with a 52µg mass of reference date of February 1st, 2010. There is no certificate specifying the mass uncertainty or reporting impurities for the source. The dose in the laboratory was established using transfer equipment Ludlum Model 2363 with 42-41L PRESCILA Detector which was calibrated at the Czech Metrology Institute (CMI). The dose was established in the laboratory in 2022. The 252Cf half-life (t1/2 = 2.65 years) is utilized to calculate the dose for daily routine use.

252Cf sources contain a mixture of four Californium nuclides (249Cf, 250Cf, 251Cf, and 252Cf), which cannot be chemically separated during the production process. The isotope 250Cf can produce neutrons through self-fission. The 250Cf/252Cf ratio in a new source can vary based on the manufacturing process; typically, it is less than 5%. 252Cf emission rate decays quickly due to its short half-life (t1/2 = 2.65 years), while the 250Cf decays much slower due to its relatively longer half-life (t1/2 = 13 years) so the content of 250Cf could be significant for older sources. The neutron source at JAEC is around 15 years old and the 252Cf decays to 1.56% and the 250Cf decays to 50% resulting in almost similar content of the two isotopes.

The established dose was approximately 10% higher than the expected dose found by decay. This might be due to a higher initial mass or reference date different from the chemical separation date. The dose used to calibrate the devices is obtained by the decay of the established dose following 252Cf half-life. If the source contains significant 250Cf content a proper decay model should be used to include the half-life of 250Cf. Characterization of the source might potentially answer some of these questions which could improve the quality of measurements performed in the laboratory.

This research aims to characterize the 252Cf neutron source using high-resolution gamma-ray spectroscopy based on a germanium detector. The gamma-ray spectrum of 252Cf neutron source is rich with valuable information, including the chemical separation date, Californium isotopes, and other isotopes. The content of 249Cf, and 251Cf can be determined from their direct gamma rays of 388 keV and 177 keV respectively. The 252Cf content can be determined using one of its fission products. Determination of 250Cf content will be harder as there is no strong gamma-ray emitted by the isotope itself or its fission products. To estimate the 250Cf content models should be implemented and compared to the obtained data [13, 15]. The activity of the source was measured regularly for quality control purposes and this data can be used to test the decay models. The chemical separation date of the source can be determined by calculating the ratio of the two fission product isotopes 137Cs and 132I. The emitted gamma-rays emitted by these two isotopes are 662 keV and 668 keV respectively. These two peaks have similar detection efficiency making the measurement result accurate and easy. Other spontaneous fission isotopes might be used to confirm the results.

IAEA-CN-332/630

Advancements in Certification Standards and Training for Non-Destructive Testing (NDT) in Civil Engineering: A Review

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Non-Destructive Testing (NDT) techniques have long been a focus of scientific research due to their versatility and critical role in evaluating material and structural integrity without causing damage. Recent global catastrophes have underscored the necessity of standardized certification and training in NDT for civil engineering to ensure reliable performance, safety, and durability of buildings and infrastructure.

This review explores the advancements made in certification standards and structured training for NDT techniques within the civil engineering sector. The aim is to highlight the progress in this area and the need for standardized certification and comprehensive training to develop competent inspectors.

The continuous development of NDT techniques necessitates a strategic approach to certification and training, emphasizing efficiency, safety, and reliability. Global organizations are currently working on establishing courses and standards for non-destructive testing, particularly focusing on nuclear techniques for civil engineering, driven by recent disasters.

However, there remains a lack of adequate standards and training programs to develop competent inspectors in this specific field of civil engineering. This gap highlights the need for further development in certification standards and training methodologies.

This review highlights the growing interest and ongoing efforts worldwide to standardize and improve certification and training in NDT. It emphasizes the current gaps and the necessity for further development in this critical sector to ensure the safety and durability of civil engineering structures.

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Dosimetry Procedures Under Specific Irradiation Conditions in EB Radiation Processing

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The safe execution of worldwide used radiation processing technologies depends to a large extent on the use of standardized liquid and solid phase reference and routine dosimetry systems. The reliable use of new radiation technologies require the introduction of upgraded dosimetry systems e.g. to measure dose in flow systems. To perform dosimetry in frozen product irradiation, on the other hand, need the detailed study of the response of the applied dosimetry system with respect to temperature and dose dependence.

The useful application of the aqueous alanine dosimeter solution has been proven already in gamma and electron irradiation. In the present work the use of spectrophotometry – beside the earlier investigated oscillometric and conductometric analysis – has also been investigated for dose evaluation in a wide dose and dose rate range. The usefulness of these dose measurement procedures were studied and evaluated under specific irradiation conditions, i.e. in flow systems both on-line and also after irradiation.

Irradiation of certain products below room temperature, i.e. in frozen temperatures require the knowledge of the behaviour of selected dosimetry systems under such irradiation conditions.

The response of the ethanol-chlorobenzene (ECB) dosimeter solution, which is known of its small irradiation temperature dependence was studied for dose control at low irradiation temperature (at around -20 °C) and was found suitable for dosimetry purposes under such conditions.

Since film dosimeters (like B3/GEX) in most cases are the best options for dosimetry purposes in EB facilities, therefore their performance at low irradiation temperatures was also investigated. The suitability of this dosimeter film at low irradiation temperatures for electron dose control is discussed also in the poster.

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TLD Dosimetry Calibration at CALLIOPE Gamma Irradiation Facility

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The Calliope is a pool-type irradiation facility equipped with a 60Co source array in a high volume (7.0 m × 6.0 m × 3.9 m) shielded cell. Source rack has a plane geometry with 25 60Co source rods (active area: 41 cm × 90 cm). The Calliope gamma irradiation facility is deeply involved in qualification and research activities, in the framework of international projects and collaborations with industries and research institutions.

Several dosimetric methods (Fricke, Red Perspex, radiochromic, alanine-ESR, TLD and RADFET dosimeters) are used, depending on the absorbed dose range of interest. The relative dosimetry methods are periodically calibrated to the Fricke dosimetry absolute method.

In this study, a calibration of thermoluminescent dosimeters (TLD) was performed in the absorbed dose range of interest for radiobiological applications (0.05-2.5 Gy). The dosimeter is composed of TLD-100 chips (3.2 mm × 3.2 mm × 0.89 mm) inserted in a cylindrical holder of polymethylmethacrylate (PMMA). The volume occupied by TLD chips represents the sensitive volume and the dosimeter signal is evaluated by the average value of 10 TLD chips. TLD irradiated in several position different for dose-rate are compared with dosimetry obtained with FRICKE solution and alanine-ESR dosimeters, showing a good agreement and reproducibility. Starting from these results, TLD calibration will be extended up to 10 Gy with a focus on low doses ($D<0.1$Gy) interesting for radiobiology study, shielding and radioprotection applications. Further activity regards the evaluation of gamma component in gamma-neutron mixed field in nuclear reactor at ENEA, using the TLD-700 and TLD-600.

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Investigation of the Effects of Gamma Radiation on Solid Polybutadiene (PB)-Based Propellants for Space Applications

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Solid propulsion is a consolidated technology for space propulsion. Over liquid propellant solutions, it grants higher energy density and thrust-to-weight ratio, and better readiness. Simplicity of production and operation makes the system reliable and relatively cheap to be produced. Industrial solutions grant excellent storability under several Earth conditions. As downsides, solid propulsion lacks flexibility and is characterized by lower specific impulse with respect to liquid propulsion.

This technology has been almost frozen for decades. Hydroxyl terminated polybutadiene cured by polyaddition through reaction with isocyanates is now the state-of-the-art for the binder matrix. This well-established solution granting the control of mechanical strength and stability of the propellant. Recently, curing of polybutadiene-based polymers has been achieved through UV-based photo-curing.

Photopolymerization presents a novel approach with benefits in terms of process control and energy efficiency. In addition, this approach is crucial to exploit these materials in additive manufacturing applications. In this context, the present contribution focuses on investigating the effects of gamma radiation, one of the most common components of the space radiation environment, on polybutadiene (PB) samples produced with different formulations via chemical synthesis or photopolymerization, for potential use in solid propellants. The PB samples are fabricated at the Space Propulsion Laboratory (SPLab) at Politecnico di Milano (Milan, Italy), while the gamma irradiation tests are performed at the Calliope Co-60 irradiation facility at ENEA Casaccia Research Center (Rome, Italy) [2]. The morphological, structural, chemical composition and radical content analyses, accomplished by coupling Micro-Raman, FTIR and EPR spectroscopies, disclosed that the gamma irradiation induces different behaviours on the PB samples produced by diverse approaches. These results point out the importance of selecting appropriate production methods to optimize the performance and reliability of PB-based solid propellants for future Space missions, providing new insights on effects produced by gamma irradiation on materials exploitable for Space exploration.

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Treatment of Effluent from Industrial, Automotive, and Refinish Paints by Electron Beam Irradiation

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Paint is a polymeric layer to protect, signal and beautify a substrate. Made up of resins, pigments, fillers, solvents and additives. The effluent generated in the production of paints must be treated to avoid causing contamination of rivers, minimizing environmental impacts. Chemical oxidation processes are promising for the degradation of toxic organic compounds. The most efficient methodology is oxidation through attack by the hydroxyl radical (OH), in the advanced oxidation process - AOP, in electron beam accelerators adopted by several countries in which complex organic compounds are removed. The objective of this study was to apply AOP by ionizing radiation in the treatment of effluent from the manufacture of automotive, industrial and automotive refinish paints. In this case study, electron beam processing applied to paint industry effluents was developed. The research was carried out in three phases: doses of 10, 30, 50, 80 and 100 kGy were applied; doped with 0.005%, 0.05% and 0.5% hydrogen peroxide by volume. The main results demonstrated an average reduction of around 10% in Chemical Oxygen Demand, COD and around 25% in Biochemical Oxygen Demand, BOD, in addition to the whitening of the effluent.

IAEA-CN-332/ 650

Dating of the Pandeiros River Floodplain

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Optically Stimulated Luminescence (OSL) is a nuclear physics technique that provides information about the last time river sediments were exposed to light or heat. It is used in geomorphology to provide geochronological data, dating materials up to 1.6 million years old. However, the use of this technique must consider that the migration of river meanders, which is faster in rivers with alluvial beds, can alter the deposition of sediments on the banks, causing errors in OSL dating in floodplains and abandoned meanders near the riverbed. The presence of a high water table at the sample collection sites is another factor contributing to dating errors. This was observed in the dating of ten trenches excavated between 15 and 115 meters from the banks along the alluvial terraces of the Pandeiros River, a tributary of the middle São Francisco River in the Brazilian semi-arid region. The water table, detected by Ground Penetrating Radar (GPR), caused shielding of natural radiation, interfering with the OSL signal and making the deeper sediments appear more recent than those of the superficial layers. Overall, however, the dating was consistent, with the more recent sediments located upstream.

IAEA-CN-332/651

Disinfection of Rare Books Using Gamma Irradiation: A Success Story

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Rare books are invaluable heritage treasures that face significant preservation challenges, particularly from insects like silverfish and microbes such as bacteria and fungi, which deteriorate these materials. Traditional fumigation techniques, which employ carcinogenic chemicals, have proven less safe and inadequate. Gamma irradiation has emerged as a safer, more comprehensive, and scalable alternative. Despite initial concerns regarding potential side effects on irradiated books, numerous studies and researchers have validated its safety and effectiveness. Countries including Romania, France, and Brazil have successfully adopted this technique. In Malaysia, the Malaysian Nuclear Agency, in collaboration with the Malaysian Museum Department, has pioneered the gamma irradiation process for rare books. Preliminary studies demonstrated that exposure doses below 10kGy did not alter various types of paper. These studies included FTIR characterization to evaluate radiation effects on cellulose bonds, color tests using a spectrophotometer, and mechanical tests using a Universal Testing Machine (UTM). Microbiological assessments confirmed that the prescribed dose effectively eradicated microbial threats. The irradiation process involved treating over 300 rare books using conventional gamma radiation techniques. The books were sealed in plastic, organized in boxes, and loaded into totes for gamma ray exposure. The arrangement of boxes and their placement in the totes were optimized to ensure uniform dose distribution. For totes with 4 boxes, the maximum dose of 8.7kGy and a minimum of 6.9kGy were used. For totes with 8 boxes, maximum, and minimum dose values used were 8.3 kGy, and 5.8 kGy, respectively. Post-irradiation characterization using FTIR and spectrophotometer confirmed no changes in the treated books, and microbiological tests verified successful disinfection. In conclusion, the implementation of gamma irradiation for preserving rare books has been successfully conducted in Malaysia, marking a significant advancement in the conservation of cultural heritage.

IAEA-CN-332/653

Monitoring Sediment Processes in Coastal Systems of Ghana Using Natural Radionuclides as Tracers

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Coastal systems are evolving at unprecedented rates and the coast of Ghana has become very vulnerable as evident in constant soil erosion, dragging of houses, bridges, and other structures close to the shore. Monitoring sediment dynamics in the Keta Basin of the Volta Delta of Ghana is critical at this stage of the country's development. The delta remains one of the candidate sites for capital intensive infrastructures such as Ghana's Nuclear Power Plant project, Keta Port project and the Hydroelectric Power Plant project. In-situ mapping (Fig. 1) and sampling measurements (Fig. 2) using gamma spectrometry of natural radionuclides of U-238, Th-232 and K-40 in soils and sediments from the Keta Basin (Keta sea shoreline, the lagoon shoreline and sandbar separating the sea and the lagoon) were investigated.

Google Earth Images with colour-graded overlays indicating U-238, Th-232 and K-40 concentrations (Bq/kg) at the Keta Strip of sandbar along the sea and the Keta Lagoon.

The graph of counts against time in all the stations shows a constant signal. Signifying constant radioactivity levels at the sandbar. However, the radioactivity of the seashore line is relatively higher than the lagoon shore line. This observation is probably because the sea receives high energy wave action and also the beach in this section is steeper than the lagoonshore line. Advance study is underway in collaboration with the Stellebortch university to Identify the various radionuclide. Preliminary results obtained indicates K-40, U-238 and Th-232 are all prominent along the sandbars with K-40 having relatively high levels. Areas with high levels of K-40 were about 10 times higher than both U and Th. Areas with lower levels of U and Th were about fifteen times and thirty times lower than the levels of K-40. To identify locations of statistically significant hot and gold spot within the study area the Getis-Ord Gi* software is being applied. Other statistical analysis such as HCA and PCA are being used to accessed correlations between the 3 radionuclides.

IAEA-CN-332/665

Tissue Bank Activity in Chile: A Journey of More Than Two Decades

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Biological tissues are key tools as therapeutic option for the treatment of a wide range of medical conditions. While clinical quality tissues and synthetic materials are commercially available for some applications, public health services in Latin America often have limited access to these products due to their high cost.

Recognizing the contribution that radiation technologies provide to tissue bank activity in the world, since 1997 the Ministry of Health and the Chilean Nuclear Energy Commission (CCHEN) have made joint efforts to provide safe tissues for medical use in the country. With the IAEA support through the Technical Cooperation Programme (inter-regional project INT/6/052, regional project RLA/6/062 and capacity building project CHI0011 - CHI0012), it was possible to create capacities for the processing and use of tissues, and also to establish the first Radio-sterilized Biological Tissue Processing Laboratory at year 2000. This experience was the foundation of what is today the National Tissue Bank (NTB). Starting its operation at year 2017, NTB is the only multi-tissue bank in the country. It has been responsible of processing, preservation, storage, distribution and traceability of human tissues, providing to the National Healthcare Network with tissues for therapeutic purposes. In addition, a part of its role is to guide and advise the implementation of new banks in the country, to monitor all activities related to the procurement and transplantation of tissues, and to promote good practices and quality standards in order to ensure compliance of tissue products in the country. Since 2017 to 2024, more than 1700 procured human tissues (bone, skin, cornea, amnios) have been processed, with about 44% of the total corresponding to radiosterilized tissues which are being used in a range of surgical and non-surgical applications and healthcare fields, including the treatment of severe burns, chronic wounds, advanced healing, orthopaedics and traumatology, reparative plastic surgery, maxillofacial surgery, dentistry, and more.

NTB and CCHEN have continued to work together. Thus, during the implementation of the regional project RLA1018, we realize that it was time to design the first national project dedicated to strengthening tissue activity in the country in critical aspects such as quality, productivity and technological development. Today, both institutions lead the CHI1020 project and are implementing a new laboratory that seeks to be a reference for the establishment of other tissue banks in the country and in the LATAM region. The goal of this strategy is to advance in a timely and equitable access to safe and effective tissues for the individual needs of patients in our country.

IAEA-CN-332/666

Electron Beam and X-Ray as Viable Alternatives to Co-60 Gamma Radiation for Microbial Inactivation and Immune Stimulation

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Gamma radiation is the most widely used ionizing radiation technology with applications in industrial sterilization, food safety, wastewater treatment and for developing immunomodulators. The stringent safeguarding and disposal requirements of Co-60 radioactive isotope make it commercially unsustainable and hence a transition to environment-friendly alternatives is crucial. Electron beam (eBeam) and X-ray represent two machine source based ionizing radiation technologies that could serve as sustainable alternatives. The current study focusses on conducting comparative studies on microbial inactivation kinetics and immune stimulation potential of key bacterial and viral pathogens between different modalities of eBeam, X-ray and gamma radiation. We hypothesize that comparable microbial inactivation and immune stimulation profile will be obtained with eBeam and X rays enabling it to serve as viable alternative to Gamma irradiation.

Three bacterial pathogens, Acinetobacter baumannii, Streptococcus pneumoniae, Listeria monocytogenes and three viral pathogens Human rotavirus, Influenza A virus, Human Respiratory Syncytial Virus are currently under investigation. Inactivation kinetics studies using High Energy Electron Beam (HEEB) showed that the decimal reduction dose (D10) of Acinetobacter baumannii, Streptococcus pneumoniae and Listeria monocytogenes, were 0.25±0.01 kGy, 0.42±0.04 kGy and 0.5±0.12 kGy respectively. The D10 value for Human rotavirus was 1.82±0.21 kGy. Further inactivation studies will be conducted using Medium and Low energy eBeam (MEEB, LEEB), X-ray and Gamma irradiation. Previous studies using HEEB in bacterial cells have shown complete inactivation of pathogen without modifying antigenic properties stimulating innate pro-inflammatory response and maturation of Dendritic cells. Retention of antigenicity profile by the inactivated microbes across different modalities of ionizing radiation will be assessed to understand the immune stimulation potential. Findings from this study will help in identifying the ideal modality of machine source based ionizing radiation that can be scaled up to serve as a viable alternative to Co-60 based gamma irradiation.

IAEA-CN-332/677

The Use of Irradiation for Production of Oligochitosan Conjugated with Oxide Graphene

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The use of natural biopolymers has attracted significant attention in biomedical areas, as they are versatile, biocompatible and sustainable, presenting a promising alternative to synthetic materials. Chitosan and its oligomeric forms - oligochitosan - are produced from chitin and have interesting characteristics, such as biocompatibility, biodegradability and potential to interact with different materials, which makes them suitable for various applications, including the development of nanocomposites.

Oligochitosans (OCH) can synthesize nanocomposites with graphene oxide (GO). To this end, in this work, ionizing radiation was used to determine the characteristics of the biopolymer in oligomers, and subsequent functionalization with graphene oxide, obtaining the OCH/GO conjugate, which was characterized and evaluated about its cytotoxicity.

Results

The incorporation of oligochitosan into graphene oxide, forming the nanocomposite, was possible, as demonstrated by the atomic force microscopy image (Fig. 5), and cytotoxicity assay (Fig.6) demonstrated good viability for to use the nanocomposite in biological aplications.

Conclusions

The results showed that it was possible to synthesize oligochitosans using irradiation and even incorporate them into graphene oxide, thus allowing the material to gain biocompatibility and can be used in various biomedical applications.

IAEA-CN-332/678

Determination of the Angular Distribution of the Muon Flux Using Plastic Scintillator Spectrum Deconvolution

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Anti/Muons in cosmic radiation are created by the interactions of high-energy protons in the upper layers of the atmosphere (15 km) and by the subsequent decay of the produced pions. They are produced with high energy (in order up to hundreds of GeV)

On the Earth's surface, muons are the largest component of cosmic radiation. The integral intensity is approximately 70 muons/(m2.s.sr).

For a detector (polystyrene plastic scintillator) with dimensions of 100 cm x 50 cm x 5 cm, measurements were made for different orientations of the detector - the detector lying flat, placed on the longer edge and on the shorter edge. For different orientations of the detector, approximately the same integral numbers in the low-energy region (approx. up to 10 MeV) equal to 711 cps were measured. For energies above 10 MeV (corresponding mainly to muons) the integral counts differed - for the lying detector they were 54 cps (0.65 imp/cm2/min), but for two different positions (on the shorter and longer edge) they were practically the same approximately 32 cps (the difference was around 4 sigma).

Due to the significant asymmetry of the detector, the interaction length varies and similarly the deposited energy circa from 10 MeV to more than 200 MeV and depends on the angle of incidence of the muon.

Using the deconvolution (SAND code) of the measured spectrum, the angular distribution of the muon flux at the measurement location can be determined. To determine the response matrix, we used Monte Carlo simulations (MCNPX) for different orientations of the detector and unidirectional fields of muons with the energy distribution obtained from EXPACs calculated using the PARMA model for the Bratislava position.

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Radiation Technology Applied to Food

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AMAZUL, a Brazilian state-owned company, undertakes cutting-edge initiatives in the fields of nuclear technology, engineering, and management with the aim of fostering national development. One of these technologies involves the utilization of e-beam and x-ray for food safety, food preservation, and biosecurity across borders. Although this technology is well-known in Brazilian research institutes, it has not yet achieved its full potential for socioeconomic benefits from agricultural resources.

Given the multidisciplinary nature of irradiation technology, AMAZUL established internal and external collaboration networks and implemented intensive programmes to improve its technical and business capacity in this area. In parallel, it has pursued close collaboration with both government agencies and the private sector to establish irradiation centers. The initiative has garnered the attention of agribusiness and investment, with the potential for the company to provide services such as planning, regulatory authorization process advisory, engineering design, quality system, procurement, construction, assembly, inspection, and commissioning of irradiation centers.

This paper presents AMAZUL's approach to strengthening capacity building and fostering collaboration among experts and institutions, with the aim of expediting the development of the irradiation center project. It also places emphasis on integrating radiation science and technology, engineering, and management for comprehensive optimization.

IAEA-CN-332/698

Application of Radiation Using Gamma Irradiation Facility for Food and Agriculture Processing in Nigeria

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The multipurpose Gamma Irradiation Facility (GIF) at the Nuclear Technology Centre (NTC), Sheda Science and Technology Complex (SHETSCO), Abuja, Nigeria is designed as a semi – commercial plant with facilities for research and development (R&D). The design takes into account the different needs of the various research applications which require a wide dose range, a variety of techniques, different product sizes, shapes, mass, volume, densities and type. Programmable doses are used for food irradiation (i. e 0.04-10KGy), biological seed mutation breeding and sterile insect technique (SIT) (0.01-5KGy), sterilization of medical, pharmaceutical and cosmetic products and packages (up to 25KGy) and cross-linking of polymers (up to 100 KGy). The six different modes of operations (sample elevators, stationary, swiveling, 2-path inner lane, 2- path outer lane and 4 - path line) were evaluated. The dose range, mass range and range of irradiation time practicable were established and advantages for radiation processing of food and industrial products were enumerated for the six modes of operations for the first time.

IAEA-CN-332/703

A Comprehensive Guide to Civil Structure Diagnostic and Integrity Assessment with Case Studies

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This paper offers a thorough guide to civil structure diagnostics and integrity assessment, utilizing a blend of non-destructive testing in civil engineering (NDTCE) methods and traditional inspection techniques. The methodology begins with visual inspections to identify surface anomalies, such as cracks and corrosion, and progresses to crack classification. The discussion extends to advanced NDTCE methods, detailing their applications in detecting internal defects, assessing material properties, and evaluating structural weaknesses. Furthermore, the paper explores how these techniques can uncover design faults and assess the impacts of overloading on structures. Through comprehensive case studies, the paper illustrates how integrating NDTCE with conventional inspection methods provides a robust framework for evaluating building integrity. This integrated approach enhances diagnostic accuracy and supports informed decision-making regarding maintenance and repair, ultimately contributing to the safety and longevity of civil structures.

IAEA-CN-332/708

Favorable Influence of Aqueous Media on Gamma Irradiated PP

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PP belongs to the polymers sensitive to ionizing radiation, even for relatively small doses. Even though the basic radiation chemistry of PP is well known, and many scientific publications and reviews are available on this topic, the interest of the academic community and the need for sterilization, modification, and additional improvements in properties vital for the medical and other industries, drive further the research in this area. PP is known to undergo excessive oxidative degradation and deterioration in properties upon irradiation in air. Usually, in the absence of effective crosslinking co-agent and/or crosslinking media, relatively high doses (≥ 250 kGy) are required before the dose to incipient gelation is reached, and the effects of crosslinking begin to show.

In this work, changes in the structure and physical properties of stabilized isotactic polypropylene (iPP) were created by gamma irradiation of PP in air and deionized distilled (DD) water. The presence and evolution of free radicals after irradiation were followed using electron spin resonance (ESR) spectroscopy. Gel and infrared (IR) spectroscopy measurements were used to determine the changes in the degree of network formation and oxidative degradation, respectively. Sol-gel analysis was studied in detail using the Charlesby–Pinner (C–P) equation. Additional characterization was conducted by optical microscopy (OM), scanning electron microscopy (SEM), wide-angle X-ray diffraction (WAXD), dielectric relaxation spectroscopy (DRS), differential scanning calorimetry (DSC), and mechanical measurements.

The results were analyzed, compared, and discussed, emphasizing the favorable influence of aqueous media on PP properties in contrast to air. Obtained results may be of interest in the practical application of ionizing radiation in polymer technologies, which involves PO medical devices, but also in cable, automotive, packaging, textile, and other industrial uses.

IAEA-CN-332/709

Efficient Copper Ion Removal from Wastewater Using Copolymeric Hydrogels Based on NIPAM, OEGMA, and Acids Synthesized via Gamma Radiation

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We report the synthesis of copolymeric hydrogels based on N-isopropylacrylamide (NIPAM), oligo(ethylene glycol) methacrylate (OEGMA), and different acids (itaconic, acrylic, and methacrylic) with varying monomer ratios. These hydrogels were polymerized and crosslinked using gamma radiation, with a dose of 25 kGy administered at a rate of about 0.5 kGy per hour in aqueous media, eliminating the need for additional crosslinking agents.

Characterization was performed using Fourier Transform Infrared (FTIR) spectroscopy to confirm chemical composition, and Scanning Electron Microscopy (SEM) to examine morphological features. Synthesized hydrogels exhibited variable water absorbency and distinct Volume Phase Transition Temperature (VPTT) responses, which were influenced by their composition and the pH of the swelling medium. This adaptability suggests their potential for diverse environmental applications.

Reswelling tests demonstrated that the hydrogels can undergo swelling and deswelling without significant performance loss, indicating their reusability. In practical applications, we evaluated their effectiveness in removing copper ions (Cu) from contaminated water using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The results reveal that hydrogels with acid comonomers are particularly effective for wastewater treatment and environmental remediation.

IAEA-CN-332/710

Radiation Sterilization of Medical Devices Based on Polypropylene - The Influence of Fabrication and Irradiation Conditions on Final Product Properties

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Sterilization is essential for implants, medical devices, and biopharmaceutical products. Medical devices, particularly those for single-use (SU) applications, are entirely made of different polymers, or some integral parts are polymeric. Such devices and most biopharmaceutical products typically require low-temperature sterilization, eliminating heat sterilization as an option. Furthermore, concerns regarding EtO health, security, environmental threats, and residual toxicity additionally shift the healthcare market towards radiation sterilization and radiation technologies as an inevitable and dominant option.

Polypropylene (PP) is widely used in the medical industry to produce syringes, vials, and numerous other SU medical devices. In most cases, commercial PP is semicrystalline material with high isotacticity and large processability; due to that, crystallinity can vary from 25 to more than 60% in commercial products. Also, it belongs to polymers sensitive to ionizing radiation even for relatively small doses (in the range of sterilization ones) and undergoes excessive oxidative degradation and deterioration in properties upon irradiation in the air at these doses. Due to the restricted mobility of chains in the crystalline regions, radiation-induced free radicals can persist for an extended time in the crystalline cores of PP. These long-lived free radicals slowly diffuse to the interface with the amorphous region, where they initiate chain degradation and oxidation. This can lead to a significant alternation in PP product properties over a long period after irradiation, especially in the case of highly crystalline products. Herein, the combined influence of variation in product fabrication and different irradiation conditions (such as absorbed dose, dose rate, etc.) on deterioration in properties of sterilized PP medical devices during post-irradiation storage was investigated in detail.

IAEA-CN-332/714

Smart Ag/P(HEMA/IA) Nanocomposite Hydrogels for Wound Dressing Obtained by Different Radiation Approaches

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Following two distinct radiolytic synthesis approaches - one-step and two-step method, two types of smart silver nanocomposite hydrogels were prepared. In a two-step process, P(HEMA/IA) copolymeric hydrogels, synthesized via gamma radiation during the first phase, were used as a matrix for the synthesis of silver nanoparticles which also employed a gamma radiolytic method during the second phase. The one-step approach integrates both phases of the two-step synthesis - silver nanocomposites were obtained by irradiating water/ethanol solutions containing HEMA, IA and AgNO3 resulting in the simultaneous formation of AgNPs and P(HEMA/IA) hydrogels. Ag/P(HEMA/IA) nanocomposite hydrogel libraries obtained using these two different fabrication methodologies were characterized through UV-Vis spectroscopy, swelling behavior studies, scanning electron microscopy, and energy dispersive spectroscopy. To assess their antimicrobial properties, the nanocomposites were tested against E. Coli, S. Aureus, and C. Albicans. Both types of synthesized copolymeric silver nanocomposite hydrogels demonstrated good antimicrobial activity, even at low silver concentrations, making them suitable for wound dressing applications. Combining this with the fact that one-step synthesis can provide the sterilized final product in one step, with a significant reduction in production time and cost compared to two-step synthesis, results in a useful synergistic combination for efficient hydrogel wound dressing production.

IAEA-CN-332/716

Application of Sterile Insect Technique for the Management of Eldana saccharina in South Africa: Two Decades of Research

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Sugarcane is the primary source of all sugar and is a promising industrial raw material for biofuel. However, sugarcane is susceptible to insect attack, resulting in the reduction of sucrose content and biomass. In South Africa, the stalk borer Eldana saccharina is the major pest that significantly reduces sugarcane yield. Over the years, scientists have attempted to eradicate pests using a variety of tactics, including insecticides, biological control, and sterile insect technique (SIT). The South African Sugarcane Research Institute has been rearing E. saccharina since the 1970s. In the past two decades, the SIT programme for controlling this pest has been investigated in collaboration with the International Atomic Energy Agency (IAEA) and Sandia National Laboratories. This paper provides an overview of the advancements made in the application of SIT to manage E. saccharina in sugarcane. This includes (i) the development of an artificial diet for mass rearing, (ii) the determination of dose rate, (iii) the biology of E. saccharina, (iv) the handling and transportation of irradiated moths, and (v) the use of X-ray as an alternative to gamma irradiation.

IAEA-CN-332/725

New Tendencies and Technologies on Tomography Applied to the Petroleum Industry: A Comparative Analysis

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This work aims to present, and critically analyze, the "State of the Art" – or the "State of the Science" – in Industrial Tomography, focusing on the Petroleum Industry, as well as comparing it with the measurements and tomographic results carried out by the authors, within a project funded by the IAEA, called: "Strengthening of Industrial Process Tomography Technology to Characterize Brazilian Reservoir Rocks and to Improve Quality Control of Refining Towers and Pipes for Enhancement of Petroleum Production - BRA1036". This industry has been one of the most advanced users of this technology for many years. Industrial Process Tomography (IPT) has many useful applications here, being able, in its recent advances, to provide increasingly more information in real time about rocks and fluids. However, the dissemination of it still faces some challenges, such as its high costs, and the need for highly qualified personnel. Gamma Ray Tomography, for instance, is still little known in this area. The main difference compared to X-Ray Tomography is that the former can generally penetrate much deeper into the reservoir rock samples, allowing analysis of much bigger samples, or with many different types of core holders: fluid flow through them, under high pressures and temperatures, can be analyzed. And new X-Ray technologies are also considered for these applications. To conduct this study, the authors first analyzed the main types of tomography applied to this sector. The focus here is on Radioactive Tomography, but other similar techniques are also presented. Microwave Tomography, for example, can also be used, with IPT. This technique has evolved considerably, although still with few non-medical applications. Another similar technology, common in this area, is Gamma Ray Logging, either Natural or Induced. Other ways of obtaining the same type of information – porosity and permeability through petrophysics, for example – are also compared. Finally, a discussion about the current terminologies for these technologies is presented, including suggestions for better classification and uniformity. All these comparative analyses take into account the United Nations Sustainable Development Goals (SDGs), to evaluate the best options for the coming decades, in the world: this industry is currently largely responsible for global warming, but it is one of the biggest Investors in CO2 capture. The most related SDGs here are the numbers 9 (Industry, Innovation and Infrastructure), and 12 (Responsible Consumption and Production). The main results presented are comparative, definitions, and classification tables, as well as suggestions for applications that can help improve the use of Industrial Tomography. In conclusion, the strong evolution of X-Ray Tomography may represent a challenge for the competitiveness of Gamma Ray. In general, real time tomography deserves a great emphasis in this scenario. But it is possible to state that Gamma Ray Tomography, and IPT, are among the most promising evolving technologies, considering their rapid growth and potential to increase the efficiency of petroleum recovery and its derivatives production.

IAEA-CN-332/728

Dielectric Properties of XLPE Obtained by High-Energy Irradiation in Different Media

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Polyethylene (PE) has good dielectric properties (excellent dielectric strength, high insulation resistance, and a low dissipation factor) and is, therefore, widely used as an insulating material for power and communication cables, although with limitations in the temperature range. Crosslinking the PE to become XLPE increases the temperature range of the insulation and chemical corrosion resistance. There are two main crosslinking methods for cable insulation: chemical crosslinking involves adding chemicals or initiators such as silane or peroxide to generate free radicals, which form the crosslinking. Physical crosslinking mainly involves subjecting the polymer to high-energy radiation.

In this study, XLPE was created by high-energy irradiation of low-density polyethylene (LDPE) in different media: air, deionized distilled (DD) water, and nitrogen. The role of irradiation media on dielectric properties and charge-trapping behavior has been studied through dielectric loss analysis and thermally stimulated discharge current (TSDC) measurements. The polar groups introduced in initially apolar PE by irradiation were regarded as tracer ones. Changes in magnitude, position, and activation energy of dielectric relaxations were found to be strongly dependent on the two main radiation-induced processes, e.g., crosslinking and oxidative degradation. Gel and infrared results confirmed that the domination of one or the other of these competitive processes is strongly determined by radiation dose and media. Oxidation, e.g., an increase in the amount of polar carbonyl groups, is accentuated for the samples irradiated in air, leading to a significant increase in the magnitude of the observed dielectric relaxations. On the other hand, crosslinking and net formation are much more extensive for the samples irradiated in DD water and/or nitrogen, and play a significant role only in the case of the dielectric β relaxation due to its nature and cooperative character; the increase in the position and apparent activation energy for this relaxation process can be clearly related to the restricted chain mobility in the amorphous phase induced by crosslinking and net formation.

IAEA-CN-332/741

The Effects of Different Radiation Sterilization Modalities on Some Polyolefins for Healthcare Applications

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Polyolefins, including Polypropylene (PP) and Polyethylene (PE) are major polymers for the medical industry, for single use systems (SUS) and for pharmaceutical packaging. Irradiation of PP can induce several physical changes including embrittlement, stiffening, yellowing and decrease of molecular weight [1,2]. Irradiation of PE can induce crosslinking. For both, it can also induce extractibles and change in aging behaviour.

X-ray is an emerging technology as a radiation sterilization modality.

Some commercial medical grades are claimed to be radio-tolerant but their comparative study under radiation including electron beam (EB), gamma irradiation and particularly new X-ray is not investigated through research.

We have investigated 4 of them with the 3 mentioned radiation modalities in the frame of the Coordinated Research Project (CRP) n°F23035, led by IAEA.

We have used different laboratory testing techniques to characterize physico-chemical, mechanical and thermomechanical properties of the material, at molecular and macromolecular levels.

We have been able to establish the behaviour of the materials with the dose and in correlation with the dose rate, as it was maintained at a standard processing level typical to each irradiation modality. We will discuss these results with several analyses: ESR, rheology, tensile tests, colorimetry and chemical analyses of extractibles.

IAEA-CN-332/746

Application of Ionizing Radiation for the Decontamination of Glass Photographic Negatives: A Study on the Preservation of Cultural Heritage

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The preservation of glass photographic negatives, a critical component of 19th and 20th-century visual heritage, poses unique challenges due to their susceptibility to deterioration caused by biological contaminants such as fungi. This study explores the application of ionizing radiation as an effective method for decontaminating glass negatives, building on previous research conducted on the decontamination of flexible acetate-based negatives.

The research investigates the effects of ionizing radiation on the structural integrity and image quality of glass negatives, aiming to assess its viability as a conservation tool. A series of controlled irradiation experiments were conducted, followed by detailed analysis using techniques such colorimetry and UV-vis spectrophotometry to measure any changes in the visual and chemical properties of the negatives.

The results indicate that ionizing radiation, when applied under specific parameters, can successfully reduce microbial contamination without causing significant alterations to the glass substrate or the photographic emulsion. However, the study also highlights the need for careful calibration of radiation doses to avoid potential side effects, such as changes in color or loss of detail in the image.

This paper contributes to the growing body of knowledge on the use of radiation technologies for the conservation of photographic materials, offering insights into the development of new methodologies for the preservation of glass negatives. The findings have significant implications for cultural institutions seeking sustainable and non-invasive conservation strategies for their photographic collections.

This research provides a critical foundation for future studies, particularly in refining the application of ionizing radiation in diverse types of photographic media, further expanding the toolkit available to conservation professionals.

IAEA-CN-332/753

Applications and Challenges of Radiation Science and Technology in the United Republic of Tanzania from the Late 1940s to Early 2020s

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The applications of radiation science and technology in the United Republic of Tanzania started in 1949, when Williamson Diamond Mining Company used three Cs – 137 as a radiation density gauge. Since then, the applications expanded to other fields such as agriculture, research and education, sterilization of insects, non - destructive testing, quality control in industries, and exploration of oil, minerals and gas. Also, between the late 1940s to early 2020s, the country has managed to use the radiation science and technology to improve rice and barley production through application of mutation breeding. Other achievements include the improvement of indigenous cattle breeds through enhanced artificial insemination, development of maize cultivars for improved yield and resistance to viral disease, evaluation of the effectiveness of infant and young child nutrition, assessment and monitoring of water resources using isotope hydrology techniques, environmental pollution monitoring and determination of toxic elements in imported and exported food stuffs. Further, the country is in the final stage to establish food irradiator which will be used for preservation of food and sterilization of medical equipment and biological samples. In order the applications of radiation science and technology to be governed safely, securely and effectively, the government passed radioactive waste management regulations and transport of radioactive material regulations in 1999 and 2011 respectively, commissioned national interim radioactive waste storage facility in 2009, reviewed the Atomic Energy Act No.7 of 2003 in 2022 to include nuclear security matters, and established coordinated nuclear emergency team in early 2024. This paper aims to evaluate the applications of radiation science and technology in the country from the late 1949 to early 2020s by emphasizing the socio-economic benefits generated by the technology; how the country is achieving the United Nations Sustainable Development Goals (SDGs) by using the radiation science and technology; and discuss the challenges and the measures taken by the government to address the raised challenges.

IAEA-CN-332/758

Traditional Methods and Gamma Ionization Technique for Disinfection of Cultural Heritage Objects: Acceptance by the Conservators Community

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Artifacts are preserved over time by cultural heritage institutions to prevent their deterioration. As organic materials, such as wood, fabrics, plant fibers, and feathers, are vulnerable to damage, chemical treatments were historically used as an effective method of preserving the physical integrity of objects. Pesticide use in cultural institutions began to increase at the end of the 19th century. To ensure the preservation of their collections, museums and libraries followed traditional recipes in addition to using chemicals that were commercially available with a variety of formulations. The use of routine and successive treatments may have affected objects with multiple contaminations from different chemical substances. Many entomologists, taxidermists, collectors, curators, and professionals from institutions shared these treatments, which facilitated an exchange of information regarding biological threats. A knowledge exchange network involving many countries generated a similar timeline for the application of chemical substances. An international survey was developed to collect information on the practices of toxic and non-toxic treatments used in different types of collections. To leave the traditional Anglo-Saxon axis, the questions was prepared in English, Spanish and Portuguese in order to make it accessible to a wider audience not always actively engaged in international surveys in conservation. This study presents the results of the questionnaire designed to identify traditional methods of disinfecting objects, as well as to understand the level of acceptance of more sustainable methods, such as gamma ionization applied to the preservation of cultural heritage.

IAEA-CN-332/765

Detection of Malfunctions in Distillation Column Using Gamma Ray Techniques Joined with GUI at MATLAB

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This study addresses a common operational issue in distillation columns—foaming on trays—which impacts separation efficiency and product quality. Foaming occurs when the liquid expands in the column due to intensive liquid-vapor interaction, often triggered by high gas velocity, specific tray design, or excessive liquid accumulation. When foaming goes undetected, it can lead to economic repercussions, as off-spec products or emergency shutdowns may result. To mitigate these risks, early fault detection is essential. Gamma-ray scanning is widely used in industrial diagnostics because of its cost-effectiveness, efficiency, and capability to identify faults without disrupting operations. This study explores the integration of gamma-ray technology with a graphical user interface (GUI) to create an online monitoring system capable of detecting and analyzing foaming issues in real-timestrong text.

The methodology involved several stages to develop and test the detection system. First, a cold flow model of a distillation column was designed, including trays and downcomers that recycle water as feedstock. The flow model was thoroughly tested for leaks and proper function, simulating real operational conditions without the risks associated with high temperatures and pressures. The next step involved gamma-ray scanning under both normal and foaming conditions. During normal operation, water levels on the trays remained stable due to a balanced inlet and outlet flow rate. For the foaming condition, flow rates were increased to simulate higher liquid levels, creating a clear abnormal scenario. Gamma rays were emitted from a Cesium-137 source, and a sodium iodide (NaI) detector captured the data, which showed distinct differences between normal and foaming cases.

To analyze this data, a MATLAB-based GUI was developed. The GUI provided an intuitive platform for loading, processing, and visualizing the gamma-ray scan results, allowing operators to distinguish normal operating conditions from foaming with ease. Data from both lab tests and IAEA references were used to validate the system's accuracy. The GUI identified foaming by displaying broader peaks in tray readings, especially on tray 2, where foaming was intentionally induced. This observation was consistent with reference data, confirming that the gamma-ray and GUI combination could reliably detect foaming.

The results demonstrated that under normal conditions, the gamma-ray scans produced clear, sharp peaks for each tray. When foaming occurred, broader peaks were observed, indicating increased liquid presence on the trays. The consistency between laboratory data and IAEA reference cases validated the system's reliability. This methodology enables operators to identify and address foaming before it escalates, offering a proactive approach to column maintenance.

In conclusion, the study successfully integrated gamma-ray technology with a MATLAB GUI to develop a robust fault detection system for distillation columns. The method proved effective in distinguishing normal conditions from foaming and provided a real-time assessment tool. The ability to monitor and diagnose foaming promptly helps prevent operational disruptions, enhances product quality, and reduces costs. This online monitoring system offers refineries a powerful tool for maintaining efficient distillation column performance, highlighting the potential of gamma-ray diagnostics and GUI interfaces in industrial applications.

IAEA-CN-332/778

Applications of Radiation Science in the Diagnosis and Management of Plant Diseases

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Plant diseases are a major limiting factor to food security in most parts of the world. They are caused by various species and strains of fungi, viruses, viroids, bacteria, phytoplasma and nematodes. Chemical-based fungicides are widely used in managing plant diseases, especially fungal pathogens. However, the usage of chemicals is unsustainable due to the health risks they pose to the environment and humans. Therefore, an integrated approach of managing plant diseases should involve chemicals, biological control agents, genetic engineering, physical means and the use of radiation. Radiation has several uses, particularly in the field of plant pathology, where it offers cutting-edge tools for managing and detecting plant diseases. Radiation-based imaging methods, including computed tomography (CT) and X-rays, have been employed in diagnostics to visualize interior plant structures and to identify plant diseases. Fluorescence and UV radiation are also used to identify pathogen-specific markers, which helps in the early disease detection. In addition to this, radiation is used in plant disease management. Gamma radiation has been used in eliminating harmful pathogens through seterilization and in post-harvest treatments to disinfect fruits and vegetables. Crops resistant to disease have also been developed using radiation-induced mutation breeding. Additionally, some imaging methods enable researchers to investigate interactions between plants and pathogens. This paper will highlight the most common uses and future of radiation in plant disease diagnosis and management, which will help in fostering sustainable agricultural practices and food security.

IAEA-CN-332/782

Application of Irradiation Technology in Türkiye

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Türkiye has more than 30 years of experience in utilizing irradiation technology for the sterilization of medical products. The country has two gamma irradiation facilities: one, operated by the private sector, is Gamma-Pak Sterilization Industry and Trade Inc., located in Çerkezköy-Istanbul; the other, run by the government, is TENMAK-NÜKEN in Sarayköy-Ankara. Both facilities have been providing sterilization services to medical product manufacturers since 1993, supported by their experienced personnel and well-equipped laboratory infrastructures.Notably, food irradiation technology has been employed in Türkiye since 2002 to enhance food quality, prolong shelf life, and eliminate pathogenic microorganisms, including Salmonella enterica, Toxoplasma gondii, Listeria monocytogenes, Norovirus, and Campylobacter in animal-derived foods and spices. It has also been used for insect disinfestation in stored products. Türkiye established food irradiation legislation in 1999, and the detection of irradiated foods has been conducted by designated government authorities since 2004.Gamma-Pak, recognized as a pioneering and leading facility with a higher irradiation capacity in Türkiye, is a versatile irradiation center. It provides sterilization for medical supplies, pharmaceuticals, and cosmetics, ensures food safety by irradiating products such as spices and fresh or frozen animal-derived items, and processes polymers for cross-linking. Gamma irradiation is considered the most efficient and effective technology compared to alternative sterilization methods.Furthermore, in recent years, polymer cross-linking EB irradiators have been introduced and commenced operations in Turkey, marking a significant advancement. This paper highlights the current state and recent developments in the implementation of irradiation technology across the country.

IAEA-CN-332/783

Assessment of the Experiences of Researchers and Blood Bank Operators with Using X-ray Irradiators

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Brookhaven National Laboratory (BNL), in collaboration with the U.S. National Academy of Sciences (NAS), conducted quantitative and qualitative surveys in three countries (Switzerland, Norway, and the United Kingdom) that made a national commitment to phase out cesium-137 irradiators with alternative technologies. The survey was designed to document the views and opinions of blood bank operators' researchers with firsthand experience operating X-ray devices for blood and research applications. The survey instrument focused on four distinct yet interrelated areas that impact users' experience: regulatory compliance specific to each modality; operational impacts, including infrastructure needs, workflow, personnel management, and training; research design and investigation impacts, including calibration, dosimetry, continuity of previous studies, development of new research agendas, and the outcomes for both; and funding impacts, specifically how grant sources and opportunities have responded to the transition.

Overall, survey responses were consistent with those of a 2021 survey of domestic users of X-ray irradiators. International respondents concurred with their US counterparts and did not experience transitioning from cesium to X-ray irradiators as disruptive to end users. Approximately 55% of respondents indicated they would recommend X-ray technology as an alternative to (Cs-137 or Co-60) irradiation. Many of the international respondents also agreed that the primary benefits of cesium-137 include the removal of risks, liabilities, and management associated with the keeping and holding of gamma sources, reduced regulatory burdens, reduced security requirements, and less impact on evacuation procedures and staff duties in the event of an emergency. Others indicated that the ease of operational use is equivalent to gamma-based irradiators and noted that a standard timer setting (no requirement to adjust for decay) is also beneficial for X-ray irradiators.

Regarding operational impacts, the need for infrastructure adjustments and personnel re-training were commonly cited. Nevertheless, half of the respondents who transitioned from cesium-137 irradiators to X-ray devices indicated that they experienced no noticeable efficiency impacts on their research. These results support the conclusion, also included in the earlier survey, that X-ray devices should be considered reliable institutional investments associated with many positive outcomes.

IAEA-CN-332/798

Enhancement of Thermal and Mechanical Properties of E-Waste ABS by E-Beam Irradiation

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The rapid growth of electronic waste (e-waste) generation presents a significant environmental challenge, particularly in terms of sustainable materials management and recycling practices [1]. Acrylonitrile Butadiene Styrene (ABS), a widely used thermoplastic polymer in electronic devices, is one of the most common materials found in e-waste plastics [2]. However, the recycling of e-waste ABS is complicated by various factors, including contamination from other materials and the degradation of its properties over time. As the global e-waste volume continues to increase, it has become crucial to explore innovative and sustainable methods for enhancing the recovery and recyclability of ABS from discarded electronics. One promising approach to improving the properties of e-waste ABS is the use of e-beam irradiation, a technique that involves exposing materials to high-energy electron beams [3]. In this paper, the effect of e-beam irradiation on thermal stability, mechanical properties, and overall recyclability of e-waste ABS are investigated in the dose range comprised between 5 and 15 kGy. Thermogravimetric Analysis (TGA) data reveals that e-beam irradiation leads to a slight improvement in thermal stability, with an increase in the temperature corresponding to 5 wt.% loss (T5%), as well as, the residue rate of e-waste ABS compared to non irradiated sample. Differential Scanning Calorimetry (DSC) analysis shows a marked increase in the glass transition temperature (Tg) of e-waste ABS, suggesting enhanced rigidity and material integrity after irradiation. Mechanical measurements reveal a significant increase in both Young's modulus and tensile strength for e-waste ABS, particularly at 10 kGy, which are attributed to the formation of a X-linking fraction within the e-waste ABS matrix, thus enhancing its overall mechanical performance. In conclusion, e-beam irradiation offers a promising approach to enhance the thermal stability, rigidity, and mechanical properties of e-waste ABS, providing a potential solution for improving the recyclability and performance of ABS from electronic waste.

Keywords: E-waste ABS, E-beam irradiation, Thermal Stability, Mechanical Properties.

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IAEA-CN-332/799

γ-Radiation Synthesis and luminescence of Eu^{3+} Ions in Nanocomposite Hydrogels Based on Poly(Vinyl-Alcohol) and ZrO_2NPs

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In this study, nanocomposite hydrogels based on polyvinyl-alcohol (PVA) containing 3w% zirconium NPs doped with 5 mole% europium (PVA/ZrO_2:Eu^{3+}) were prepared via γ-radiation (0-45 kGy) used as initiator to induce crosslink network structure. After irradiation, the solutions were dried at room temperature to obtain nanocomposite films. The corresponding changes in structural, morphological and optical properties were studied. XRD data showed the variation in peak intensities and ZrO_2 phase transition from monoclinic to tetragonal structure when the γ-dose reaches 35kGy. FTIR spectra show a remarkable change with increasing of γ-doses. SEM micrograph showed that the dose of 35kGy inhibits the agglomeration of ZrO_2:Eu^{3+} NPs in PVA host and improves the transparency of the nanocomposite film. The optical band gap decreases with increasing of γ-doses. The best red emission centered at 607 nm, corresponding to $^5D_0 \rightarrow {}^7F_2$ transition of Eu^{3+} ions was achieved at a dose of 35kGy. Based on the obtained results, γ-radiation is a very effective way to produce advanced hybrid systems for optical applications.

Keywords : γ-radiation, nanocomposite, luminescence.

IAEA-CN-332/814

Effects of Ionizing Radiation on the Physical and Mechanical Properties of Polylactic Acid: The Presence of Moisture

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Background of the Study:

Polylactic acid (PLA) is a biodegradable polymer widely used in various applications due to its environmental benefits. However, its mechanical properties including brittleness and low thermal stability, limit its broader adoption. Ionizing radiation (gamma irradiation, electron beam) is known to modify polymer properties by inducing chain scission and crosslinking reactions. The impact of radiation on PLA has been mainly investigated in blends, while research on pure PLA remains limited. Additionally, the effect of moisture content on radiation-induced changes has yet to be explored.

Methodology:

This study aimed to analyze the effect of gamma irradiation on the mechanical properties of PLA samples with different moisture contents. Three types of PLA with varying D-lactide contents were tested. Samples were produced by injection molding. Prior to irradiation, some specimens were stored in ambient humidity conditions, while others were dried and kept in a low-moisture environment. These were subjected to gamma irradiation at doses of 50, 100, and 150 kGy. Mechanical properties were assessed using tensile testing, Charpy impact testing, dynamic mechanical analysis (DMA), and differential scanning calorimetry (DSC). Scanning electron microscopy (SEM) was used to examine fracture surfaces.

Results:

The findings indicated that gamma irradiation significantly altered the properties of PLA. At 100 kGy, a substantial decrease can be observed in tensile strength, and at 150 kGy, brittle fracture occurred. Charpy impact tests confirmed reduced toughness at higher doses. DMA results revealed no significant change in storage modulus or glass transition temperature. DSC analysis showed only minor alterations in thermal properties, while crystallinity changes were not substantial. The presence of moisture before irradiation did not significantly affect the measured properties.

Conclusion:

Gamma irradiation induced degradation in PLA, with chain scission being the dominant effect over cross-linking. The most pronounced impact on mechanical properties was observed at higher doses, while thermal properties remained relatively stable. Moisture presence prior to irradiation had no significant influence on the degradation trends. These findings contribute to the deeper understanding of PLA's behaviour under radiation stress, providing insights for controlled degradation applications.

IAEA-CN-332/306

Inhibition of cross-linking for radiation sterilization of collagen gels

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Collagen is one of the most interesting biopolymers for biomedical applications, but there are some challenges in terms of manufacturing sterile products. Aseptic manufacturing is expensive and there are not many options when it comes to terminal sterilization. Radiation sterilization is advantageous, considering the biological origin of the raw material, but care must be taken for the changes induced in the collagen. While for dry forms (lyophilized collagen sponges) the main effect of irradiation is degradation (breakage of triple helix chains) and there is a narrow dose range for sterilization, for aqueous gels the main effect is cross-linking. In applications where the rheological properties of the collagen gel must be preserved, low temperature irradiation proves to be a feasible option.

The purpose of this study is to determine the appropriate dose window for gamma radiation sterilization of certain collagen gels under ISO 11137 conditions.

Two collagen gels (0.5% and 1%) were irradiated at room temperature and under protective conditions (dry ice, -79°C) at three doses covering the usual dose setting range for sterilization validation (15–40 kGy). Physico-chemical characterization of non-irradiated and irradiated gels under protective conditions or at ambient temperature included: viscosity measurements, thermal analysis, FT-IR and SDS-Page. The results obtained, taking into account the preliminary microbiological evaluation of the batches of laboratory gels, show that the targeted biomedical products based on collagen gels can be successfully sterilized in a higher dose range than previously reported in the literature.

IAEA-CN-332/225

Radiation Fabrication of Hyaluronate/Polyvinyl Alcohol Scaffolds for Regeneration: In-vitro and In-vivo Evaluation

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Background: Bioactive scaffolds are of significant advancement in skin regeneration and wound healing. In tissue regeneration, biomaterial-based scaffolds provide conducive environments for successful cellular regeneration in effect mimicking native tissue. Because of their safe interactions with different cells and lack of immunological response, natural polymers are among the first scaffold materials to be used in clinical practice; however, together with natural polymers, biocompatible synthetic polymers are used to address functionality, hydrophilicity, cell adhesion, and biodegradability issues. Skin wounds that pierce the dermis do not heal or recover on their own as they require specialist care and may leave behind significant scarring that limits joint motion and results in severe esthetic abnormalities. 3D- hydrogel scaffolds are effective in many applications, including bone, muscles, tendons and ligaments, and skin regeneration. Fabricating hydrogel scaffolds for tissue regeneration requires appropriate material selection which plays a significant role in their success. The scaffold should have appropriate mechanical and physical characteristics and a strong physiological foundation that promotes cell adhesion, proliferation, and/or differentiation. Scaffolds can be functionalized with bioactive substances to improve cellular responses and expedite wound healing. Ionizing radiation technology is an excellent tool for fabricating materials used in biomedicine. It combines matrices synthesis and sterilization in a single technological step, it reduces production time and costs while maintaining environment-friendliness.

Methodology: Bioactive hydrogel scaffolds based on Sodium Hyaluronate (SHA), and polyvinyl alcohol (PVA) functionalized with Frankincense essential oil (FKO) (3, 5, 7, and 10wt%) were fabricated using γ-irradiation technique. 2-Hydroxyethylmethacrylate was used as a crosslinker to enhance its network structural consistency. The parameters affecting the gel content, and swelling capability such as total feed concentration and composition, irradiation dose, FKO content were studied. Fluid absorption efficacy was evaluated in water (as blood plasma contains about 90-92% of water), physiological saline solution 0.9% NaCl (as its osmotic pressure is approximately equal to that of human tissue fluid), and simulated wound fluid (PECF) gravimetrically using on sponge swelling method to simulate an exuding wound. The morphological aspects, water vapor transmittance rate, hemolytic potential, and anti-inflammatory, and antioxidant efficiency were assessed. Antimicrobial activity was tested against Staphylococcus aureus (S. aureus), Escherichia coli (E. coli), and Candida albicans (C. albicans). The effectiveness of wound healing was assessed in a rat model.

Results: As obtained, the gel fraction increased as SHA content increased up to 30 (wt%) in the presence of 0.2% HEMA. 25 kGy was found to be suitable for obtaining sufficient gel fraction (94%). The developed scaffolds' swelling degree in different media was in the following order: water >PECF> NaCl. (SHA /PVA)-FKO scaffolds show antioxidant, and antimicrobial efficacy that enables protection against microorganism invasion. In vivo, wound healing evaluation confirms that scaffolds containing FKO induce faster wound healing compared with FKO-free scaffolds.

Conclusion: In-vitro and in-vivo results indicate the potential of the developed (SHA /PVA)-FKO bioactive hydrogels to be promising candidates as scaffolds for wound care candidates.

IAEA-CN-332/609

Development of Radiometric System of Black Sand Tracing Based on Gamma Spectroscopy

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Black sand in Egypt is an important natural resource found along the Mediterranean coast, particularly in the Nile Delta region. These sands are rich in heavy minerals such as ilmenite, magnetite, zircon, garnet, and monazite, which are valuable for various industrial applications. In this paper, gamma spectrometry system is implemented based on Cortex-M4-based microcontroller features digital signal processing capabilities. To create the specialized gamma spectrums, the black sand samples were processed at various sampling rates. Three distinct digital filters—Trapezoidal, Sin-like, and Moving Average filters have been evaluated throughout the processing of the collected signals in order to determine how they can affect the energy resolution at lower sampling rates. The ideal filter to employ for processing data at low sample rates is the moving average filter with a long filtering window. The energy resolution is less impacted by the sample rate decrease as the filtering window widens. The developed system is employed to analyze the radioactive isotopes of random samples from black sands collected from different location and the results shows these spectrums of different naturally occurring radioactive materials (NORMs) such as Radium-226, Radon-222, Thorium-232, and Potassium-40.

IAEA-CN-332/540

Condition monitoring for lifetime extension of interim storage facilities

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In Germany, there are currently three interim storage facilities for high level radioactive waste (HLW), which were commissioned in the 1990s, and twelve interim storage facilities, which were commissioned between 2002 and 2007. The licenses for these interim storage facilities are limited to 40 years from the first emplacement of a container, while the structural engineering regulations used in the design of the interim storage facilities generally assume a service life of 50 years. The availability of a final disposal site for HLW in Germany will be way past the end of the current licenses. To renew the licenses, condition assessment and prognosis will be required.

The research project ZuMoBaul-ZL (condition monitoring of civil structures in interim storage facilities) aims to develop partial aspects of a condition recording and monitoring concept suitable for interim storage facilities, including service life prediction models, with the help of which the remaining service life can be predicted, verified and monitored as realistically as possible. To this end, it is planned to continuously record the condition of the structure, including the degradation and ageing processes. The current condition of the structure is derived from sensor and inspection data and its future development is predicted with the help of suitable damage models. This adaptive service life prediction makes the prediction of the service life more precise and thus enables maintenance measures to be optimized. The procedure is demonstrated on replacement structures. The currently applicable standards and regulations are used as a basis. With this combined approach, it should be possible, despite the complex interactions between actions and component behavior during interim storage, a) to achieve a high degree of certainty regarding the current condition of the structure as an essential prerequisite for further operating permits and b) to identify a reasonable time for maintenance from a technical and economic point of view.

Current work is focused on the selection and optimization of NDT/SHM measurement techniques. First tests have been performed out at a test facility. The results are presented.

The project is being carried out as a joint project by the Institute for Building Materials, Solid Construction and Fire Protection at the Technical University of Braunschweig (iBMB, coordinator), the Federal Institute for Materials Research and Testing (BAM) and the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH.

IAEA-CN-332/227

Using Artificial Neural Networks and Non-Destructive Tests to Predict the Compressive Strength of Geopolymer Concrete

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Using Artificial Neural Networks and Non-Destructive Tests to Predict the Compressive Strength of Geopolymer Concrete.

Geopolymer Concrete (GPC) has garnered increasing attention as a sustainable alternative to conventional concrete, driven by its potential to significantly reduce the environmental footprint of construction activities. Traditional Portland cement production is a major source of CO_2 emissions, accounting for approximately 8% of global emissions. In contrast, GPC utilizes industrial by-products such as slag and fly ash, which not only recycle waste materials but also require less energy-intensive processes, resulting in substantially lower CO_2 emissions. This makes GPC an attractive option for environmentally conscious construction practices.

The compressive strength (CS) of concrete is a critical parameter that directly influences the structural performance and safety of buildings and infrastructure. Conventional methods for assessing CS involve destructive testing, where concrete specimens are subjected to crushing forces until failure. While these methods provide accurate measurements, they are inherently destructive, leading to the loss of tested samples and posing practical challenges in terms of time and resources. Moreover, destructive testing cannot be applied to in-situ structures without causing damage, limiting its applicability for ongoing quality control and structural health monitoring.

Non-Destructive Testing (NDT) methods offer a viable alternative for evaluating the CS of GPC. Techniques such as Ultrasonic Pulse Velocity (UPV) and Schmidt Rebound Hammer (SRH) are widely recognized for their ability to provide rapid and reliable assessments without damaging the concrete. UPV measures the velocity of ultrasonic waves passing through the concrete, with the wave velocity being influenced by the material's density and elastic properties, which correlate with its compressive strength. SRH, on the other hand, measures the rebound of a spring-driven mass impacting the concrete surface, which is indicative of surface hardness and, indirectly, compressive strength.

This study focuses on enhancing the utility of NDT methods by developing an Artificial Neural Network (ANN) model to predict the compressive strength of GPC. ANNs are a class of machine learning models inspired by the human brain's neural networks, capable of capturing complex, non-linear relationships within data. By training the ANN with data derived from UPV and SRH tests, the model learns to predict the compressive strength based on the observed patterns in these non-destructive measurements.

The integration of UPV and SRH results into the ANN model enables a more comprehensive evaluation of GPC's compressive strength. The model achieved a high correlation coefficient, indicating strong predictive accuracy and reliability. This innovative approach allows for quick, cost-effective, and non-invasive assessment of GPC compressive strength, making it suitable for both laboratory and field applications.

The implications of this study are significant for the construction industry. The ability to accurately predict compressive strength using NDT methods and ANN modeling can enhance quality control processes, ensure the structural integrity of GPC structures, and reduce the reliance on destructive testing. This contributes to more sustainable construction practices by minimizing material waste and preserving the structural integrity of tested samples.

IAEA-CN-332/267

Preparation of radioactive microspheres for particle tracking experiments using different methodologies

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Radioactive microspheres are used in radioactive particle tracking (RPT) experiments for flow visualisation of multiphase reactors. The physico-chemical properties of the radioactive microspheres are crucial for their targeted applications. Designing a suitable method for synthesis of these microspheres with desired properties is utmost important. Three different methods for synthesis and preparation of microspheres (dia: 500-2000μm) containing scandium oxide and cobalt oxide have been developed (Fig. 1). In the first method a sol-gel technique has been developed for synthesis of pure scandium oxide microspheres. The obtained microspheres were irradiated with neutrons in DHRUVA reactor, at Trombay, Mumbai, India for a period of 7 days, with a flux of 1 x 1013 cm-2 s-1 to produce scandium-46 (46Sc) radioisotopes in the microspheres. The radioactivity measured in a single microsphere (dia: 1000 μm) was in the range 60-74 MBq. In another method scandium oxide as well as cobalt oxide glass microspheres with 5-10 wt % loading of the respective oxides were prepared by melt-quench followed by microwave heating [1]. In the third method a microfluidic platform was designed and used for synthesis of pure scandium oxide microspheres. The size of the microspheres was controlled by optimising the flow rates of different precursor solutions as well as the internal diameter of the T-junction of the microfluidic device. 46Sc and 60Co radioactive microspheres were obtained by neutron irradiation of the stable microspheres for 7 days with flux of 5 x 1013 cm-2 s-1. The activity of 60Co glass microspheres was found to be ranging from 5-15 MBq, whereas the activity of 46Sc glass microspheres was found to be in the range 40-110 MBq, respectively. The prepared radioactive microspheres have been used in RPT studies in various laboratory as well as pilot-scale systems.

IAEA-CN-332/683

Uninterrupted Control of Smuggling in Iron Ore Rains with a Neutron Scanner

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Customs control of iron ore transported by freight trains is complicated when using x-scanners. The potential information on the violation of the homogeneity of the ore material by contraband found out by the scanning beam, , is lost during further interactions of x-rays with the ore in the deeper layers of the ore load. Thus, finally on the x-ray images, the scanner, instead of an image of contraband, reveals an image of the last layer of cargo, including the structure of the wagon wall. In contrast to x-ray scanners, the information about contraband capture detected using a T(d,n) neutron scanner, is preserved to greater thicknesses of the ore load.

The goal of the presentation is to design and experimentally verify a neutron scanner for customs control of iron ore imported by rail to Slovakia and the EU.

We have used the MCNP simulation to dedicate the suitable neutron source - detector system for inspection of iron ore in the moving trains. Our results show that in the case of T(d,n) neutron source with a 10e10 n/s emission rate combined with a NE213 detectors of 15% fast-neutron detection efficiency and 300x300 cm2 detection area, the 700 pulses per second will be registered in the case of train speed of 2 km/h. Such arrangement will enable custom control of iron ore without necessity of stopping the trains.

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IAEA-CN-332/735

Radiation Technique as Means for the Synthesis of New Biopolymer-Based Nanocarriers for Nanoradiotherapy

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Melanoma is the most dangerous skin cancer and metastatic lesions are the major issue for diagnosis and therapy of this malignant disease. They are more detrimental than primary tumors, and their occurrence is an important predictor of patients' survival and disease recurrence. Therefore there is a constant need to develop new means of detecting and treating malignant melanoma. Polymer nanogels are believed to bring about change in the field of cancer management. Functionalized with targeting ligands, nanogels could facilitate the detection of both primary and metastatic melanoma sites, and, if equipped with radioisotopes with proper decay characteristics (both β and γ), they can be rendered theranostic.

Hereby we aim to develop a new approach to the synthesis of polymer nanocarriers with radiation technique. As nanocarriers from many biocompatible, yet synthetic, polymers have already been demonstrated, we report a radiation methodology based on biopolymers such as polysaccharides for the synthesis of nanogels with desired size, crosslinking density, colloidal stability, and biological properties.

Pristine biopolymers tend to degrade upon irradiation, however using the tailored reaction conditions and functional biopolymer derivatives we are able to fine-tune the processes occurring during irradiation and, as a result, achieve the crosslinking of the chains in aqueous solutions. The presented results focus on the development of nanogels from carboxymethylcellulose with a high degree of substitution, allowing successful crosslinking. We show the influence of the radiation dose rate as well as solution properties (such as concentration and pH) on the physicochemical properties of the obtained irradiated products. We demonstrate that upon optimization of the reaction conditions, it is possible to obtain nanostructures with desired properties using radiation technology. This is an important development, because biopolymers such as polysaccharides, in contrast to most synthetic polymers, upon biodegradation release safe chemical moieties, that can be easily eliminated from the body. It makes biopolymers very promising materials for the development of nanocarriers for applications in nanotheranostics.

IAEA-CN-332/453

Enhancing Constructed Wetlands Design and Operations with Radiotracer Technology for Sustainable Wastewater Treatment

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Constructed wetlands (CWs) are artificial wastewater treatment systems designed to mimic the processes taking place in natural wetlands. These systems, mainly comprised of vegetation, substrates, soils, microorganisms and water, applying complex processes involving physical, chemical, and biological mechanisms to remove various water contaminants thus improving the water quality. The design of CW involves inputs from biological and ecological sciences, aquatic chemistry, engineering hydrology and hydrodynamics. The understanding of hydrodynamics of wastewater flowing through the wetlands is one of the important aspects for the design and optimum operation of CWs. Although hydrodynamics is applied to define the flow, It can also be used to define the mass transfer processes within the CW. Due to relatively low concentration of pollutants in wastewater treatment systems (compared to chemical reactors) mass transfer is in most cases the limiting step for pollutant removal. The study was designed to define hydrodynamics in a horizontal subsurface flow constructed wetland using radiotracers. Together with the tracer experiments, we have also designed the experimental system to give information on the interstitial velocity and how it affects removal of different water pollutants. Through this we are able to evaluate the mass transfer coefficient of a specific pollutants and evaluate how design and shape affects the wastewater treatment in a CW. Pollutants tested include BOD, COD, TN, TP, NO_3, NH_4^+ and PO_4^{3-}.

Keywords: Constructed Wetland, Radioactive tracer, Residence Time Distribution, Mass Transfer in Constructed Wetland

IAEA-CN-332/754

Advancing Landmine Detection: Investigating the Capability of backscatter X-Ray Imaging for Buried Landmines

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Background:
Landmines pose a significant threat to civilians and military in conflict regions worldwide. Innovative detection methods are needed because traditional approaches are inaccurate and inefficient. This study studies X-ray imaging as a unique landmine detection tool at various depths.

Methodology:
The study used Monte Carlo simulations to evaluate the effectiveness of X-ray imaging for landmine identification by modeling interactions with various soil and landmine materials. Experimental validations involved burying landmine replacements at different depths and using backscatter x-ray imaging to assess their detectability.

Results:
Our findings demonstrate that backscatter x-ray imaging can identify landmine locations. This method can dramatically reduce false positives and improve detection accuracy, according to the results. The studies validated the simulations, proving the viability of using X-ray imaging for landmine detection.

Conclusion:
This study suggests that backscatter X-ray imaging can improve the accuracy and safety of humanitarian demining activities by providing a non-invasive technique for landmine detection. The inclusion of X-ray technology into current demining methods could boost the effectiveness of landmine clearing operations internationally, adding to the decrease of landmine-related mortality.

IAEA-CN-332/115

Gamma Irradiation Technology Supports the Preservation of Tunisian Cultural Heritage

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The preservation of Tunisian cultural heritage using nuclear technology involves a comprehensive program that includes expertise for museums, field prospection, inventory of objects needing intervention, degradation assessment, scientific validation of irradiation protocols, and database establishment. Practical applications include the Habib Bourguiba Museum in Skanes, where five batches of furniture made of textile, wood, and glass affected by yeast, mold, and insects were treated with doses of 1-7 kGy. At the Douz Museum, eleven batches of dress carpets, animal skins, and blankets affected by insects receive doses of 7-9 kGy. The National Guard Tunisia's collection of police artifacts from 1957-1969, including leather hats and vests, undergoes treatment with doses of 2-5 kGy, with special care for mixed textile and leather vests. The National Military Museum involves prospection, inventory, and corrective actions for military artifacts. Najma Zahra Museum's 320 musical instruments, affected by high humidity, are categorized and treated in batches based on degradation levels.

The Tunisian National Library addresses old books and papers, optimizing irradiation protocols for contaminated materials with a 5 kGy dose evaluation. This program ensures the effective preservation of Tunisia's cultural heritage through tailored nuclear technology applications. Following each treatment, standardized irradiation protocols are developed.

Keywords: Tunisian cultural heritage, preservation, nuclear technology, expertise, field prospection, degradation assessment, irradiation protocols, artifact treatment, museum conservation.

IAEA-CN-332/231

Performance Assessment of a Crude Oil Distillation Unit Using Gamma Column Scanning Technique in Ghana

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The gamma column scanning technique is useful for assessing the internal condition of the trays in crude oil distillation units. The technique can be used to check for missing trays, collapsed or buckled trays without shutting down the entire processing unit for diagnosis. This saves cost and also reduces downtime required for maintenance by pinpointing the exact tray to be repaired. The scanning work was done at the Akwaaba oil refinery located at Spintex, Ghana. These were baseline scans of the primary tower and the packed tower. They were done before operation of the refinery commenced as part of the regulatory requirements. Subsequent scans are scheduled to assess the operational efficiency of the scanned columns.

The work was done with a 50 mCi Cesium-137 (Cs) gamma source, NaI(TI) scintillation detector, winches, ColScan data acquisition system with NibraS software. Using the engineering drawing of each of the columns, appropriate scan lines were selected with the Cs-137 source and NaI detector diametrically opposite. The scans were started at the top of each column, marked as 0mm, and gradually lowered to the base of each column, with step changes of 50mm and acquisition time of 10 seconds for each position.

The resulting scan profiles showed that all trays were in their correct positions, and this was expected as these were baseline scans. These scans will be the basis for comparison and diagnosis of the two columns, after the next scheduled scans, also to be presented.

IAEA-CN-332/424

Degradation and Reduction of Toxicity of Individual and Mixed Emerging Organic Pollutants

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Emerging organic pollutants pose significant concern due to their increasing presence in household and industrial effluents. The impact of nuclear techniques was investigated on four drugs (atenolol, carbamazepine, methylparaben, and sildenafil citrate), both individually and in combination dissolved in water (50 ppm), using electron beams (1-4 kGy – 1.4 MeV, 37.5 kW). Physical-chemical and toxicity parameters were analyzed. The results indicated minimal changes in pH, dissolved oxygen, conductivity, and TOC, but substantial reduction in UV-Vis absorption. Peak area comparisons demonstrated over 90% reduction in all compounds with a 2 kGy dose.

Toxicological assessments using Daphnia similis and Vibrio fischeri indicated methylparaben and sildenafil citrate as the most toxic compounds. In V. fischeri, methylparaben toxicity decreased with 4 kGy, whereas sildenafil citrate toxicity remained unchanged. Conversely, in D. similis, irradiation increased toxicity of carbamazepine, methylparaben, and sildenafil citrate at 2 kGy. However, irradiation of a mixture of methylparaben and sildenafil citrate (50 and 100 ppm) with doses ranging from 1 to 4 kGy significantly reduced toxicity in V. fischeri.

These findings highlight the potential of ionizing radiation treatments for integrating into effluent treatment plants to eliminate micropollutants effectively.

IAEA-CN-332/369

Studying the Effects of Gamma Radiation for Disinfection Purposes of Cellulosic Cultural Heritage: Innovative Measurements on a Pharaonic Object Belonging to the First Dynasty

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Wood, as a natural organic material, is susceptible to biodeterioration by insects, fungi, and bacteria. Microorganisms' secretions can considerably degrade wooden objects, resulting in a significant loss of their polysaccharidic components. As ancient wooden artifacts are invaluable, their appropriate restoration is of particular importance. The first step in restoration is the detection and quantification of wood pests and their phases; accordingly, the disinfestation of ancient wooden artifacts could be needed. Besides disinfestation prior to restoration, sterilization of wood is applied after restoration to extend the resistance of wood against the recovery of wood-destroying organisms. For both purposes, gamma radiation is considered a suitable decontamination method.

In this work, the King Den funerary boat, the oldest one ever found in Egypt, was studied to identify its wooden species and its biodeterioration status, then to set a sustainable preservation strategy. For this purpose, minute wooden samples were subjected to different analyses. Synchrotron radiation-based microtomography (SR-µ CT) was used to identify the wood species as a carob tree. SR-based X-ray diffraction technique (SR-XRD) and Fourier transform infrared (µ-FT-IR) spectroscopy indicated the presence of brown-rot and white-rot fungi causing chemo-physical modifications of the main wood polysaccharidic components. In parallel with these results, full microbiological tests were performed to identify the most frequently isolated species, which were Aspergillus Niger and Aspergillus Flavus. A set of standard wood replicas infected by the indicated species were subjected to different energies of gamma radiation (from 2 to 20 K Gy) to study their power as disinfection tools and the effects of higher irradiation energies on the chemical structure and consequently the mechanical properties of treated wood.

Gamma radiation proved to be a strong disinfection tool for the mentioned fungal species at 12 K Gy, no observed changes in the wood color or mechanical properties were recorded except in the case of 20 K Gy. This truth was confirmed by the results of SR-µ FTIR, which was used to study the effect of gamma irradiation at different energies on the chemical transformations of the treated wood. The promising results gave us a deep insight into the degradation state of the object as well as the identity of the microbial attacks, guiding the strategy of conservation and preservation of such wooden objects using gamma radiation as a powerful and safe tool for treatment.

IAEA-CN-332/515

Lithium Fluoride Photofluorescent Film Dosimeter: New Investigations for Phytosanitary Irradiation Application

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Two decades ago there were significant efforts to develop and characterize a new dosimeter for the radiation processing industry that utilized the fluorescence signal emitted from microcrystals of lithium-fluoride (LiF) within a polyethylene matrix. For this dosimeter technology, fluorescence emissions in both the visible and infrared regions of the spectrum are induced with bright blue light. This present work focuses on comparing the performance properties of the red emission of this technology, for low-energy X-ray and high-energy electron beam (E-beam), for phytosanitary purposes. An old batch of the "Sunna" version of the film was used, which has a useable dose range of approximately 0.1-150 kGy. Using the red-sensitive Innolabor fluorimeter, the dose response curve showed a nonlinear correlation for both radiation types, and with a significantly different sensitivity. A post-irradiation growth of signal was measured for the dosimeter for doses of 0.5 kGy and 2.0 kGy for the 100 keV X-rays, which stabilized after approximately 3.5 hours. The data shows that the signal remained stable until one month after irradiation. More testing of the technology is planned for phytosanitary applications – in particular for low-energy photons and electrons – to determine which of the green, red or infrared fluorescent signals performs best.

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Gamma induced effect on the structural and magnetic properties of rare earth doped cobalt ferrite

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Rare earth doped cobalt ferrites have been widely used in different applications include biotechnology, catalysis, magnetic drug delivery, solar cell, recording devices, water treatment, and sensors due to its unique properties especially magnetic properties. In this work, rare earth doped cobalt ferrite was prepared by coprecipitation method. ultraviolet–visible (UV–VIS) spectrophotometry, Transmission electron spectroscopy (TEM), and X-ray diffraction (XRD) were performed to assure that the samples have been prepared in single-phase structure. The prime focus of this research is to study the impact of γ-irradiation at a certain dose on the structural and magnetic characteristics. The γ-irradiations demonstrate a great influence on optical bandgap energy that illustrated by (UV–VIS) spectrophotometry data using Tauc polt equation. The saturation magnetization (Ms) increases at low γ-dose and decreases at high γ-dose.

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Evaluating and Repairing Earthquake Damage in Aleppo: The Role of Non-Destructive Testing

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Following the devastating earthquakes in Syria in 2023, the Syrian Engineers' Association -Aleppo Branch spearheaded a series of Non-Destructive Testing (NDT) activities to assess and address structural damages. The immediate response involved the formation of inspection committees to evaluate buildings, using visual inspections and initial classifications of damage severity. Subsequent stages incorporated more advanced NDT techniques, facilitated by equipment provided by international organizations such as IAEA. Special attention was given to cultural heritage sites in Aleppo, involving experts to ensure the preservation of historical structures.

Some examples are presented for inspecting, evaluating, NDT testing and preparing repair engineering studies for affected buildings to explain the complete cycle for proper response after the earthquake.

These efforts were critical in coordinating relief, ensuring safety, and planning for repairs and reconstruction.

E-POSTER PRESENTATIONS

IAEA-CN-332/027

The use of combined synchrotron radiation FT-IR and XRF for the characterization of Roman Wall paintings from Bayt Ras tomb, Jordan

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The modern-day Bayt Ras in the north of Jordan stands on the ruins of the ancient Roman city of Capitolias, one of the ten cities in the Decapolis League, which was founded by Pliny the Elder during the Hellenistic age. Archaeological research suggests that the city was established at the end of the 1st century AD, as indicated by coins minted by the city. The tomb features dozens of frescoes that depict details of daily life not often mentioned in historical records.

In this project, we invistigate the composition of the pigments and binding materials used in the wall paintings by carrying out combined synchrotron radiation analysis; FT-IR and XRF techniques. The analysis was performed on selected fragments that were detached from the tomb walls and were not suitable for restoration and relocation on the wall.

The first observation was that all the pigments are incorporated into a calcium carbonate matrix, serving as binding material for the pigments. Red and brown pigments were mainly composed of iron oxides, as revealed by the multiple analytical methods. Red ochre, consisting of iron oxides (Fe_2O_3 Hematite), is the main source of the red pigment. Black color, being carbon-based, can be easily detected by Raman spectroscopy. The green pigment is a more complicated case. Most likely, the pigment is "green earth" (containing Al_2O_3 and Fe_2O_3) as it is the most common green pigment used in the Roman Empire.

IAEA-CN-332/246

Application of Radiation and Technology in Environmental Studies in Uganda

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Here are some possible applications of radiation in environmental studies in Uganda:

1. Radiation monitoring: Radiation monitoring is an essential aspect of environmental studies in Uganda. It involves measuring and assessing the levels of radiation in different environmental media such as air, water, soil, and food.
   This helps in identifying potential sources of radiation and evaluating their impact on the environment and human health.

2. Radioisotope techniques: Radioisotope techniques are commonly used in environmental studies to trace and track the movement of substances in the environment. Radioactive isotopes are introduced into the environment, and their behavior and distribution are monitored to understand processes such as water flow, sediment transport, and pollutant movement. These techniques provide valuable information for managing and protecting the environment.

3. Environmental radioactivity assessment: Radiation is used to assess the levels of natural and artificial radioactivity in the environment. This includes measuring the concentrations of radionuclides in soil, water, plants, and animals. These assessments help in understanding the baseline levels of radioactivity in different regions of Uganda and identifying any potential sources of contamination.

4. Radiation dosimetry: Dosimetry is the measurement and assessment of radiation doses received by individuals or populations. In environmental studies, dosimetry is used to estimate the radiation exposure of people living or working in areas with potential radiation sources.

This information is crucial for evaluating the potential health risks associated with radiation exposure and implementing appropriate protective measures.

1. Environmental impact assessment: Radiation is also used in environmental impact assessments to evaluate the potential effects of human activities on the environment. For example, in the case of mining or nuclear power plant projects, radiation assessments are conducted to determine the potential release of radioactive materials and their impact on the surrounding environment.

2. Radiological emergency preparedness: Radiation is an important consideration in emergency preparedness and response planning for radiological incidents or accidents. Environmental studies in Uganda may involve assessing the preparedness of emergency response systems, evaluating the effectiveness of evacuation plans, and conducting simulations to understand the potential consequences of radiological incidents.

It is important to note that the specific applications of radiation in environmental studies in Uganda may vary depending on the research objectives, available resources, and regulatory frameworks. The information provided here is based on general knowledge and may not reflect the specific practices and research activities in Uganda.

IAEA-CN-332/277

Determination of lethal doses of gamma radiation for pupa of Plutella xylostella (Linnaeus, 1758) (Lepidoptera: Plutellidae) diamondback moth for phytosanitary treatment.

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Tropical and subtropical countries such as Brazil are the ones that suffer most under the attack of insects, due to the ecological conditions of high temperature and relative humidity. The diamondback moth, Plutella xylostella is one of the most serious pests of cultivated Brassicaceae. It is cited as being the first crop insect to become resistant to dichloro-diphenyl-trichloroethane (DDT), and it has been found to have developed resistance to many other field insecticides, it is also reported to be the first insect to develop resistance to the bacterial insecticide Bacillus thuringiensis. The objective was determine the lethal doses of gamma radiation for pupa of Plutella xylostella and establish an appropriate phytosanitary irradiation treatment against this pest. Pupa irradiation: for each treatment were used 5 repetitions with 10 pupa each, in total of 50 pupa of 6 days old per treatment. They were irradiated in a Petri dish with measuring 2.5 cm in height and 10.0 cm in diameter. The doses of gamma radiation used were: 0 (control), 25, 50, 75, 100, 125, 150, 200, 250, 300, 350, 400 e 500 Gy. Were irradiated in a Cobalt-60 source, type Gammacell 220, with dose rate of 0,876 kGy/hour. After irradiation they were in a climatized chamber with temperature around 28±2 °C, relative humidity 70±5% and a photoperiod of 12 hours. By the results we can conclude that the sterilizing and lethal doses to pupae were 300 and 500 Gy. Therefore, the recommended dose for phytosanitary treatment of pupae of P. xylostella is 500 Gy.

IAEA-CN-332/278

Irradiation processing impact on microbiological quality of Hermetia illucens larvae meal contaminated with different pathogens

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Edible insects have been widely used in animal feed and their inclusion in diets is justified by their excellent nutritional value, being proposed as a high-quality, sustainable, and efficient protein source. However, the quality of raw materials is as important as their efficiency and it can be altered by the presence of biological contaminants. Additionally, larvae chemical composition of some species can be modified through their diet and this alteration offers great potential for developing formulas that more objectively meet the nutritional needs of animals, aligning with the modern agricultural concept of precision nutrition. In this regard, one of the most effective methods to ensure the safety of foods and raw materials is the prevention of contamination and the concept of treatment through irradiation is already widely applied in the food industry, aiming to control or eliminate living organisms such as fungi and bacteria. This concept becomes even more important when part of the raw materials used in the production of these foods comes from insects that may be fed organic waste. From this perspective, this study will aim at evaluating the mycological and bacteriological effects of the treatment of Hermetia illucens larvae meal contaminated with pathogenic fungi such as Fusarium spp., Aspergillus spp. and Penicillium spp. and bacteria such as total coliforms, coliforms at 45 ºC, Escherichia coli and Salmonella spp. using gamma irradiation at doses of 5 kGy, 7.5 kGy and 10 kGy. The results will be compared with the standards of current legislation, investigating the effectiveness in inactivating those microorganisms at the tested doses and the optimal dose achieved will be determined. Therefore, the results obtained will pave the way for the safe supply of customized food ingredients that can meet the modern concept of precision nutrition.

IAEA-CN-332/466

Planned Destruction of PFAS in Soils and Sediments using a Mobile Electron Beam Technology Platform

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Since the 1970s, aqueous film-forming foams (AFFFs) have been used at U.S. Department of Defense (DOD) installations for firefighter training and emergency response. Per- and polyfluoroalkyl substances (PFAS) used as active ingredients in AFFF have impacted underlying soil and groundwater. Other than offsite incineration as the remediation technology, very few destructive treatment technologies are currently available to treat PFAS in soil and sediments. We are proposing a compact mobile electron beam (eBeam) technology platform for demonstrating effective and innovative PFAS destructive technology. The overall goal is to design, fabricate, integrate, and demonstrate a prototype mobile eBeam technology platform. The mobile system will be designed to focus on solids and slurries, and liquids. The mobile system will be designed with all the necessary critical safety requirements including shielding and ozone abatement. The accelerator energy will allow for self-shielding with the beam power optimized to meet the target throughput of up to one drum of PFAS-impacted solids per day. The mobile platform's weight will be configured to meet the US Department of Transportation (DOT) requirements. The electrical power source will designed to support both grid power and electrical generators. The mobile platform will be designed to operate indoors or outdoors. The presentation will discuss the accelerator, shielding, and material handling system.

IAEA-CN-332/580

Specialist International Group (SIG) on NDT in civil engineering (NDT-CE) at ICNDT (International Committee for NDT)

C. Belinco (CNEA), S. Laprida (AAENDE - CEND) – Argentina

The ICNDT Specialist International Group on NDT in civil engineering was created at ICNDT during the ECNDT (European Conference on NDT) in Portugal, July 2023. It was decided that AAENDE (Argentina) will lead the group.

Since that, several meetings (virtual and in person) were done.

As a result three main sub- groups were created: SG 1 NDT-CE Standardization; SG 2 NDT-CE Applications and SG 3 NDT-CE Emerging Technologies.

The sub-group NDT CE Standardization includes the developing of standards for the executions of different methods, new technologies, etc.; and the standards for training people and certification as Level 1, 2 or 3 for those methods. That include the documentation related with training for each method.

The sub-group NDT CE Standardization includes the developing of standards for the executions of each known different methods, new technologies, etc.; and the standards for training people and certification as Level 1, 2 or 3 for those methods.

The sub-group NDT CE Applications will treat with the application of the different NDT-CE methods in the typical constructions or structures of the Civil Engineering. The task to perform, is to develop guidelines and related documentation about the use of different NDT techniques in conventional and heritage buildings and constructions, civil infrastructure, or industrial facilities. The intention of the documents to be develop will be to help with the selection and use of the correct method to obtain the information required by the architects, civil and structural engineers, users or owners of the in-study construction or structure. Typical applications are the quality control of in progress constructions, or in the repair of structures and building; the investigation of structural ability or integrity in case of deterioration or corrosion, change of use or enlarging; durability aspects; and specially in case of the of damage situation. The last case is critical in case of pre and post disaster intervention, such earthquakes, floodings, volcanoes; or those due to human interventions, such wars or industrial accidents.

IAEA-CN-332/635

ARG1029 Advanced Training in Radiation Processing: Electron beam Applications in Polymer Modification, Sterilization, and Functional Material Synthesis

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As part of the TC project ARG1029, which aims to introduce electron beam technology in Argentina, a training program was conducted. The activities were held at the University of Maryland (Department of Materials Science and Engineering), and provided extensive knowledge and practical skills into electron beam processing, emphasizing its potential applications in various fields, such as obtaining functional materials, polymer modification, and sterilization of medical devices. The program included an in-depth study of the effects of gamma rays and electron beams on polymeric materials, alongside mechanical, physical, and chemical characterization techniques (such as EPR, DSC, FTIR). The National Institute of Standards and Technology was visited, and practical sessions on electron beam dosimetry, as well as irradiation experiments under various atmospheric conditions, were conducted.

Further, numerous lectures were conducted covering radiation chemistry of polymers, mechanisms and characterization of electron-induced grafting, the role of antioxidants, and the identification of radiolytically produced free radicals using electron spin resonance spectroscopy. Additionally, the training explored the radiation synthesis of advanced materials through graft polymerization.

In conclusion, this training provided essential knowledge and practical experience in the application of radiation processing using electron beam sources. The skills and insights gained will aid in the development of functionalized materials and promote the industrial application of electron beam accelerators for environmental and industrial purposes in Argentina.

IAEA-CN-332/738

Effects of Doping- Rare Earth and High Energy Irradiation on Silicon Carbide in Nuclear and Advanced Application

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The progress in SMR technology and accidental tolerance capable TRISO TRi-structural ISOtropic fuel, designed for high-temperature reactors, includes multiple layers that encapsulate the fissile material. The termost layer, typically made of SiC, acts as the primary barrier against the release of fission products. A highly explored area for optimizing commercial nuclear fuel efficiency is managing the Kr/Xe fission gas budget, as these gases act as time limiters due to thermal fission gas swelling or nucleating high swelling behaviour (HSB) structures' expansion. This investigates the potential benefits of doping this SiC layer with rare earth elements to improve its performance within the TRISO fuel structure as well as for long storage -stability. An alternative approach involves introducing these gases along with other reactive evaporation products such as H, He, Sr, and Li into the grain or sub-grain. This is done to form the HSB or rim structures, followed by MeV Ar+ high energy irradiation. Such studies are critical for better understanding the behaviour of SiC and SiC(x)ReO(x-1) under these conditions. Pre-irradiation and post-irradiation examination are understood and studied via characterization techniques like RBS, FESEM, XRD and TEM techniques.