ICARST 2017

International Conference on Applications of Radiation Science and Technology (ICARST-2017)

Programme and Abstracts

IAEA Headquarters | Vienna, Austria

24–28 April 2017

IAEA
International Atomic Energy Agency
Atoms for Peace

IAEA-CN-249

Organized by the:

IAEA

60 Years

Atoms for Peace and Development

International Conference on

Applications of Radiation Science and Technology

24–28 April, 2017

Vienna, Austria

Programme & Book of Abstracts

Version: July 7, 2017, web enabled

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Colophon

This book has been assembled from the abstract sources submitted by the contributing authors via the Indico conference management platform. Layout, editing, and typesetting of the book, including customized TEX & LATEX macros, was done by Dr. P. Knowles, LogrusData, Vienna, Austria. The font is TeX Gyre Pagella, a decendent of Hermann Zapf's Palatino.

This book is PDF hyperlinked: activating coloured text will, in general, move you throughout the book, or link to external resources on the web.

Introduction

The saga of the radiation sciences goes back to the astonishing discoveries by Röntgen and the Curies at the turn of the twentieth century. Driven initially by the quest to comprehend the complex effects of radiation fields on chemical processes, radiation chemistry, in particular, has emerged as a valuable tool for understanding the intricate chemical reactions of importance to a variety of disciplines. It has also found wide-ranging commercial applications in such areas as materials processing, health care, food and agriculture. While the development of ultrafast techniques such as pulse radiolysis has allowed for the exploration of important chemical processes, the simultaneous technological development of high intensity gamma radiation sources and high powered electron beam accelerators has assured the radiation sciences' ongoing tryst with industry, leading to the successful commercial utilization of many of the applications developed by scientists and researchers. The International Atomic Energy Agency (IAEA), working in close partnership with its Member States as well as with professional scientific bodies and the industry, has striven to maximize the contribution of radiation sciences and technologies towards the achievement of the Member States' development priorities in a safe manner.

While acknowledging the many innovations and accomplishments achieved in the field of radiation sciences so far, it is now time to take a comprehensive look at their status in academia and industry in the years ahead and their ability to meet the challenges of contemporary times. Radiation scientists are currently engaged in addressing issues related to producing advanced high performance materials through "green" industrial processes ensuring cleaner environment, attaining a thorough understanding of the chemical effects of radiation under extreme conditions (which is important for extending the lifetime of present nuclear reactors, making their fuel cycles safer and secure to operate), and overcoming impediments regarding the transportation and storage of waste materials (which requires novel approaches to address the complicated chemistry at interfaces). Radiation technologists on the other hand are faced with such tremendous challenges as ensuring the safe and reliable operation of large radiation facilities, implementing requisite international standards for process control, ensuring the continued supply and transport of large ^{60}Co consignments across continents, and developing a new generation of high power electron beam accelerators and X-ray sources for emerging applications. Besides radiation processing applications, there are other radiation technologies such as the use of radiotracers to improve and optimize the performance of industrial processes, as well as to study environmental processes, and the use of nucleonic measurement systems to control the quality of products.

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Sung-Hee Jung	Korea, Republic of
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Paul Livolsi	France
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✠Names are listed alphabetically in each section.

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✠Names are listed alphabetically in each section.

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Natesan Ramamoorthy	India
Masao Tamada	Japan
Seungho Yu	Republic of Korea

✠Names are listed alphabetically in each section.

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Exhibits

Exhibits will be located in M–Building, on floors M0E and M01, and the Rotunda. Participants are encouraged to view the exhibits during the hosted coffee breaks. The following organizations and companies will have information stands during the conference.

- CGN Dasheng Electron Accelerator Technology Co. Ltd.
- National Association for Advancement of Radioisotopes and Radiation in Industry (NAARRI)
- China Isotope & Radiation Corporation (CIRC)
- IBA Industrial
- World Council on Isotopes (WCI)
- Baltic Scientific Instruments (BSI)
- EB Tech Co. Ltd.
- Gamma Service Group
- International Source of Suppliers and Producers Association (ISSPA)
- Nuctech Co. Ltd.
- Canberra Packard Central Europe GmbH
- Flir Systems, GmbH
- Institute of Isotopes Co. Ltd. (IZOTOP)
- Shimadzu HandelsgesmbH
- Wuxi EL PONT Radiation Technology Co. Ltd.
- Aérial
- Atomtex
- JSC Isotope
- Meet Instruments GmbH
- Mirion Technologies
- SI Detection
- Sterigenics
- Steris AST
- UAB Polimaster Europe
- Vanform Corporation

Exhibits (continued)

- CEA-INSTN
- VWR International GmbH
- Dozimetrs Ltd.
- Berthold Technologies GmbH
- Best Theratronics
- Budker Institute of Nuclear Physics
- F&J Speciality Products
- Harwell Dosimeters Ltd.
- Beijing SanQiangHeLi Radiation Engineering Technology (SQHL)
- Elysia-Raytest GmbH
- Fraunhofer FEP
- Gamma Technical Corperation
- GC Technology GmbH
- Institute of Nuclear Chemistry and Technology (INCT)
- International Irradiation Association (IIA)
- Nordion
- Pacific Northwest National Laboratory (PNNL)
- Texas A&M AgriLife Research
- World Nuclear Association/World Nuclear University
- ZRF RITEC SIA

Representatives from MEVEX and Comissão Nacional De Energia Nuclear (CNEN-IPEN) will also be at ICARST.

The fact that the IAEA has provided facilities for exhibiting equipment and products at the conference does not imply that it endorses the equipment and products.

Working Language & Resolutions

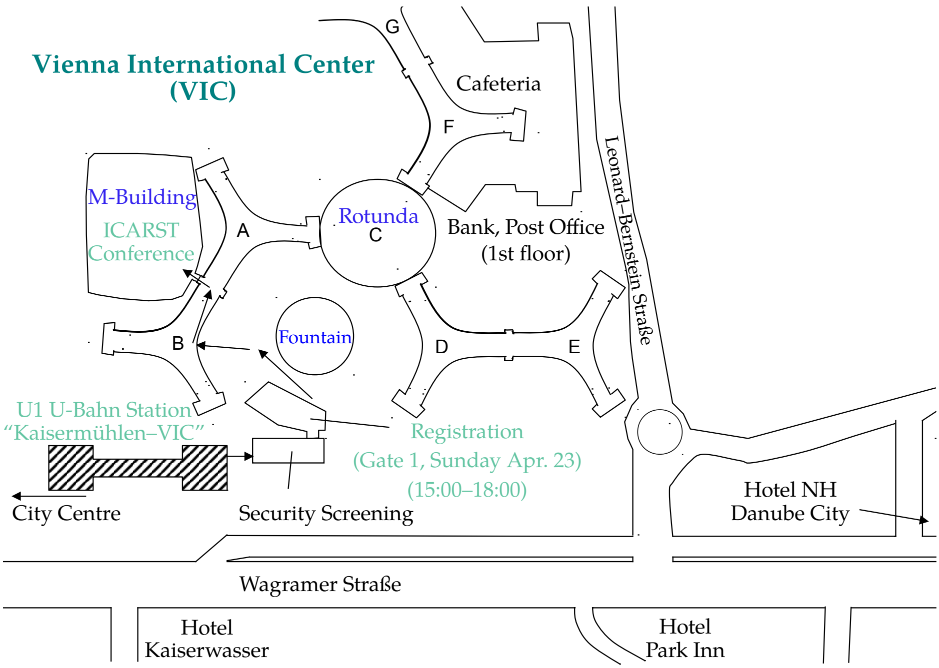
Working Language: English. No simultaneous interpretation will be provided.

Resolutions: No resolutions may be submitted for consideration on any subject; no votes will be taken.

Conference Location

International Atomic Energy Agency (IAEA)
Wagramer Str. 5, 1220 Vienna, Austria

M–Building Conference Rooms: M01 (First Floor) Board Room B/M1
Room M2



Wireless Internet

Public access WiFi is available throughout the IAEA buildings. Select access point WLAN-GUEST and the connection will be automatic: there is no password.

Hosted Coffee Breaks

There will be complimentary mid-morning and afternoon refreshments which have been funded using the voluntary contributions from those exhibitors acknowledged in the last few pages. Participants are encouraged during these breaks to not only enjoy the refreshments but to profit from the posters and exhibition stands displayed on M–Building floors M0E and M01, and in the C–Building ground floor Rotunda.

Refreshments, snacks and lunch can be purchased either from the VIC Cafeteria and Restaurant on the ground floor of the F–building, or from the coffee corners located on the M–Building ground floor or 7th floor of the C–Building.

Conference Proceedings

The Conference Proceedings containing selected original contributions will be published as a special issue of Nukleonika, an open access journal with special rates for ICARST. The best 30 peer-reviewed manuscripts will be selected for publication according to the journal's criteria.

Participants are encouraged to submit their contribution together with the statement of originality of the work in electronic format to the Guest Editor, Mr Natesan Ramamoorthy, (nramasta@gmail.com). The submission deadline is April 14th 2017. Instructions for manuscript preparation can be found on the ICARST website.

Posters

All posters will be displayed for the full duration of the conference on the ground floor of the M–Building and in the A–Building concourse. Authors are asked to be available at their posters for discussions with interested participants according to their assigned poster session (Wednesday or Thursday, 14:15–16:15). Participants are also encouraged to view the posters during the hosted coffee breaks.

Book of Abstracts

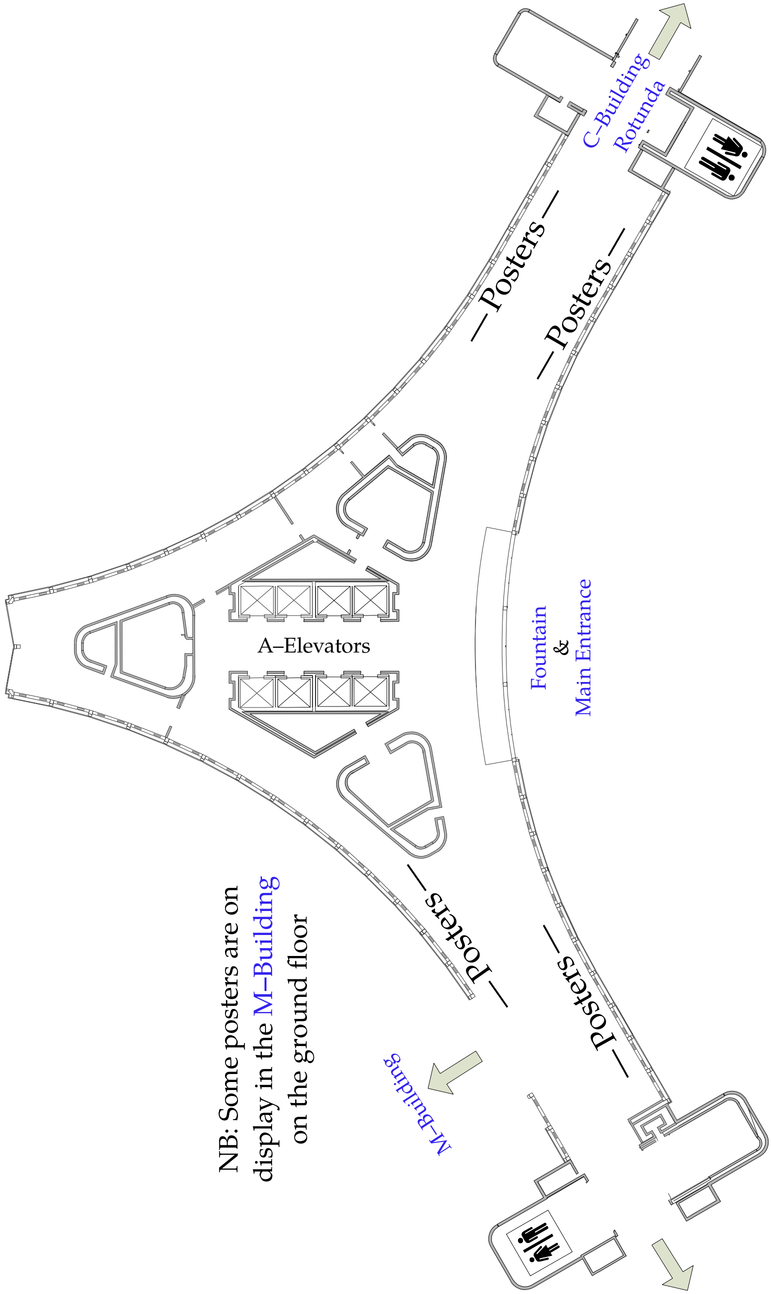
This book contains all contributions and abstracts to be presented at the conference. Abstracts have been edited for IAEA style uniformity. The views expressed remain the responsibility of the named authors. No responsibility is held by the organizers for any material reproduced, or linked, in this book.

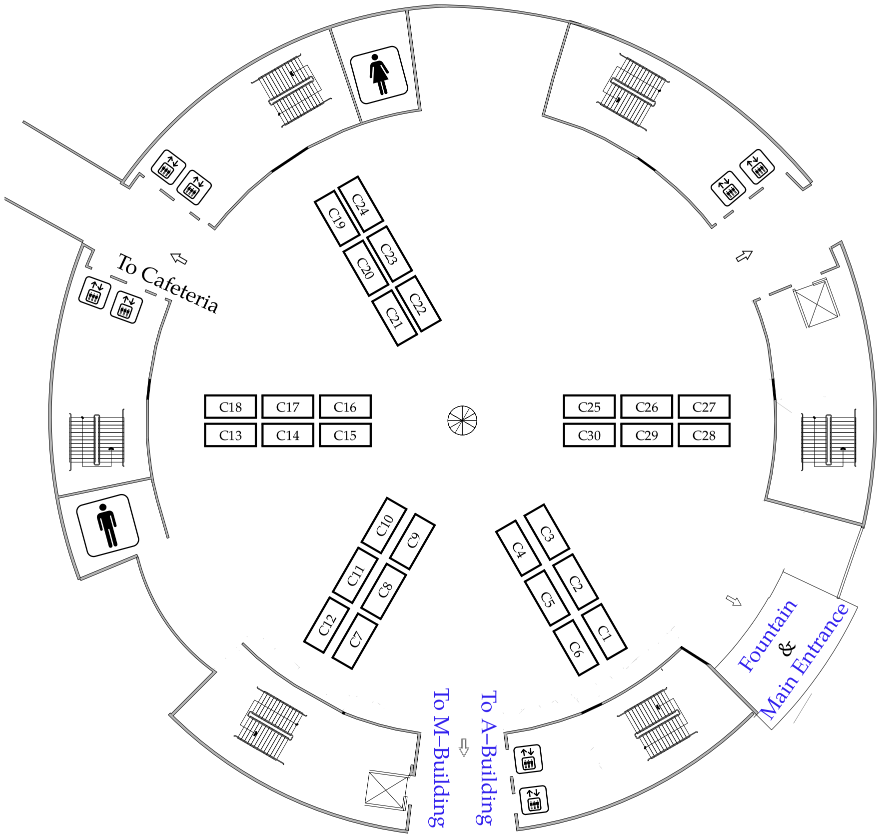
Abbreviations

AAEA	Arab Atomic Energy Agency
CFD	Computational Fluid Dynamics
CL	Closing Session
E&T	Education and Training
EB	Electron Beam
EC	European Commission
ENEN	European Nuclear Education Network
EU	European Union
IAEA	International Atomic Energy Agency
ISTRA	International Society of Tracers and Radiation Applications
KAERI	Korea Atomic Energy Research Institute
NAA	Neutron Activation Analysis
OECD	Organisation for Economic Co-operation and Development
OECD/NEA	Organisation for Economic Co-operation and Development/Nuclear Energy Agency
OP	Opening Session
RPT	Radioactive Particle Tracking
TSec	Technical Secretary


— Posters —
M1
M1: CGN Dasheng Electron Accelerator Technology Co. Ltd.
M0E 68 Briefing
M0E 67 Office
Snack Bar
Cloak Room
Registration & Information
A–Building & Rotunda

A–Building, VIC

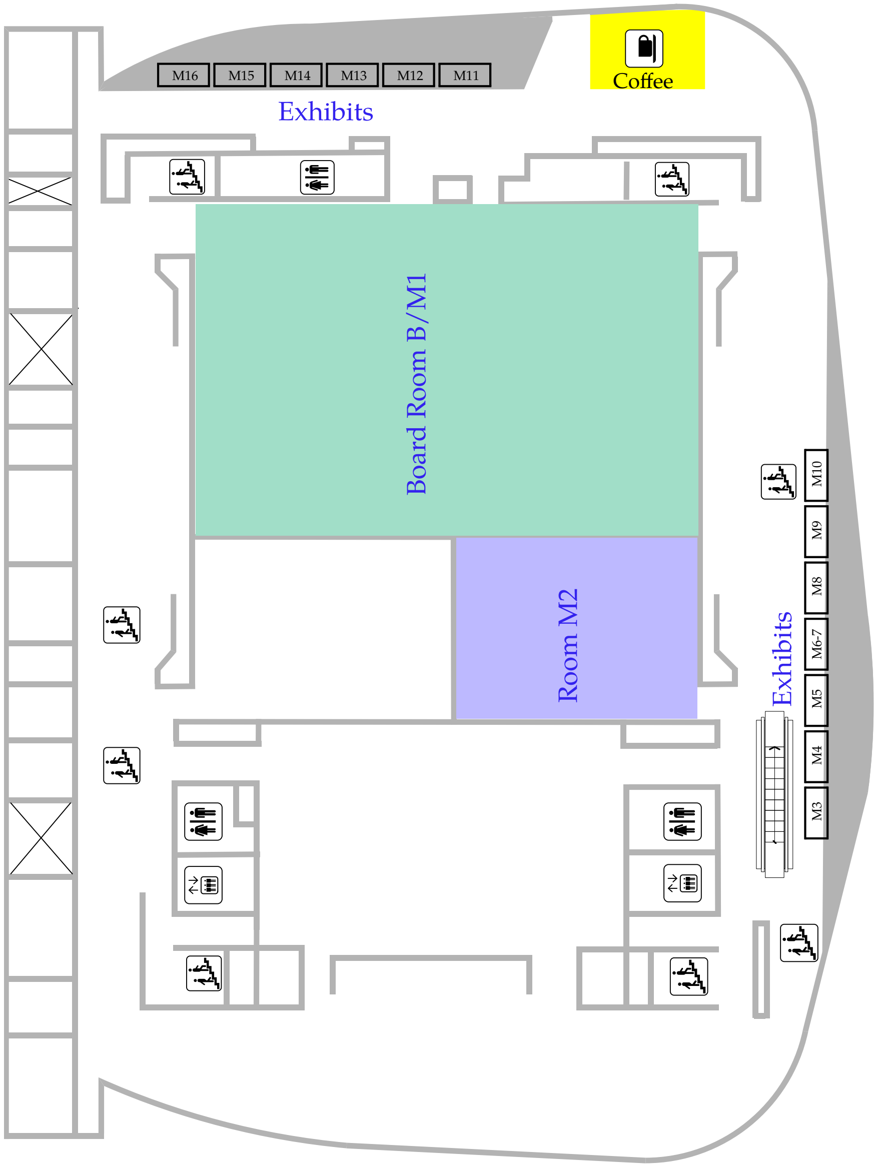




C1: Aérial
C2: Mirion Technologies & CANBERRA PACKARD Central Europe GmbH
C3: UAB Polimaster
C4: Atomtex & Meet Instruments GmbH
C5: Baltic Scientific Instruments (BSI)
C6: Texas A&M Agrilife
C7: Berthold Technologies GmbH
C8: Nordion
C9: SI Detection
C10: Pacific Northwest National Laboratory (PNNL)
C11: Fraunhofer FEP
C12: Elysia-raytest GmbH
C13: ZRF RITEC SIA
C14: International Irradiation Association (IIA)
C15: World Nuclear Association/World Nuclear University
C16: Shimadzu HandelsgesmbH
C17: Vanform Corporation
C18: STERIS AST
C19: JSC Isotope
C20: Wuxi EL PONT Radiation Technology Co. Ltd.
C21: Nuctech Co. Ltd.
C22: Beijing SanQiangHeLi Radiation Engineering Technology (SQHL)
C23: STERIGENICS
C24: Harwell Dosimeters Ltd.
C25: Best Theratronics
C26: F&J Specialty Products Inc.
C27: Budker Institute of Nuclear Physics
C28: CEA-INSTN
C29: VWR International GmbH
C30: Dozimetrs Ltd.

M–Building, M01 (First Floor)

M3: EB Tech Co. Ltd.
M4: ISSPA
M5: IBA Industrials
M6-7: NAARRI
M8: China Isotope & Radiation Corp. (CIRC)
M9: World Council on Isotopes
M10: International Atomic Energy Agency
M11: Gamma Service Group
M12: GC Technology GmbH
M13: Inst. Nucl. Chem. & Tech. (INCT)
M14: Gamma Technical Corporation
M15: Flir Systems GmbH
M16: Institute of Isotopes Co. Ltd. (IZOTOP)



Day Date	Monday Apr. 24, 2017	Tuesday Apr. 25, 2017	Wednesday Apr. 26, 2017	Thursday Apr. 27, 2017	Friday Apr. 28, 2017
09:00 — 11:00	08:00 Registration 10:00 Opening OP	Parallel Sessions A04 B04	Parallel Sessions A08 B08	Parallel Sessions A11 B11	Parallel Sessions A14 B15
	Coffee break, Posters and Exhibits				
11:15 — 13:15	Parallel Sessions A01 B01	Parallel Sessions A05 B05	Parallel Sessions A09 B09	Parallel Sessions A12 B12	Parallel Sessions A15 B16
	Lunch break: 13:15–14:15				
14:15 — 16:15	Parallel Sessions A02 B02	Parallel Sessions A06 B06	Poster Sessions PA1 PB	Parallel Sessions PA2 B13	14:15 Closing CL
	Coffee break, Posters and Exhibits				
16:30 — 18:30	Parallel Sessions A03 B03	Parallel Sessions A07 B07	Parallel Sessions A10 B10	Parallel Sessions A13 B14	
18:30 — 20:00	Welcome Reception	S01 Chinese Mission Side Event	S02 ISTRA Side Event		

REG 08:00–16:00 Conference Registration

Venue: *Entrance M–Building*

OP 10:00–11:00 Opening Plenary

Venue: *Board Room B/M1*

Time	Id	Presenter		
10:00	OP-01	Y. Amano	IAEA	Opening Remarks
10:10	OP-02	A. Malavasi	IAEA	Welcome by DDG-NA
10:20	OP-03	D. Yang	IAEA	Welcome by DDG-TC
10:30	OP-04	A. G. Chmielewski	Poland	Ionizing Radiation: Innovative and Effective Tool for Science and Industry

Coffee break: 11:00–11:15

A01 11:15–13:15 Trends in Radiation Science and Technology

Venue: *Board Room B/M1*

Chair: **Natesan Ramamoorthy (India)**

TSec: João Alberto Osso Júnior (IAEA)

Time	Id	Presenter		
11:15	A01-01	P. Ulański	Poland	Radiation Synthesis of Polymer Nanogels for Biomedical Applications
11:35	A01-02	L. Shen	China, P. R.	Status and Prospect of Application of Radiation Science and Technology in China: A National Report
11:55	A01-03	B. Croonenborghs	USA	Emerging Areas of Radiation Sterilization
12:15	A01-04	L. V. Abad	Philippines	Radiation-Modified Carrageenan as Plant Food Supplement: Making a Breakthrough with Philippine Farmers
12:35	A01-05	J. Wishart	USA	Recent Progress in Pulse Radiolysis Detection Methods and their Application to Ionic Liquid-Based Systems for Closing the Nuclear Fuel Cycle
12:55	A01-06	P. Vasquez	Brazil	Overview of Disinfection of Cultural Heritage Artefacts and Archive Materials by Ionizing Radiation in Brazil: Culture Meets Nuclear

Lunch break: 13:15–14:15

B01 11:15–13:15 Advances and Trends in Radiotracer and Radiation Science and Technology I

Venue: *Room M2*
Chair: **Tor Bjørnstad (Norway)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
11:15	B01-01	Q. Nguyen Huu	Viet Nam	Improved Procedures for Preparation of Argon-41 Gaseous Radiotracer from Solid Clathrate Compound
11:35	B01-02	L. Kalo	India	Experimental Study of Conical Fluidized Bed Using Radioisotope Based Technique
11:55	B01-03	J. Phirani	India	Predicting Dead Pore-Volume of Pores in a Porous Media from Single Tracer Experiment
12:15	B01-04	S. Roy	India	Application of RPT and Densitometry for Measuring Liquid Velocity Field and Void Fraction in Convective Boiling Flows
12:35	B01-05	C. H. de Mesquita	Brazil	Holdup Analysis of a Bubble Column Using an Industrial Fourth Generation Like γ-Ray Tomography

— Discussion —

Lunch break: 13:15–14:15

A02 14:15–16:15 Advanced Polymeric Materials

Venue: *Board Room B/M1*
Chair: **Celina Horak (Argentina)**
TSec: Agnes Safrany (IAEA)

Time	Id	Presenter		
14:15	A02-01	O. Güven	Turkey	Past, Present and Near Future of Radiation Processing of Polymers
14:35	A02-02	X. Coqueret	France	Radiation Curing by Cross-Linking Polymerization of Multifunctional Monomers: A Comparison Between Free Radical and Cationic Mechanisms
14:55	A02-03	M. Lacroix	Canada	Use of Irradiation, for the Development of Active Edible Coatings, Beads and Packaging to Assure Food Safety and to Prolong Preservation
15:15	A02-04	Z. Ghazali	Malaysia	Radiation Grafted Antimicrobial Film for Advanced Active Packaging Application

Continued...

A02 *continued…*

Time	Id	Presenter		
15:35	A02-05	C. Vasile	Romania	Radiation Mediated Bioactive Compounds Immobilization on Polymers to Obtain Multifunctional Food Packaging Materials
15:55	A02-06	E. Hegazy	Egypt	Radiation Processing of Natural and Synthetic Polymers for Potential Applications

Coffee break: 16:15–16:30

B02 14:15–16:15 Education, Training and Safety

Venue: *Room M2*
Chair: **Thorsten B. O. Jentsch (Germany)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
14:15	B02-01	O. Potier	France	A New Approach to Teach Beginners How to Analyze Tracing Results by a Rapid Visual Method
14:35	B02-02	P. Livolsi	France	Education Training: INSTN Designated as an IAEA Collaborating Centre
14:55	B02-03	P. Brisset	IAEA	Training and Certification in Radiotracers and Sealed Sources Industrial Applications
15:15	B02-04	D. Telleria	IAEA	The IAEA Methodology for Radiological Protection of the Environment, Including Human and Non-Human Biota
15:35	B02-05	A. Mahjoub	Tunisia	Radiation Sciences and Applications Programme in Arab Countries
15:55	B02-06	S. A. Masinza	Kenya	Quality Management in Radiotracer Technology and Sealed Source Applications

Coffee break: 16:15–16:30

A03 16:30–18:30 Advances and Trends in Radiation Science and Technology

Venue: *Board Room B/M1*
Chair: **Xavier Coqueret (France)**
TSec: Agnes Safrany (IAEA)

Time	Id	Presenter		
16:30	A03-01	M. Zhai	China, P. R.	Novel Ion Exchange Membranes Synthesized by Radiation Grafting Technique for Application in Vanadium Redox Batteries
16:50	A03-02	J. Li	China, P. R.	Irradiation Induced Modification of Nanoporous Metal Organic Frameworks
17:10	A03-03	G. Burillo	Mexico	Synthesis of Amine-Containing Surfaces in Poly(Tetrafluoroethylene) by γ-Radiation
17:30	A03-04	Y. Kodama	Brazil	Polycarbonate Chromatography Column to Be Used in a ^{99}Mo/^{99m}Tc Generator Irradiated in Saline Solution with EB and γ-Rays
17:45	A03-05	G. Melilli	France	EB Irradiation on Piezo-PVDF: Beneficial Effect for Harvesting Energy Application
18:00	A03-06	J. Chen	China, P. R.	Co-Reduction Synthesis of Graphene/Au Nanocomposite from Graphene Oxide/Au^{3+} Solution upon γ-Irradiation
18:10	A03-07	N. A. F. Othman	Malaysia	An Improved Method of Producing Adsorbent for Metal Removal Using Radiation Induced Graft Polymerization
18:20	A03-08	V. Luo	China, P. R.	Fabric Modification by Radiation Methods

B03 16:30–18:30 Radiotracers for Industrial Processes Optimization and Safety I

Venue: *Room M2*
Chair: **Jovan Thereska (Albania)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
16:30	B03-01	R. Alami	Morocco	Study by Radiotracer of a Phosphoric Acid Production Line
16:45	B03-02	V. Yelgaonkar	India	Studying Flow Dynamics of Catalyst Powder in CCU for Troubleshooting
17:00	B03-03	H. A. Affum	Ghana	The Application of CFD for Modelling Flow and Visualization in a Cement Mill and Experimental RTD Validation Using Radiotracer Technology
17:15	B03-04	H. Ben Abdelouahed	Tunisia	Radiotracers for Pulp Flow Dynamics Study in Three Different Phosphoric Acid Reactors
17:30	B03-05	S. Sugiharto	Indonesia	Residence Time Distribution Study of Geothermal Vapour Flow in Pipe Using Axial Dispersion Modelling
17:45	B03-06	V. K. Sangal	India	Radiotracer Investigation of a Pulp and Paper Mill Effluent Treatment Plant

— ***Discussion*** —

18:30–20:00 Welcome Reception

Venue: *Rotunda*

Tue

A04 09:00–11:00 Radiation for Environmental Protection I

Venue: *Board Room B/M1*
Chair: **El-Sayed Hegazy (Egypt)**
TSec: Sunil Sabharwal (IAEA)

Time	Id	Presenter		
09:00	A04-01	E. Takács	Hungary	Ionizing Radiation Induced Decomposition of Antibiotics in Waste Water
09:20	A04-02	J. Wang	China, P. R.	Ionizing Irradiation-Induced Degradation of PPCPs in Aqueous Solution
09:40	A04-03	S. Pillai	USA	Efficacy of Electron Beam Irradiation to Address Emerging Microbial Contaminants in Water Reuse Programmes
10:00	A04-04	S. Borrely	Brazil	Toxicity Assays Applications for Assessing Acute Effects for Radiation Decomposition of Organics in Waters
10:20	A04-05	Y. Sun	Poland	Radiation Technology Application in Environmental Protection

— ***Discussion*** —

Coffee break: 11:00–11:15

B04 09:00–11:00 Mitigating Climate Change: Protecting Coast Line and Environment

Venue: *Room M2*
Chair: **Catherine Hughes (Australia)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
09:00	B04-01	C. Hughes	Australia	Radiotracer Methods for Understanding Contaminant Dynamics in Aquatic Environments
09:15	B04-02	D. Pham Van Bang	France	Nuclear Technologies Applied to Sediment Transport in River, Estuarine and Coastal Zones to Validate CFD Codes
09:30	B04-03	K. Bhar	India	Radiotracer Study to Investigate the Spatial Dispersion Pattern of Dredged Materials in Hooghly Estuary, West Bengal, India
09:45	B04-04	J. Vianna Bandeira	Brazil	Technetium-99m: From Nuclear Medicine Applications to Fine Sediment Transport Studies

Continued…

Tue

B04 *continued...*

Time	Id	Presenter		
10:00	B04-05	P. Brisset	IAEA	The Use of Nucleonic Gauge JTTX in the Port of Nantes Saint-Nazaire
10:15	B04-06	R. Suárez-Antola	Uruguay	Water Renewal in Montevideo's Bay II: A Compartmental Fractional Model for Tritium Kinetics
10:30	B04-07	A. Ioannidou	Greece	The Radiotracer ^{7}Be in Studying Environmental Processes

—Discussion—

Coffee break: 11:00–11:15

A05 11:15–13:15 Advances in Radiation Chemistry Research I

Venue: *Board Room B/M1*

Chair: **Olgun Güven (Turkey)**

TSec: Agnes Safrany (IAEA)

Time	Id	Presenter		
11:15	A05-01	L. Wojnárovits	Hungary	Basic Radical Reactions in Water Treatment by Ionizing Radiation
11:35	A05-02	M. Al-Sheikhly	USA	Synthesis of Novel Fabrics for Extraction of Uranium from Seawater
11:55	A05-03	M. Mostafavi	France	Ultrafast Electron Transfer Studied by Picosecond Pulse Radiolysis
12:15	A05-04	M.-C. Dubois-Clochard	France	Advances in Etched Ion-Track Polymer Membranes for Environmental and Microelectronic Applications
12:35	A05-05	S. Goldstein	Israel	Using Ionizing Radiation for Studying Radical Reactions with Nitroxides: Implications for their Biological Activity
12:55	A05-06	J. Barilla	Czech Republic	Influence of N_2O and Ethanol on the Chemical Stage of Radiobiological Mechanism
13:05	A05-07	K. Marzouki	Tunisia	EPR Characterization of γ-Irradiated Xerogels

Lunch break: 13:15–14:15

B05 11:15–13:15 Radiotracers for Energy of the Future I

Venue: *Room M2*
Chair: **Muthanna Al-Dahhan (USA)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
11:15	B05-01	M. Al-Dahhan	USA	Liquid Holdup Studies in a Co-current Gas-Liquid Upflow Moving Packed Bed Reactor with Porous Catalyst Using γ-Ray Densitometry
11:30	B05-02	V. Alexander	USA	Bed Expansion Studies in Upflow Moving Catalytic Packed/Expanded Bed Hydrotreating Reactor Using γ-Ray Densitometry
11:45	B05-03	A. Chandra	India	Radioactive Tracing of an Industrial Scale Continuous Pulp Digester
12:00	B05-04	D. Aquino	Philippines	Evaluating the Operating Conditions of a Rectifier Column Using γ-Column Scanning
12:15	B05-05	Q. Nguyen Huu	Viet Nam	γ-Scanning Technique as an Efficient Investigation Tool for Diagnostics and Troubleshooting in Industry: Case Studies
12:30	B05-06	C. P. K. Dagadu	Ghana	Validation of CFD Codes Using Radiotracer RTD Analysis of Stirred Vessels

— ***Discussion*** —

Lunch break: 13:15–14:15

A06 14:15–16:15 Dosimetry and Standards for Radiation Processing

Venue: *Board Room B/M1*
Chair: **Wilson A. P. Calvo (Brazil)**
TSec: Bum Soo Han (IAEA)

Time	Id	Presenter		
14:15	A06-01	A. Kovács	Hungary	Process Control Methods in Radiation Technologies
14:35	A06-02	M. Bailey	Denmark	Dosimetry and Process Control for Using Low Energy Electron Beams for Sterilization or Decontamination of Surfaces
14:55	A06-03	F. Kuntz	France	Is IQ/OQ/PQ Part of Irradiation Process Control?

Continued...

A06 *continued...*

Time	Id	Presenter		
15:15	A06-04	Y. Zhang	China, P. R.	Dosimetry Standards and Dissemination Systems for Radiation Processing in China
15:35	A06-05	S. Ebraheem	Egypt	EPR Dosimetry Systems; Assessment and Developed in NCRRT

— Discussion —

Coffee break: 16:15–16:30

B06 14:15–16:15 Radiation Techniques for Energy of the Future

Venue: *Room M2*

Chair: **Rubens Martins Moreira (Brazil)**

TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
14:15	B06-01	I. M. Fernández Gómez	Cuba	The γ-Scanner: A Tool for the Quality Control of the Process of Alcohol Distillation
14:35	B06-02	T. Abd El Slam	Egypt	A New Method for Detecting Trace Oil Concentration by Neutron Radiography Technique
14:55	B06-03	C. Sebastian Calvo	Peru	Leaks Determinations in Reboilers from Natural Liquid Fractioning Units
15:15	B06-04	L. Sabri	USA	RPT for Tracking Microalgae Cell Movement in Split Photobioreactor Column
15:35	B06-05	A. Toukan	USA	Flow Regime Identification in a Co-Current Gas-Liquid Upflow Moving Packed Beds Reactor Using γ-Ray Densitometry

— Discussion —

Coffee break: 16:15–16:30

A07 16:30–18:30 Advances in Radiation Chemistry Research II

Venue: *Board Room B/M1*
Chair: **Sara Goldstein (Israel)**
TSec: Agnes Safrany (IAEA)

Time	Id	Presenter		
16:30	A07-01	V. Feldman	Russian Fed.	The Radiation Chemistry of Organized Systems: Basic Studies and Implications
16:50	A07-02	M. Jonsson	Sweden	Interfacial Radiation Chemistry in Nuclear Technology
17:10	A07-03	C. I. Horak	Argentina	Radiation Sterilization of Devices and Scaffolds for Tissue Engineering
17:30	A07-04	S. Korraa	Egypt	Effect of Sterilization by γ-Irradiation on Biocompatibility of Starch-Based Polymers and Composites Suitable for Stem Cell Growth
17:50	A07-05	I. P. Kavirayani	India	Radiation Chemical Studies Leading to the Development of Selenium Radioprotectors
18:10	A07-06	O. Belyakov	IAEA	The IAEA Research on Radiation Sterilization in Tissue Banking

S01 ***Chinese Mission Side Event***

B07 16:30–18:30 Radiotracers for Energy of the Future II

Venue: *Room M2*
Chair: **Quang Nguyen Huu (Viet Nam)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
16:30	B07-01	Z. Idiri	Algeria	Simulation and Optimization of a Neutron Backscattering Analysis Set-Up Using MCNP5 Code
16:45	B07-02	S.-H. Jung	Korea, Rep. of	RPT Study on a Vertical Impeller Mixer
17:00	B07-03	A. Sultan	USA	Linear Attenuation Coefficients and Gas Holdup Distributions of Bubble Column with Vertical Internal Bundle for FT Synthesis
17:15	B07-04	R. Alami	Morocco	Numerical Simulation of Measurement by γ-Ray Scanning of Coke Deposition in Packed Bad of Distillation Column
17:30	B07-05	S. Roy	India	Noninvasive Radiation Based Densitometry and Velocimetric Monitoring of Fluidization of Coal and Bottom Ash Mixtures
17:45	B07-06	V. Khane	USA	Experimental Study of Pebble Flow Dynamics in a PBMR Using RPT

— Discussion —

S01 Chinese Mission Side Event

A08 09:00–11:00 Radiation Sources and Facilities: Panel Discussions

Venue: *Board Room B/M1*
Chair: **Suresh Pillai (USA)**
TSec: Sunil Sabharwal (IAEA)

Time	Id	Presenter		
09:00	A08-01	P. Dethier	Belgium	Review of the Two New Rhodotron Accelerators: The Compact 10 MeV TT50 and the High Energy 40 MeV Rhodotron
09:20	A08-02	R. Wiens	Canada	A Billion Curies and Counting: Ensuring ^{60}Co Supply and Disposal for Decades to Come
09:40	A08-03	B. Han	Korea, Rep. of	How to Apply Radiation Technology for Pollution Control
10:00	A08-04	A. Bryazgin	Russian Fed.	ILU Industrial Electron Accelerators
10:20	A08-05	W. Peng	China, P. R.	EB Technology vis-a-vis γ-Radiation for Irradiation Sterilization: Emerging Scenario
10:40	A08-06	A. K. Kohli	India	γ-Irradiator Technology: Challenges and Future Prospects

Coffee break: 11:00–11:15

B08 09:00–11:00 Seeing the Invisible: Structure Imaging — Safe and Effective Industry I

Venue: *Room M2*
Chair: **Nicholas George Cutmore (Australia)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
09:00	B08-01	N. G. Cutmore	Australia	Next-Generation Fast-Neutron/X-Ray Scanner for Air Cargo Interrogation
09:20	B08-02	H. Ben Abdelouahed	Tunisia	Monte Carlo Simulation and Experimental Verification of Blockages in Pipelines Using γ-Ray Computed Tomography
09:40	B08-03	P. Cong	China, P. R.	Associated Image Processing Algorithm in Dual-Projection Systems
10:00	B08-04	K. N. Myaing	Myanmar	Comparison of Image Reconstructions for γ-Transmission Computed Tomography System by Using MATLAB and i-Gorbit Software

Continued. . .

B08 *continued…*

Time	Id	Presenter		
10:20	B08-05	T. D. Dang Nguyen	Viet Nam	Gorbit – The Flexible γ-Computed Tomography System for Pipeline Inspection

— Discussion —

Coffee break: 11:00–11:15

A09 11:15–13:15 Preservation of Cultural Heritage

Venue: *Board Room B/M1*
Chair: **Pablo Vasquez (Brazil)**
TSec: Sunil Sabharwal (IAEA)

Time	Id	Presenter		
11:15	A09-01	J. Havermans	Netherlands	Disinfection and Consolidation of Archived Materials and Cultural Heritage Artefacts by Radiation Processing Techniques
11:35	A09-02	B. Katušin-Ražem	Croatia	Irradiation Method in the Protection of Cultural Heritage Objects Endangered by Massive Biodegradation
11:55	A09-03	I. V. Moise	Romania	Radiation Processing for Cultural Heritage Preservation: Romanian Experience
12:15	A09-04	Q.-K. Tran	France	Development of New Radiation-Curing Monomers-Resins Systems for the Consolidation of Wooden Cultural Heritage Artefacts
12:35	A09-05	A. Cemmi	Italy	Application of Ionizing Radiation for Cultural Heritage
12:55	A09-06	L. Cortella	France	Uses and Prospects in γ-Biocide Treatments for Cultural Heritage

Lunch break: 13:15–14:15

B09 11:15–13:15 Radiotracer for Managing Natural Resources

Venue: *Room M2*

Chair: **Rachad Alami (Morocco)**

TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
11:15	B09-01	S. Mimount	Morocco	Development of Radiometric Methods for Optimization of Phosphate Transport Process by “Slurry Pipe”
11:30	B09-02	F. Diaz	Chile	Determination of Mineral Behaviour in Ball Mills at Chilean Copper Minning Using Radioactive Tracers
11:45	B09-03	M. Rogowski	Poland	Radiotracer Methods for Ore and Flotation Tailings Leaching
12:00	B09-04	H. J. Pant	India	Radiotracer Investigation in an Industrial-Scale Fluid Catalytic Cracking Unit
12:15	B09-05	J. Tickner	Australia	Developing a Commercial Facility for Rapid Assay of Gold and other Elements in Mineral Ores Using γ-Activation Analysis
12:30	B09-06	R. M. Moreira	Brazil	A Tracer Application in Detecting Damage to Oil Industry Piping

— ***Discussion*** —

Lunch break: 13:15–14:15

PA1 Irradiation Facilities and their Applications

Venue: *A–Building*
Chair: **Mark Bailey (Denmark)**
TSec: Sunil Sabharwal (IAEA)

PA1-01	A. Abaza	Egypt	New Trends in Radiation Dosimeters
PA1-02	S. Abdelgawad	Egypt	Setting up of New Radiation Facilities in Alexandria, Egypt
PA1-03	J. Abdullah	Malaysia	In Situ and Non-Destructive Detection of Oleoresin in Standing Agarwood Trees Using Portable γ-Ray Tomography Imaging System
PA1-04	A. Adjerad	Algeria	Facilitating Sustainable Education in Nuclear Science and Technology
PA1-05	F. Djouider	Algeria	Pilot-Scale Study of the Radiation-Induced Silica Removal from Underground Brackish Water in Saudi Arabia
PA1-06	A. Cemmi	Italy	Radiation Activities at ENEA Calliope γ-Facility
PA1-07	J. Kim	Korea, Rep. of	Detoxification of High Toxicity Substances by Radiation Transformation Technique
PA1-08	K. Bergaoui	Tunisia	Evaluation of Radiation Shield Integrity of DD Neutron Generator Facilities by Monte Carlo and Experimental Methods
PA1-09	R. Betesho Babrud	I. R. Iran	Fungal Decontamination of Historical Oil Painting by Using γ-Ray
PA1-10	R. Betesho Babrud	I. R. Iran	The Study of γ-Ray Efficiency in Converting Tehran Municipal Sewage Sludge into a Sanitary Fertilizer
PA1-11	C. A. D. Carvalho Filho	Brazil	The Application of Radiochemical and Isotopic Studies to Inform on the Impact of Acidic Effluent Discharges from the Caldas Uranium Mine into Neighboring Surface Waters
PA1-12	D. Chmielewska-Śmietanko	Poland	Application of Electron Beam for Preservation Biodeteriorated Cultural Heritage Paper-Based Objects
PA1-13	L. Coretchi	Moldova, Rep. of	Using of Radiation Sterilization
PA1-14	M. L. Costa	Brazil	Relevant Safety Aspects for Radioactive Tracers in Industrial Process
PA1-15	F. Djouider	Algeria	Radiation Induced Environmental Remediation of Toxic Cr(VI) Heavy Metal in Aerated Neutral Solution under Simulated Industrial Effluent
PA1-16	A. Docters	Argentina	Intergrating Management Systems to Good Irradiation Practices within a Framework of Social Responsibility

Continued...

Id	Presenter		
PA1-17	S. E. Eid	Egypt	ESR Dosimetric Properties of Sodium Glutamate
PA1-18	R. El-Motaium	Egypt	Ionizing Radiation as a New Technique for Treating Sewage Wastewater and Sludge in Arid Regions
PA1-19	K. Farah	Tunisia	EPR Characterization of a Medical Grade Polyethylene for High Dose Dosimetry
PA1-20	M. Fulop	Slovakia	Treatment of Organic Pollutants Based on PCB in the River Sediment by Electron Beam
PA1-21	E. Furuta	Japan	A New Fluorescence Detection Method with Plastic Scintillators Using a Conventional LSC-Organic Waste Less Method
PA1-22	F. Gao	China, P. R.	Optimal Design of ^{60}Co Single Source Radiation Facility with Monte Carlo Method
PA1-23	J. R. George	India	Conceptual Development of an Irradiator for Cross-Linking of Cables Using ^{60}Co γ-Rays
PA1-24	R. Gomes	Brazil	Assessment of Safety Systems Design of Industrial Irradiation Facilities in Brazil
PA1-25	S. Goswami	India	Measurement of Residence Time Distribution of Wastewater in a Constructed Wetland System Using Radiotracer Technique
PA1-26	U. Gryczka	Poland	Application of Low Energy Electron Beam in Microbiological Decontamination Process
PA1-27	A. Ihsan	Pakistan	Core Neutronic and Source Strength Analyses of ^{60}Co Production in Local Power Reactors
PA1-28	B. S. Jang	Korea, Rep. of	RI-Biomics Technology for the Advance Radioisotope Application in Modern Life
PA1-29	S. Yu	Korea, Rep. of	Effect of γ-Ray and Electron Beam Irradiation on Reduction of Graphene Oxide Suspension in Aqueous Alcoholic Solution
PA1-30	W.-G. Kang	Korea, Rep. of	Radiation Shielding Analyses of a 10 MeV LINAC for Electron Beam and X-Ray at KACST
PA1-31	Y. Karakirova	Bulgaria	Optimizing the Size and Composition of Solid State/EPR Dosimeters
PA1-32	S. Yu	Korea, Rep. of	Degradation Characteristics and Transformation Products of Iodinated Contrast Media Using Ionizing Radiation
PA1-33	S. Ladjouzi	Algeria	Structural Characterization of γ Irradiated $GdBO_3$/Silica Composite Obtained by Sol Gel Process
PA1-34	K. K. Lay	Myanmar	Research on Conversion of Natural Wastes to Useful Products by Application of Radiation Processing for Agricultural Sector of Myanmar

Continued...

Wed

Id	Presenter		
PA1-35	G. Liu	China, P. R.	Dose Increase System in a γ-Irradiator
PA1-36	K. Y. Lwin	Myanmar	Human Resource Development for the Application of Radioisotope Techniques to Industry in Myanmar
PA1-37	S. Cabo Verde	Portugal	Application of Ionizing Radiation for Treatment and Valorization of Cork Wasterwater
PA1-38	B. Mihaljević	Croatia	Detoxification of Aflatoxin B1 and Ochratoxin A by γ-Radiation
PA1-39	S. Mimount	Morocco	Dosimetric Evaluation in Industrial Gammagraphy Operations
PA1-40	W. Mohamed Moustafa	Egypt	Application of Isotopic Techniques Using Mathematical Models in Environmental Process
PA1-41	V. Morgunov	Ukraine	The Numerical Simulation of Cultural Heritage Radiation Treatment by Monte Carlo Method
PA1-42	M. Mouhib	Morocco	Upgrading of ^{60}Co in Temporary Pool for Dry Storage Irradiation Facility SIBO INRA/Tangier Morocco
PA1-43	M. Mouhib	Morocco	Enhancing Safety and Control Features of Radiation Processing Facility SIBO INRA/Tangier Morocco
PA1-44	L. Ounalli Mejri	Tunisia	The Efficiency of Radiation Processing by the Tunisian ^{60}Co Industrial Irradiator after 16 Years of Use
PA1-45	H. J. Pant	India	Measurement of Voidage/Holdup in Industrial Process Systems Using γ-Ray Densitometry
PA1-46	E. F. Prieto Miranda	Cuba	Dosimetric Characterization of the ISOGAMMA LLoCo Irradiator
PA1-47	I. Pucić	Croatia	γ-Irradiation in Protection of Cultural Heritage: Effects on Model Cellulose Based Textiles
PA1-48	B. Mihaljević	Croatia	Dosimetric Calibration of a Panoramic ^{60}Co γ-Ray Source
PA1-49	M. Rushdi	Sudan	EPR Dosimetric Potential of Ammonium Oxalate Monohydrate in Radiation Technology
PA1-50	F. Salgado	Ecuador	Development of a Digital Model for the Dosimetry of the ^{60}Co Irradiator at the National Polytechnic School of Ecuador
PA1-51	M. Šegvić Klarić	Croatia	γ-Irradiation for Cultural Heritage: Treatment of Selected Fungi on Linen Textile
PA1-52	B. R. Shah	Nepal	Personal Radiation Dosimetry at Radiological Facilities, Nepal
PA1-53	S. Yu	Korea, Rep. of	Electron Beam Techniques for Air Pollution Control

Continued...

Id	Presenter		
PA1-54	D. Souza	Brazil	Dosimetric Properties of MgB_4O_7:Ce and MgB_4O_7:Ce, Li for Thermoluminescence Dosimetry Applications
PA1-55	A. Tegze	Hungary	Radiolysis Induced Degradation of Fluoroquinolones
PA1-56	M. H. Trabelsi	Tunisia	Tunisian Experience Assessment of Installing a Pilot ^{60}Co Source for Irradiation
PA1-57	A. Tripathi	India	γ-Radiation-Co-Cryogelation Induced Synthesis of Macroporous rpCryogels for Bioengineering Applications
PA1-58	P. Vasquez	Brazil	Kinetics of Free Radicals Decay Reactions in Cellulosic-Based Heritage Materials Disinfected by γ-Radiation
PA1-59	M. V. Vogt	Argentina	Feasibility of Using Irradiation to Degrade a Toxic Dye Compound
PA1-60	A. Weidauer	Germany	Toroidal Electron Source
PA1-61	A. Zaouak	Tunisia	γ-Radiation Induced Decolouration and Degradation on Aqueous Solutions of Indigo Carmine Dye
PA1-62	Z. Zimek	Poland	Electron Accelerator for R&D Study and Radiation Processing

PB Radiation Technologies for Measurement

Venue: *A–Building*

Chair: **Haifa Ben Abdelouahed (Tunisia)**

TSec: Patrick Brisset (IAEA)

PB-01	A. O. A. Abdelbari	Sudan	The Study of Industrial Process with Radioactive Tracer RTD Method Enhanced System Analysis
PB-02	J. K. J. Al-Saedi	Iraq	The Concentrations of Major and Trace Elements in Powdered Milk Using XRF and NAA, and Comparison to Other Techniques
PB-03	R. Alami	Morocco	Development of a New Ambient Dosimetry Monitor for In Situ Environmental Monitoring at the Nuclear Studies Centre of Maâmora, Morocco
PB-04	K. Broce	Panama	Study of Sediments in a Sub-Basin of the Panama Canal Using Nuclear Techniques
PB-05	M. J. G. Gichuru	Kenya	Tracers of High Altitude Pollution Sources and Impact on Mt. Kenya Ecosystem
PB-06	M. Goes Nunes	Brazil	$CaSO_4$:Dy and $CaSO_4$:Ce,Eu Intrinsic Efficiencies Dependence on Ionizing Radiation Type and Quality

Continued. . .

Id	Presenter		
PB-07	C. C. Bueno	Brazil	Evaluation of TL and OSL Response of CaF_2:Tm for Electron Beams Dosimetry in Radiation Processing
PB-08	J. D. R. Lopes Gomes	Brazil	Radiation Shielding Design Assessment of Nucleonic Gauges
PB-09	A. H. Lopez Gonzales	Brazil	Axial Computed Tomography Phase-Space Source Model in the PenEasy/PENELOPE Monte Carlo System: Implementation and Validation
PB-10	U. Mirsaidov	Tajikistan	Application of Radiation Science and Technology in the Republic of Tajikistan
PB-11	M. S. Mohammed	Sudan	Simulation Studies on the Image Quality of Industrial Film Radiography
PB-12	K. N. Myaing	Myanmar	Comparison of Image Reconstructions for γ-Transmission Computed Tomography System by Using MATLAB and i-Gorbit Software
PB-13	H. K. Namburi	Czech Republic	Neutron Radiography Studies for Detection of Hydrogen Distribution in Nuclear Fuel Claddings at Research Centre Řež
PB-14	J. Phirani	India	Adsorption Behaviour of Chloroauric Acid, a Generic Adsorbing Tracer, for Finding Wetting Behaviour of Fluids in Oil and Gas Industry
PB-15	A. Quaranta	Italy	Ion Irradiation Effects on the Optical Properties of Quantum Dots for Nano-Dosimetric Systems
PB-16	M. Rodríguez Alayón	Cuba	Results of Radiation Protection in Practices with Sources of Ionizing Radiation in the Petroleum Refining Industry
PB-17	M. I. A. Sagiroun	Sudan	Radiation Dosimetry of Laboratory Practices based on Radiotracers Techniques
PB-18	R. Koos	Germany	Application of Complementary Beam Techniques to Study Deformation Mechanisms in Heterogeneous Materials for Automotive Industry
PB-19	L. Sereeter	Mongolia	Neutron Activation Installments for Control of Flour Spar Enriching Factory in Mongolia
PB-20	T. Smolinski	Poland	Synthesis Method of Multimodal Radiotracers for Industrial Processes and Environmental Research
PB-21	S. Sugiharto	Indonesia	Examination the Performance of the Trayed Ethylen Production Column Using γ-Ray Scan Techique

Continued...

Id	Presenter		
PB-22	I. D. A. Sutapa	Indonesia	Resident Time Determination of IPAG60 in Order to Increase Efficiency of Drinking Water Treatment Plant for Peatland Area
PB-23	T. Weerakkody Appuhamillage	Sri Lanka	Terrestrial Background Radiation in Norochcholai in the North Western Coast of Sri Lanka

A10 16:30–18:30 Development in Electron Accelerators Technology

Venue: *Board Room B/M1*
Chair: **Lixin Shen (China)**
TSec: Bum Soo Han (IAEA)

Time	Id	Presenter		
16:30	A10-01	Y. Zhang	China, P. R.	Addressing Challenges Posed by Electron Beam Irradiation through Innovation
16:50	A10-02	C. Cooper	USA	Illinois Accelerator Research Center
17:05	A10-03	T. Kroc	USA	A Compact Superconducting RF Accelerator for Electron Beam and X-Ray Irradiation
17:20	A10-04	F.-H. Roegner	Germany	Low-Energy Electron Irradiation for Novel Applications in Medical Production and Pharma
17:35	A10-05			Withdrawn
17:50	A10-06	N. Kuksanov	Russian Fed.	DC ELV Accelerators: Development and Application
18:05	A10-07	A. Weidauer	Germany	Electron Treatment of Seed

— Discussion —

S02* *ISTRA Side Event

B10 16:30–18:30 Radiotracers for New Materials Development

Venue: *Room M2*
Chair: **Gerardo Maghella (Peru)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
16:30	B10-01	H. Makil	France	Quality Control of Neutron-Absorber Materials for the Nuclear Fuel Cycle: Principle of the JEN_3 Neutron Backscattering Gauge
16:50	B10-02	A. Kleinrahm	Germany	Radionuclide Technique in Mechanical Engineering: A Powerful Measuring Method for Tribological Tasks — Installations at and Services of ZAG Zyklotron AG
17:10	B10-03	B. Artemiev	Russian Fed.	Replacing the Isotopic Radiation Sources in Thickness Measurement on X-Ray
17:30	B10-04	F. Ditrói	Hungary	Development of Thin Layer Activation for Wear Measurement
17:50	B10-05	W. A. P. Calvo	Brazil	Industrial Applications of the IEA-R1 Research Reactor in Brazil

— Discussion —

S02 ISTRA Side Event

A11 09:00–11:00 Safety and Security Perspectives of Radiation Facilities

Venue: *Board Room B/M1*
Chair: **András Kovács (Hungary)**
TSec: Sunil Sabharwal (IAEA)

Time	Id	Presenter		
09:00	A11-01	M. Frenzel	Germany	Upgrading Safety and Security of γ-Irradiation Facilities: Possibilities and Limitations
09:20	A11-02	F. Schmitz	Belgium	Safety Improvements of an Industrial Irradiation Facility
09:40	A11-03	M. Alcerreca	Mexico	Upgrading and Continuous Improvement of ININ γ-Irradiation Facility
10:00	A11-04	M. Mouhib	Morocco	Enhancing Nuclear Security System of Irradiation Facility SIBO INRA/Tangier Morocco
10:20	A11-05	G. Yu	China, P. R.	Development and Application of Electron Linear Accelerator of CIAE

— Discussion —

Coffee break: 11:00–11:15

B11 09:00–11:00 Seeing the Invisible: Structure Imaging — Safe and Effective Industry II

Venue: *Room M2*
Chair: **Ghiyas Ud Din (Pakistan)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
09:00	B11-01	G. Ud Din	Pakistan	Investigation of Two-Phase Flow Behaviour Across a 90 Degree Horizontal Bend: CFD Simulation and γ-Computer Tomography Validation
09:15	B11-02	J.-H. Jin	Korea, Rep. of	New Developments on the Automatic γ-Column Scanner
09:30	B11-03	H. J. Pant	India	Radiotracer Applications in Industry and Environment
09:45	B11-04	G. A. Johansen	Norway	Tomographic Methods for Multiphase Flow Measurement

Continued…

Thu

B11 *continued...*

Time	Id	Presenter		
10:00	B11-05	G. Maghella	Peru	Determination of Interfaces in Packed Columns by Using Sealed Sources
10:15	B11-06	A. Saadaoui	Morocco	A γ-Ray Computed Tomography for Investigating the Wood Structure

—Discussion—

Coffee break: 11:00–11:15

A12 11:15–13:15 Radiation for Environmental Protection II

Venue: *Board Room B/M1*

Chair: **Erzsebet Takács (Hungary)**

TSec: Sunil Sabharwal (IAEA)

Time	Id	Presenter		
11:15	A12-01	S. Cabo Verde	Portugal	Virucidal Potential of γ-Radiation
11:35	A12-02	S. Mezyk	USA	Removal of Wastewater Pharmaceutical Chemical Contaminants Using AOPs
11:55	A12-03	M.-H. Wu	China, P. R.	Applications of Radiation Technology in Control and Treatment for Environmental Pollution
12:15	A12-04	S. Yu	Korea, Rep. of	Application of Mobile Electron Beam for Remediation of Soil and Groundwater Contaminated with Leachate from Animal Carcass Burial Sites
12:35	A12-05	S. Pillai	USA	Electron Beam Treatment for Potable Water Reuse: Removal of Bromate and Perfluorooctanoic Acid
12:55	A12-06	G. Sági	Hungary	Changes in the Biological Degradability and Toxicity of Sulfonamide Antibiotics in Activated Sludge and River Water due to Ionizing Radiation Treatment

Lunch break: 13:15–14:15

B12 11:15–13:15 Radiation Techniques for Industrial Processes Optimization and Safety II

Venue: *Board Room B/M1*

Chair: **Geir Anton Johansen (Norway)**

TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
11:15	B12-01	J. Thereska	Albania	Radiotracer Residence-Time Distribution Method in Diagnosing Industrial Processing Units: Case Studies
11:30	B12-02	J. S. Rawat	India	Investigation of the Multiple Side Injections on Hydrodynamics of the Gas-Solids Fluidized Bed Using Radiotracer Based Techniques
11:45	B12-03	G. Ud Din	Pakistan	Radiotracer and Sealed Source Technologies for Measurements in Industry
12:00	B12-04	K. El Korchi	Morocco	Radioisotope Techniques for Detection of Coking in Liquid Flow through a Solid Phase in a Lab-Scale Distillation Column's
12:15	B12-05	S. Goswami	India	Measurement of Residence Time Distribution of Wastewater in a Constructed Wetland System Using Radiotracer Technique
12:30	B12-06	I. I. Mumuni	Ghana	Radiotracer Investigation of the Effect of Impeller Type on Mixing in Industrial Process Simulator

— Discussion —

Lunch break: 13:15–14:15

Thu

B13 14:15–16:15 Radiotracer for Managing of Natural Resources, Energy and Processes

Venue: *Room M2*

Chair: **Jefferson Vianna Bandeira (Brazil)**

TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
14:15	B13-01	T. B. O. Jentsch	Germany	Investigation of Heavy Metal Release at a Municipal Solid Waste Incineration Facility: An Excellent Example for the Unique Potential of Intrinsic Radiotracer Application to the Investigation of Industrial Processes in Chemical Engineering
14:35	B13-02	J. Abdullah	Malaysia	Radiotracer Investigation in an Aeration Tank of a Waste Water Treatment Plant
14:55	B13-03	R. Alami	Morocco	Data Fusion Approach for Improving the Reliability of Radiographic Testing and other Complementary NDT Techniques
15:15	B13-04	I. I. Mumuni	Ghana	Neutron Backscatter Technique as an Alternative Method for Quality Assurance and Standardization of Petroleum Products
15:35	B13-05	M. P. Hlaing	Myanmar	Identification of the Internal Condition of Crude Oil Distillation Unit Using γ-Column Scanning Technique in Myanmar

— ***Discussion*** —

PA2

Venue: *A–Building*

Radiation Creation of Materials from Fundamentals to Application

Chair: **Laszlo Wojnárovits (Hungary)**

TSec: Agnes Safrany (IAEA)

PA2-01	S. Abdelrehim	Egypt	Developing a Simple Method Using Ionizing Radiation to Produce Polyacrylic Acid Based Nanoparticles
PA2-02	Y. Aguilera-Corrales	Cuba	Synthesis by γ-Radiation and Characterization of Poly(Vinylpyrrolidone) Nanogel
PA2-03	M. K. Pramanik	Bangladesh	Application of γ Radiation and Physicochemical Treatment to Improve the Bioactive Properties of Chitosan Extracted from Shrimp Shell
PA2-04	M. C. Anessi	Argentina	Predicting the Behaviour of a Biomaterial as Bone Replacement
PA2-05	I. C. Calina	Romania	Electron Beam Synthesis of Inulin Hydrogels Extracted from *Helianthus Tuberosus L.*
PA2-06	J. Cardoso	Brazil	Recycled HDPE/Vulcanized EPDM Mixtures Obtained by Irradiation Processes
PA2-07	K. R. C. De Silva	Sri Lanka	Determination of the Radiation Dose Required to Obtain Desired Viscosity Average Molecular Mass Using Commercially Available Chitosan and Signification of this Technique in its Applications
PA2-08	E. Eisawy	Egypt	The Effect of Radiation Environment on Electrical Insulation Materials
PA2-09	N. El-Sawy	Egypt	Radiation Synthesis of Acrylic Acid onto Poly(tetrafluoroethylene-perfluorovinyl ether) Film: Chemical Modifications and Electrical Conductivity
PA2-10	N. Farahat	Egypt	Sorption of Iodine on Ion Exchange Resins
PA2-11 Verde	L. M. Ferreira	Portugal	Distinct Polymeric Based Materials Prepared/Functionalized by γ-Irradiation for Biomedical Applications and Roman Mosaics Preservation
PA2-12	L. Garcia-Uriostegui	Mexico	Synthesis of Cross-Linking Films Based of 3-(Trimethoxysilyl) Propyl Methacrylate Silanized Xanthan Gum/Lignin and their Cross-Linking by γ-Radiation, to Potential Application and Films Packing
PA2-13	X. W. Ge	China, P. R.	Monodispersed Polypyrrole Nanoparticles Prepared via Water Padiolysis and their Photothermal Therapy on Cancer Cells

Continued…

Id	Presenter		
PA2-14	A. Geraldo	Brazil	Obtention and Characterization of γ-Irradiated Recycled HDPE/EPDDM Blends
PA2-15	S. Ismail	Egypt	γ-Radiation Enhancement of Photocatalytic Activity of Conducting Polyaniline-TiO_2 Nanocomposites for Degradation of Methyl Orange Dye under Visible Light Irradiation
PA2-16	T. Jurkin	Croatia	Radiolytical Synthesis and Mechanism of Gold Nanoparticle Formation
PA2-17	M. Kaci	Algeria	Functional Properties and Ecotoxicity of Bionanocomposites Based on PHBV/PLA Blend under Electron Beam Irradiation
PA2-18	I. U. Khan	Pakistan	Studying the Biological Efficacy of Radiation-Treated Radiolabelled DOTA-Bombesin-Decorated Nanoconstructs as Potential Nanosized Drug Delivery Systems
PA2-19	S. Yu	Korea, Rep. of	Fabrication of Advanced Soft Magnetic Nanomaterials Using the Radiation
PA2-20	G. H. C. Varca	Brazil	Development of Advanced Scaffolds and Polymeric Systems for Improved Cell and Tissue Growth
PA2-21	J. Krstić	Serbia	Mechanical Characteristics and Antibacterial Properties of Ag-Poly(Vinyl Alcohol)/ws-Chitosan Hydrogel Nanocomposites Synthesized by γ-Irradiation Combined with Freeze/Thaw Cycles
PA2-22	J. Li	China, P. R.	Dyestuff Free: Colouring Fabrics by Graft Polymerization
PA2-23	D. Lucan	Romania	Influence of the Coolant Chemistry on the Structural Materials Surfaces Exposed into the Candu NPP Primary Circuit
PA2-24	E.-M. Lungulescu	Romania	Radiation-Induced Oxidation in γ-Irradiated UHMWPE Modified with Hydroxyapatite
PA2-25	J. Madrid	Philippines	Optimization of Electron Beam-Induced Synthesis of Polypropylene-g-poly(Glycidyl Methacrylate) for Cr(VI) and Cd(II) Adsorption Using Full Factorial Design
PA2-26	G. Mahmoud	Egypt	Radiation Development of (Polyvinyl Pyrrolidon/Acrylic Acid)- Silver Nanocomposite for the Disposal of Phenolic Compounds from their Aqueous Solutions
PA2-27	A. Mahmoud	Sudan	A Comparative Study of Radiation Sterilization of Cell Culture Media and Filtration Sterilization Method in Cell Culture Laboratory

Continued…

Id	Presenter		
PA2-28	H. Bhunia	India	Simultaneous Radiation Grafting of Acrylic Acid on Polypropylene Films: Optimization, Biodegradability and Evaluation of Ecotoxicological Impact
PA2-29	K. Marušić	Croatia	Metal Surface Modification with Fatty Acids Using Ionizing Radiation
PA2-30	K. Marzouki	Tunisia	Irradiation Effects on Structure and Spectroscopic Properties of Sugar Doped Sol-Gel Silica
PA2-31	S. Mohd Janib	Malaysia	Ionizing Radiation Engineered Functional Nanogels for Biomedical Applications
PA2-32	M. Z. I. Mollah	Bangladesh	Effect of γ-Radiation on the Physico-Mechanical Properties of Gelatin-Based Films and Jute-Reinforced Polymer Composites
PA2-33	M. Negrin	Italy	Ionizing Radiation as a Tool to Affect Polymer Biodegradation
PA2-34	N. G. Nik Salleh	Malaysia	Development of Nanocomposite Coatings by Radiation Curing
PA2-35	H. Nizam El-Din	Egypt	Swelling and Drug Release Kinetics of Polyacrylamide/Sodium Alginate Copolymer Hydrogels Synthesized by γ-Irradiation
PA2-36	R. Papaléo	Brazil	Effect of Spatial Confinement on the Radiolytic Efficiency of High-Energy Ions in Polymers
PA2-37	A. Ortega	Mexico	Functionalization of Polypropylene Films with Glycidyl Methacrylate by γ-Radiation
PA2-38	M. P. Pérez-Calixto	Mexico	Synthesis and Characterization of PP Films Rich in Primary Amines for Cell Cultures, by γ-Radiation
PA2-39	T. Piroonpan	Thailand	Biopolymer-Silver Nanoparticle as a CIELAB Colour Space Dosimeter
PA2-40	I. Pucić	Croatia	Nanocarbon Based PolyLY(Ethylene-Terephthalate) Nanocomposites and Various Irradiations
PA2-41	A. Raafat	Egypt	In Situ Deposition of Nanohydroxyapatite within N,O-Carboxymethylchitosan/ Polyvinylpyrrolidone Hydrogels: Characterization and Bioactivity Evaluation
PA2-42	A. Radosavljević	Serbia	Morphological, Physico-Chemical and Mechanical Properties of Radiolytically Synthesized Nano-Ag/ poly(N-isopropylacrylamide) Hydrogels

Continued...

Id	Presenter		
PA2-43	N. Rahman	Bangladesh	Preparation of Selective Hazardous Metal Ion Adsorbents from Acrylic Monomer Grafted PET Films
PA2-44	M. Rapado Paneque	Cuba	Nanogels of Polyvinylpyrrolidone Obtained by γ-Radiation: Physicochemical and Biological Characterization
PA2-45	S. Y. Ratnayake	Sri Lanka	Chemical Reduction of Nitrate by Zerovalent Iron Nanoparticles Adsorbed Radiation Grafted Copolymer Matrix
PA2-46	A. Sagatova	Slovakia	Lifetime Study of Electronic Devices for Extreme Radiation Conditions
PA2-47	F. Saghatchi	I. R. Iran	The Hormetic Effect of X-Rays on Biosynthesis of Gold Nanoparticles by Actinobacteria
PA2-48	M. Salla Ferreira	Brazil	Correlation of Traditional and One-Step Irradiation Process for Chitosan Production from Charybdis Hellerii Crab Shells
PA2-49	H. Sayed	Sudan	Effect of γ-Irradiation on the Molecular Weight and Structure of Guar Gum
PA2-50	S. Shayanfar	USA	Investigations on Immobilizing Anthocyanin and Betacyanin onto Polyethylene Films
PA2-51	N. A. Shukri	Malaysia	Shelf Life Assessment of Sliced Bread by Sorbic Acid Based Active Film
PA2-52	Z. Kačarević-Popović	Serbia	Structural Characterization, Antibacterial Properties and Citotoxicity of γ-Irradiation Synthesized Ag-poly(N-isopropylacrylamide/itaconic acid) Hydrogel Nanocomposites
PA2-53	I. Tartaro Bujak	Croatia	The Effect of Natural Antioxidants in Thiyl Radical-Induced Lipid Modification Processes
PA2-54	T. M. Ting	Malaysia	Evaluation of Thorium Adsorbent Prepared by Radiation Grafting and Functionalization with Glucamine
PA2-55	M. Wang	China, P. R.	γ-Ray-Radiation-Scissioned Chitosan as a Gene Carrier and its Improved in vitro Gene Transfection Performance
PA2-56	Y. Yin	China, P. R.	In Situ Compatibilization of Polyblends and Polymer Based Composites Induced by γ-Irradiation
PA2-57	S. Yu	Korea, Rep. of	Low Dimensional Nanomaterials-Based Interfacial Engineering in Organic Solar Cells
PA2-58	T. Zaharescu	Romania	Radiochemical Stability and Life Time of LDPE-Based Flexible Composite Filled with Ce-Doped PZT-$PbZrTiO_3$

Continued...

Id	Presenter		
PA2-59	A. Zaouak	Tunisia	Decolouration and Degradation of Erythrosine by γ-Irradiation
PA2-60	H.-L. Ma	China, P. R.	γ-Ray Induced Reduction and Modification of Graphene Oxide

A13 16:30–18:30 Advanced Nano Materials

Venue: *Board Room B/M1*
Chair: **Piotr Ulański (Poland)**
TSec: Agnes Safrany (IAEA)

Time	Id	Presenter		
16:30	A13-01	C. Dispenza	Italy	Radiation Synthesis of Nanosized Drug Delivery Devices
16:50	A13-02	M. Grasselli	Argentina	Protein-Based Nanoparticles Prepared by Radiation-Induced Cross-Linking
17:10	A13-03	W. Pasanphan	Thailand	Molecular Design and Synthesis of Different Polymer-Based Nanoparticles as Nanocarriers Using Irradiation Techniques
17:30	A13-04	K. V. Katti	USA	Green Nanotechnology in Nuclear Medicine: Tumor Specific Radioactive Gold Nanoparticles for New Approaches in Cancer Therapy
17:50	A13-05	G. H. C. Varca	Brazil	State of the Art and Current Advances on Protein Cross-Linking by Irradiation: Protein Based Nanocarriers and Bioactive Nanoparticles
18:10	A13-06	Y. Bondar	Ukraine	Radiation-Chemical Synthesis of Nanocomposite Adsorbents Based on Polypropylene Fibres for Selective Removal of Heavy Metals and Radionuclides
18:20	A13-07	A. Salih	Sudan	Preparation of Polyurethane Acrylate/ Organically Modified Montmorillonite Nanocomposites by Electron Beam Radiation Curing

B14 16:30–18:30 Radiation for Cultural Heritage Characterization

Venue: *Room M2*
Chair: **Jean Louis Boutaine (France)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
16:30	B14-01	J. L. Boutaine	France	A Survey of the Possibilities of Various Radiographic Techniques for the Non Destructive Examination of Cultural Heritage Artefacts
16:45	B14-02	M. J. G. Gichuru	Kenya	Application of Ionizing radiation in Studying Akaba and Masai Art Objects Made from Glass
17:00	B14-03	Ş. Ekinci	Turkey	Radiographic Investigation of Archaeological Objects
17:15	B14-04	B. Artemiev	Russian Fed.	Using X-Rays to Detect Hidden Images (Old Masters) on Priming Canvases
17:30	B14-05	R. Alami	Morocco	Some Applications of X-Rays in the Service of the Archaeological Site of Volubilis
17:45	B14-06	F. De Beer	South Africa	Secrets and Mysteries of our Past Revealed by Neutron and X-Ray Radiography/Tomography
18:00	B14-07	R. Alami	Morocco	The Radiography in the Service of the Preservation of the Moroccan Historical Heritage

— ***Discussion*** —

A14 09:00–11:00 Technical Cooperation Success Stories

Venue: *Board Room B/M1*
Chair: **Luis Carlos Longoria Gandara (IAEA)**
TSec: Sunil Sabharwal (IAEA)

Time	Id	Presenter		
09:00	A14-01	B. Mihaljević	Croatia	Recent Radiation Research and Technology Development in Croatia
09:20	A14-02	W. A. P. Calvo	Brazil	Multipurpose γ-Irradiator and Mobile Unit with an Electron Beam Accelerator Developed in Brazil
09:40	A14-03	L. Lanuza	Philippines	Radiation Processing in the Philippines: Developments and Prospects
10:00	A14-04	A. Adu-Gyamfi	Ghana	Radiation Processing in Ghana: Achievements, Prospects and Challenges
10:20	A14-05	E. F. Prieto Miranda	Cuba	Radiation Processing in Cuba: Past, Present and Perspective
10:40	A14-06	J. W. Rangel Urrea	Mexico	Drafting and Preparation of Proposals of Irradiation Plants: Mexico Experience

Coffee break: 11:00–11:15

B15 09:00–11:00 Advances and Trends in Radiotracer and Radiation Science and Technology II

Venue: *Room M2*
Chair: **Harish Jagat Pant (India)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
09:00	B15-01	T. Bjørnstad	Norway	Nuclear-Based Monitoring of Industrial Mass Flow I: The Potential Use of Small Transportable Neutron Generators
09:10	B15-02	T. Bjørnstad	Norway	Nuclear-Based Monitoring of Industrial Mass Flow II: The Potential Use of Small Transportable Neutron Generators
09:20	B15-03	R. K. Gupta	India	Residence Time Distribution Measurements in Industrial Scale Reactors with Recycle Using Radiotracer Technique
09:40	B15-04	H. Arahmane	Morocco	Neutron-γ Discrimination Using Non-Negative Matrix Factorization Blind Sources Separation Algorithms

Continued…

Fri

B15 *continued…*

Time	Id	Presenter		
10:00	B15-05	Y. Yang	China, P. R.	Contrabands Detection with a Low Energy Electron Linac Driven Photoneutron Source
10:20	B15-06	P. Francus	Canada	Combining CT Scan and Particle Imaging Techniques: Developing New Applications to Sediment Transport

— Discussion —

Coffee break: 11:00–11:15

A15 11:15–13:15 Emerging Radiation Technologies

Venue: *Board Room B/M1*
Chair: **Monique Lacroix (Canada)**
TSec: Bum Soo Han (IAEA)

Time	Id	Presenter		
11:15	A15-01	N. Ramamoorthy	India	Economics of Radiation Processing Technology: Posers and Prospects
11:35	A15-02	R. Wach	Poland	Radiation Modification of Carboxymethylated Chitosan: From Basics to Applications
11:45	A15-03	D. Staack	USA	Remediation of Petroleum Impacted Soils with Electron Beam Irradiation
11:55	A15-04	M. Driscoll	USA	Electron Beam Pretreatment of Lignocellulosic Biomass
12:05	A15-05	K. Hemvichian	Thailand	Radiation-Induced Admicellar Polymerization of Methyl Methacrylate on Cassava Starch
12:15	A15-06	B. Doan	Viet Nam	Preparation and Characteristics of Reduced Graphene Oxide in Ethanol/Water Solution by γ-Ray Irradiation
12:25	A15-07	G. Wu	China, P. R.	Radiation Induced Oxidation, Cross-Linking and Grafting of Ultra-High Molecular Weight Polyethylene

— Discussion —

Lunch break: 13:15–14:15

B16 11:15–13:15 Technical Cooperation Success Stories: Country Reports

Venue: *Room M2*
Chair: **Joon-Ha Jin (Korea, Rep. of)**
TSec: Patrick Brisset (IAEA)

Time	Id	Presenter		
11:15	B16-01	K. M. Rodolfo	Angola	The Participation of the Technological National Centre in the Technical Cooperation Programme Activities
11:35	B16-02	A. S. Abdullahi	Nigeria	Progress, Problems and Prospects of Radioisotope Technology in Nigeria
11:55	B16-03	P. Baricholo	Zimbabwe	Industrial Application of Radioisotopes in Zimbabwean Industries: A Report on RTD Experiments in Cement Industry, Radon Monitoring in Coal and Fly Ash of a Small Thermal Power Plant and NDT Activities
12:15	B16-04	D. Aquino	Philippines	Computed Tomography for Characterizing Industrial Materials
12:35	B16-05	C. Omondi	Kenya	Measurements of Radiotracer Residence Time Distribution Using a Flow Rig in Kenya

— Discussion —

Lunch break: 13:15–14:15

CL 14:15–16:15 Closing Plenary

Venue: *Board Room B/M1*
Chair: **Meera Venkatesh (IAEA)**

Time	Id	Presenter		
14:15	CL-01	W. A. P. Calvo	Brazil	Closing Remarks
14:35	CL-02	X. Coqueret	France	Closing Remarks II
14:55	CL-03	R. Alami	Morocco	Closing Remarks III
15:15	CL-04	S. Pillai	USA	Summary
15:35	CL-05	M. Venkatesh	IAEA	Closing of the Conference

Fri

Tuesday April 25:

S01 18:30–19:30 Chinese Mission Side Event

Venue: *Room M2*

The Chinese Permanent Mission will be holding a side event called “China’s Development in Radiation Science and Technology” on Tuesday, 25 April from 18:30 to 19:30 in room Room M2, followed by a small reception for approximately 100 people from 19:30 to 21:00 on the first floor of the M–Building.

Wednesday April 26:

S02 18:30–19:30 ISTRA Side Event

Venue: *Room M2*

There will be the “ISTRA Meeting”, organized by the International Society of Tracers and Radiation Applications, on Wednesday late afternoon in Room M2, from 18:30 to 19:30. (NB: No reception).

Contents

OP: Opening Plenary

Ionizing Radiation: Innovative and Effective Tool for Science and Industry

A. G. Chmielewski[1]

[1] *Institute of Nuclear Chemistry and Technology (INCT), Warsaw, Poland*

Corresponding Author: A. G. Chmielewski, a.chmielewski@ichtj.waw.pl

Ionizing radiations in the form of γ-rays, energetic electrons and X-rays (Bremsstrahlung) are being used for many practical applications. Successful irradiation processes provide significant advantages in comparison to typical thermal and chemical processes, such as higher throughput rates, reduced energy consumption, less environmental pollution, more precise process control and products with superior qualities. Ionizing radiation can modify the physical, chemical and biological properties of materials on an industrial scale. Many γ-sources and electron accelerators were built and installed for these purposes over the past fifty years and the field is still expanding. The biggest industrial use of ionizing radiation is the modification of polymer properties in a variety of industrial applications such as wire and cable insulation, tire manufacturing, production of polymeric foams, hydrogels and heat-shrinkable films and tubing, curing of coatings, adhesives and composites. Ionizing radiation became a perfect tool for formation and synthesis of nanoparticles and nanocomposites. Sterilization by ionizing radiation accounts for the preparation of approximately 50% of single use medical devices in UK and 40–50% of all disposable medical products in North America. Radiation technologies may also be applied to environmental protection and cultural heritage preservation. Efficient radiation technologies for gas, liquid and solid wastes treatment were developed to reduce environmental degradation. Cultural heritage artefacts based on paper, textiles or wood are prone to biological attack and their disinfection using ionizing radiation has been successfully demonstrated. Another field of applications is based on ionizing radiation penetration properties and its precise detection, through utilization of open and sealed radiation sources. Optimization of industrial processes is essential not only for efficient, safe and sustainable operation, but also to save materials, energy, protect the environment and reduce plant shutdown time. Complex industrial processes include environmentally related processes (such as harbours and dams, oil fields and ore/coal mines) so it is essential to have suitable means to investigate them for process optimization and trouble-shooting — preferably without shutting down the plant or process. Radiotracers and sealed source techniques are best-suited methods to address these problems. Nuclear techniques in most of the cases provide on-line investigations without shutting down the plant or process. Automation and improvements in instrumentation and hardware, such as tracer injection systems, detectors and data acquisition systems are developed for safer and reliable application. All applications are based on science developed in universities and research centres and then transferred to industry to be used in a safe and proper manner. It is a joint input of scientists and professionals working in the field to the main UN Millennium Goals of achieving a resource-efficient and climate-change-resilient economy and society, protecting and sustainably managing natural resources and ecosystems, and ensuring a sustainable supply and use of raw materials and other environmental resources. This universal humanistic role of science was articulated by Madame Curie, a lady born exactly 150 years ago in Warsaw as Maria Skłodowska. She developed a new innovative and effective tool — ionizing radiation — which broke new ground in physics and chemistry, opening the door for advances in engineering, biology and medicine.

A01: Trends in Radiation Science and Technology

Radiation Synthesis of Polymer Nanogels for Biomedical Applications

P. Ulański[1]

[1] *Institute of Applied Radiation Chemistry, Lodz University of Technology, Łódź, Poland*

Corresponding Author: P. Ulański, ulanskip@mitr.p.lodz.pl

One of the most rapidly developing fields of nanotechnology is nanomedicine. Creation of nanoscale materials which could be transported via the cardiovascular system, penetrate cellular membranes and selectively target specific tissues or organs opens a new range of possibilities for controlled drug delivery, gene therapy, radiotherapy, etc. An important class of nanoparticles for medicine are nanogels.

Nanogels can be defined either as tiny fragments of hydrogel networks, or as internally cross-linked single macromolecules. Classical polymer chemistry offers several ways to synthesize polymer nanoparticles, but most of them require complex procedures and the use of monomers, cross-linking agents, initiators, surfactants, which are difficult to remove from the final product, while some of them may be toxic. Since the late 1990's, an alternative approach based on radiation chemistry has been proposed and developed, where the only substrates are polymer chains and solvent (usually water). The basic idea of this technique is to irradiate a dilute polymer solution in such a way that many radicals are present simultaneously on each macromolecule. Their intramolecular recombination creates new covalent bonds linking the segments of the polymer chain and thus a nanogel particle is formed. Understanding the mechanism and kinetics of these processes can be facilitated by using pulse radiolysis and Monte Carlo simulations. Procedures have been developed to synthesize nanogels having their mass and size tailored to meet specific needs.

This talk, besides presenting the basics of radiation synthesis of nanogels and recent developments from authors' lab, is also intended to briefly summarize important progress in this field achieved by teams from many countries. Co-operation between these research groups has been greatly facilitated by a number of recent CRPs on these topics, initiated and coordinated by IAEA.

Status and Prospect of Application of Radiation Science and Technology in China: A National Report

L. Shen[1]

[1] *China Atomic Energy Authority (CAEA), Beijing, People's Republic of China*

Corresponding Author: L. Shen, shenlx@cnnc.com.cn

As an emerging strategic industry supported by the Chinese government, application of radiation science and technology has seen rapid development in recent years and is now at its golden age of fast development. The annual output of the industry in China has exceeded 300 billion RMB yuan (approximately 46 billion USD) in 2016, which is expected to maintain an annual growth of 15% to 20%.

Entrusted by the China Atomic Energy Authority (CAEA) and other related ministries, the Chinese Nuclear Society (CNS) has carried out a two-year-long nation-wide survey on this industry of radiation science and technology application since late 2015 in order to have an overall idea of the major achievements in the past ten years, its important role in improving people's living and health and the opportunities and challenges facing the industry in order to predict its development trend in future. A comprehensive report is under preparation.

This paper present the key outcome of the survey. Part one provides a general description of the development status of application science and technology in China. Part two details on China's efforts in development ray source such as accelerator, isotope, and related integrated installations based on accelerator or with γ-ray, inspection equipment based on ray imaging, non-destructive inspection equipment, etc. Part three introduces more in detail the application of radiation science and technology in industry, agriculture, health care, environment protection, and national security in China. Part four sketches China's effort in education and training for this industry. Part five estimates the prospect of the application of radiation science and technology in China in the future.

Emerging Areas of Radiation Sterilization

B. Croonenborghs[1]

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Corresponding Author: B. Croonenborghs, bcroonenborghs@eu.sterigenics.com

Since the installation of the first γ-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, new challenges for developing, establishing and controlling a radiation sterilization process have come across the industry. Customized solutions need to be developed in order to be successful in this area.

Examples of such processes qualified within the Sterigenics network of gamma and high energy electron beam irradiators are presented.

Radiation-Modified Carrageenan as Plant Food Supplement: Making a Breakthrough with Philippine Farmers

L. V. Abad[1], D. R. Montefalcon[1], F. Aurigue[1], R. M. Dela Cruz[1], G. Magsino[2], and A. Carpio[3]

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[2]*National Crop Protection Center (NCPC), Crop Protection Cluster (CPC), University of the Philippines Los Baños College of Agriculture (UPLB), Los Baños, Laguna, Philippines*
[3]*Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD), Los Baños, Laguna, Philippines*

Corresponding Author: L. V. Abad, lvabad@pnri.dost.gov.ph

Radiation processing of kappa carrageenan by either γ-or EB irradiation produces low molecular weight fragments that can induce growth promotion effects on plants. The fragments that are produced have an average molecular weight (MW) of less than 10 kDa. These low MW kappa carrageenan increases yield in Pechay plants when applied either by foliar spraying or in hydrophonics condition. [1] Recent studies in the Philippines indicated improved agronomic traits with a dramatic increase in yield in mungbean and peanut plants of 200–400% and 150–200%, respectively using screen house experiments. Field experiments in mungbean produced around 10 times higher yield than the normal farmer's practice.

A01

Multi-location trials of around 2000 ha rice field in different regions of the Philippines indicated an average increase in yield of 15–30% compared to normal farmer's practice. Highest yield of as much as 60% was obtained. Increased resistance to tungro virus was also noted. Likewise, there was extensive root growth and sturdy stems that prevent lodging of rice plant. Testimonies given by farmers indicated a substantial increase in their income with the utilization of radiation-modified carrageenan.

Degradation of κ-carrageenan by EB irradiation is inhibited by the formation of cross-links. Optimization by addition of hydrogen peroxides to improve degradation is discussed. Data on pilot scale production of radiation-modified carrageenan is presented.

References

[1] L. V. Abad, *et al.*, Radiation Physics and Chemistry **118**, 75–80 (2015).

Recent Progress in Pulse Radiolysis Detection Methods and their Application to Ionic Liquid-Based Systems for Closing the Nuclear Fuel Cycle

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Recent developments in instrumentation have opened up new vistas for radiation research using pulse radiolysis techniques. Picosecond pulse radiolysis has become a routine technique in several countries, and new techniques are under development to further expose physical events occurring at very short times following radiolysis. Optical fibre-based "single-shot" methods providing picosecond-timescale transient spectroscopy detection for sub-millilitre liquid and solid samples now exist. New technologies such as mid-IR quantum cascade lasers enable detailed mechanistic studies of radiation-induced reactions using the high resolution and structural specificity of vibrational spectroscopy to identify intermediates. Broadband multispectral detection has increased the power and throughput of pulse radiolysis detection methods in the infrared and UV-Vis-NIR. In addition to the current progress described above, a perspective will be offered identifying important areas for future instrumentation development in support of cutting-edge radiation science.

Ionic liquids (ILs) attract the interest of researchers and industry due to their remarkable properties, and many applications in the fields of energy and technology, including as a potential medium for the treatment of spent nuclear fuel for the sustainable use of nuclear energy. For several years we have studied aspects of ionic liquid radiation chemistry from primary species reactivity through long-term product accumulation, to elucidate their degradation pathways. We aim to develop innovative, effective and durable IL-based separations systems, so we must also describe how radiolysis interferes with the separation process. During this project we found several classes of ions that are resistant to ionizing radiation and we will present some examples. The recent development of mid-infrared transient absorption detection has been particularly useful. For example, we observed the immediate formation of acetaldehyde and vinyl alcohol during pulse radiolysis of choline NTf2.

This work and use of the LEAF Facility of the BNL Accelerator Center for Energy Research, were supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Chemical Sciences, Geosciences and Biosciences, under contract DE-SC0012704 (BNL).

Overview of Disinfection of Cultural Heritage Artefacts and Archive Materials by Ionizing Radiation in Brazil: Culture Meets Nuclear

P. Vasquez[1]

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Brazil is a multicultural South American country has had the influence of the pre-Columbian native civilizations, the Portuguese and African colonization and lately the European colonization especially from Germany and Italy, not to mention that Brazil is home to the largest Japanese population outside Japan. In addition other factors, this situation makes the country own a vast variety collection of historic value objects. Brazilian weather conditions have been affected directly tangible materials causing deterioration besides on insects and fungi attack. Natural disasters particularly floods also have been affected many collections inside the country. Within this scenario, the γ-radiation processing arises as an alternative to traditional methods to the disinfection of cultural heritage artefacts and archived materials. Over the last years, the Nuclear and Energy Research Institute (IPEN), mainly through the Multipurpose Gamma Irradiation Facility located inside the São Paulo University campus, started a strong interaction programme with conservation and preservation institutions and too with the conservation community to disclose the irradiation technique. Currently, this facility has irradiated for disinfection purposes effectively several works of art, museum collections artefacts, books, manuscripts, drawings, archive documents, musical instruments, ethnographic objects, archaeological findings, natural history collections among others from various regions of the country. γ-irradiation has several advantages when compared with conventional preservation methods mainly related to the safety, efficiency, reliability, capacity, process time and safe for environment. The success obtained in Brazil with these applications is due to the support of the IAEA to many regional projects related to the nuclear techniques applied to cultural heritage preservation and research. The IAEA policies are helping to understand that the cultural heritage is a legacy of physical artefacts and intangible attributes of a group or society that are inherited from past generations, maintained in the present and restored for the benefit of future generations.

A02: Advanced Polymeric Materials

Past, Present and Near Future of Radiation Processing of Polymers

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In the early years of radiation processing, radiation-induced cross-linking of polymers and radiation sterilization of medical products have developed into substantial industries. Radiation processing of polymers in its widest sense is the application of radiochemical effects of ionizing radiations (γ-rays, X-rays, accelerated electrons, and swift heavy ions) on polymers and plastics on industrial scale. When polymers are irradiated with high energy radiation the ultimate effects are observed as cross-linking and/or scissioning of main or side chains, grafting, curing and formation of oxidized products. Among the established industrial applications of radiation processing of polymers; cross-linking of insulation of cables and wires, preparation of heat-shrinkables, polymer foams, automotive parts, tyres, water distribution pipes, tubes, plastic medical devices, hydrogel burn and wound dressings, composites, controlled degradation of teflon and marine-based cellulosics can be mentioned. The field of lignocellulosic fibre-polymer composites utilizing radiation technology in their formulation is re-emerging[1].

The applications mentioned above are based on radiation-induced control of structure formation in polymers on macroscopic scale, with the growing interest on development of nanomaterials based on polymers. However, the unique role and power of ionizing radiation in nanostructuring have been rediscovered. Nanostructure formation by using ionizing radiation encompass a wide range of products namely, nanocomposites, nanogels, metallic nanoclusters, surface grafting at nanoscale, functionalization of track-etched membranes, molecular imprinting. This review will highlight chronologically the milestones of radiation processing of polymers in bulk, radiation-grafted materials for separation and purification[2], for energy conversion and energy storage[3] and health-care applications. Established and emerging applications of radiation technology for nanotechnology will be elaborated with a future outlook.

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Radiation Curing by Cross-Linking Polymerization of Multifunctional Monomers: A Comparison Between Free Radical and Cationic Mechanisms

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A02

Radiation-curing by polymerization of multifunctional monomers is a well-established technology in the field of coatings and adhesives as well as in the graphic arts. UV-visible light and high energy radiation are alternative activation processes exhibiting their specific scope, advantages, and limitations depending on the application. The situation is quite different when the industrial goal is to cure thick and large parts of composites reinforced by fillers or by fibrous materials that induce opacity with respect to UV visible light. High-energy radiation processing has been identified since decades as a promising method for performing out-of-autoclave curing, with several advantages in terms of processing time, energy consumption, environmental footprint and sanitary concerns. The challenging objective of developing the EB/X-ray curing technology for high performance composite materials drives the needs of the advanced knowledge and understanding of reactivity to structure to properties inter-relations. Our paper will focus on the nanostructural features of radiation-cured networks.

The radiation-induced polymerization of multiacrylate monomer compositions is known to proceed heterogeneously at various dimension scales, depending of monomer composition. In radiation-cured materials based on a single type of monomer, the network were shown to display heterogeneities of cross-link densities resulting from a complex interplay between mechanistic and kinetic factors along the solidification process. Compared to free-radical chain polymerization, radiation-initiated cationic polymerization exhibits peculiarities at the different steps of the chain process (complex initiation and propagation mechanisms, pseudo-living character, …). The influence of these features on the reactivity and on the microstructure of multifunctional aromatic epoxy monomers and of their acrylate analogs has been examined using various types of radiation (UV, visible, EB, X-ray). Complementary spectroscopic and analytical methods were implemented in order to correlate the changes of network physical properties with the progress of polymerization.

AFM analysis of the networks in the topographic, phase contrast and indentation modes provides quite informative data with indications on the actual dimensions of the soft and rigid domains, and of their evolution, as the curing level is driven to higher values.

Solid-state proton T_2 NMR relaxation experiments were also performed on radiation-cured materials with valuable quantitative information on the local mobility in the nanoheterogeneous samples as well as on the associated fraction of material, as polymerization proceeds.

On the basis of these observations and measurements, a consistent scenario for the build-up of radiation-cured networks is proposed for both types of polymerization mechanisms. The influence of this general behaviour is discussed in the perspective of elaborating materials with demanding use properties.

Use of Irradiation, for the Development of Active Edible Coatings, Beads and Packaging to Assure Food Safety and to Prolong Preservation

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There is a need to develop active packaging and active edible coating by using natural ingredients. To reduce the pollution problems caused by synthetic and non-biodegradable packaging films, biodegradable packaging materials are encouraged to be developed especially in case of antimicrobial packaging. Also, the consumer demand to replace synthetic antimicrobial by natural compounds is rising. However, natural antimicrobials are not stable and should be encapsulated or immobilized in polymers to preserve their bioactivity and to assure a control release of the active compounds during time. Edible polymers should possess the appropriate barrier and chemical properties and should retain its properties during commercial marketing of foods. Proteins and polysaccharides have been used to develop edible coatings, beads and biodegradable films. However, these polymers are soluble in water and their functional properties should be improved. This presentation will focus on the use of cross-linking and functionalization of polymers by γ-irradiation for the development of active edible coating, beads and packaging and the use of γ-irradiation in combination with these active polymers to assure food safety.

Radiation Grafted Antimicrobial Film for Advanced Active Packaging Application

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Low density polyethylene (LDPE) film was grafted with sorbic acid (SA) using radiation induced grafting (RIG) technique to develop advanced antimicrobial grafted film for active packaging application. Instead of mixing antimicrobial additive as food additive directly with food, this additive was incorporated in films via RIG and allowed the functional effect at the food surface, where microbial growth is mostly found. Therefore, removal or reduction of preservatives from food formulate with non-migratable additives increases food safety and meets consumer demands for fresher food. The evidences of sorbic acid (SA) grafting film were studied using grazing-angle Fourier transform infra-red spectroscopy (GA-FTIR), field emission scanning electron microscope (FESEM), atomic force microscopy (AFM) and X-ray photoelectron spectroscopy (XPS). The antimicrobial properties of LDPE film functionalized by sorbic acid were evaluated with respect of its mechanical properties and surface properties. The analysis of fungi killing time during storage of freshly baked bread packed in grafted shows a significant antimicrobial efficacy on food indicating the potential of grafting of this active agent on a LDPE film instead of adding it in the food itself.

Radiation Mediated Bioactive Compounds Immobilization on Polymers to Obtain Multifunctional Food Packaging Materials

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Irradiation of polymeric surface is a versatile way to implement specific functionalities which further can react with bioactive compounds in order to confer to materials antimicrobial, antioxidant and biological functions absolutely necessary to protect, prolong self life of food products and make them beneficial for health.

Both undegradable and degradable polymers were exposed in optimal conditions to γ-rays or cold plasma in various atmospheres (air, oxygen, nitrogen) and oxygen- and nitrogen-containing groups were reacted with chitosan, vitamin E and C and vegetable oils with high therapeutic value encapsulated in nanostructures obtained by co-axial electrospinning or emulsion techniques. The nanoencapsulation of active (antimicrobial and antioxidant) vegetable oils into chitosan matrix by leads to a significant decrease of total viable counts when compared with the PLA substrate plasma pretreated and surface modified only with chitosan. The bioactive layer was covalently linked onto a polymeric substrate so it is stable, and compounds do not migrate in food products and bulk properties of base materials are not changed.

Bioactive multifunctional polyethylene based food packaging with antimicrobial activity against both gram positive and gram negative bacteria and antioxidant activities have been obtained. Use of chitosan/vegetable oils shows synergistic activities. Two other biodegradable substrates as polylactic acid and cellulosic materials (cellulose/chitin blends and kraft papers) were subjected to the same procedures with very promising results, moreover, these are easily recyclable and integrate into environment after use. Assessment of degradation of materials was investigated by enzymatic degradation in presence of phanerochaete chrysosporium by biochemical investigation (superoxide dismutase activity in fungi mycelium samples, content of malondialdehyde, catalase enzyme, extracellular protein), changes in average molecular weight, ATR-FTIR and AFM. The plasma and γ-radiation exposed PLA and PLA/CHT stratified composites supported fungal growth resulting in their degradation, which is reflected in change in polymeric substrate structure. The presence of bioaccessible material, i.e., PLA and chitosan, facilitated degradation. The plasma and γ-irradiated PLA samples show increased degradation. Natural and synthetic polymeric substrates, plasma activated and/or γ-irradiated, were tested as active-food packaging to improve the shelf-life of poultry meat, fresh beef meat, fresh curd cheese and apple juice. Rosehip seed oil was found to impart the best antioxidant and antimicrobial properties.

By comparison of γ-rays or cold plasma exposure we can conclude that γ-irradiation is more efficient in terms of bioactive functions of obtained materials.

Radiation Processing of Natural and Synthetic Polymers for Potential Applications

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The effect of ionizing radiations on the cross-linking and degradation of some natural polymers such as CMC-Na, chitosan, carrageenan, alginates and starch was investigated. Trials were made to control and reduce the irradiation dose required for the CMC-Na degradation by the addition of some additives and controlling the irradiation conditions. The possibility to cross-link CMC-Na/PAAm and starch/PAAm blends using electron beam irradiation to obtain good adsorbent materials of unique properties for possible practical uses were also investigated. The end product of irradiated natural products such as carboxy-methylcellulose, chitosan and Na-alginate may be used as food additive or benefited in agricultural purposes. From an economic point of view these doses are not accepted, it was significantly reduced by the addition of APS, KPS and H_2O_2. The addition of such additives to chitosan or Na-alginate during irradiation process accelerates their degradation. Degraded Na-alginate and chitosan could be used as growth promoter for plants in agriculture purposes. The growth and other responses of Zea maze and bean plants that treated with irradiated Na-alginate or chitosan of different Mw's were investigated. The test field results showed that the treatment of the zea plant with irradiated Na-alginate or chitosan enhanced the plant growth and increases its productivity.

Chemically cross-linked, pH-sensitive PVP/PAAc hydrogel nanoparticles were successfully prepared in a high yield via γ-radiation-induced polymerization of acrylic acid in aqueous solution of poly(vinylpyrrolidone) (PVP) as a template polymer. The particle sizes of the PVP/PAAc nanogels at different pH values were evaluated using dynamic light scattering (DLS) and the morphology was assessed using atomic force microscopy (AFM) and transmission electron microscopy (TEM). Smaller and more stable nanogel particles can be produced by irradiating a feed solution of 50–75 mol% AAc and using PVP of high molecular weight. Factors affecting size and encapsulation efficiency were optimized to obtain nanogel sufficient to entrap drug efficiently. The use of PVP/PAAc nanogels prepared at different compositions and irradiation doses was evaluated for dry eye syndrome application.

A03: Advances and Trends in Radiation Science and Technology

Novel Ion Exchange Membranes Synthesized by Radiation Grafting Technique for Application in Vanadium Redox Batteries

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Vanadium redox battery (VRB) has attracted more and more attention as energy storage system due to its long cycle life, deep discharge ability, high energy efficiency and low cost. The ion exchange membrane (IEM) is one of the key components of VRB to prevent the crossover of vanadium ions, and allow the transport of ions to complete the conducting circuit. The ideal IEM should possess low permeation rates of vanadium ions to minimize self-discharging, high conductivity, good chemical stability and cost-competitiveness. The current available commercial membranes cannot satisfy all of the above requirements. In this report, a series of amphoteric ion exchange membranes (AIEMs) were prepared by co-grafting of styrene/ N,N-dimethylaminoethyl methacrylate (DMAEMA), α-methylstyrene/DMAEMA or sodium styrene sulfonate/DMAEMA binary monomers into fluoropolymer films and sequent chemical reactions. The properties of the AIEM strongly depended on the composition and grafting yield of the membrane, i.e., higher content of DMAEMA brought lower permeability of vanadium ions, while higher grafting yield led to higher water uptake, IEC and conductivity. By changing the conditions of the grafting reaction, The AIEM exhibited high ion exchange capacity (IEC) and conductivity, as well as significantly reduced permeability of vanadium ions. VRB assembled with the AIEM maintained an open circuit voltage (OCV) higher than 1.3 V after placed for 300 h, and exhibited higher Coulombic efficiency and energy efficiency than that with Nafion 117 membrane. Furthermore, the AIEM grafted DMAEMA and α-methylstyrene has high chemical stability. The preparation of AIEM with grafting DMAEMA and sodium styrene sulfonate avoids sulfonation, which is an environmental friendly process. In order to optimize the synthesis method, radiation grafting technique and solution casting method have been used to synthesize the AIEM by grafting styrene and DMAEMA into poly(vinylidene fluoride) (PVDF) powder. This AIEM with new process could get higher conductivity than traditional method using PVDF film as substrate, due to the uniform distribution of ion exchange group in the AIEM. Based on the above experiments, an upscaling radiation grafting technique has been developing for the preparation of the AIEM with an area of 850 mm $\times$ 750 mm.

A03

Irradiation Induced Modification of Nanoporous Metal Organic Frameworks

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Metal organic frameworks (MOFs) are a class of nanoporous materials built from nodes of metal clusters connected by organic ligands. The high specific area and abundant nanopores have made MOFs promising in application such as gas storage, molecular separation, heterogeneous catalysis and drug delivery. In the present work, the irradiation effect and irradiation induced modification of MIL-101 (Cr) —a typical MOF material synthesized by the coordination of Cr(III) ions with benzene-1,4-dicarboxylate ligand— was investigated.

The results of electron spin resonance (ESR) showed that the free radicals generated on MIL-101 (Cr) after γ-ray irradiation were benzoyl free radicals and the concentration of benzoyl radicals decayed with time upon storage. The reactivity of the benzoyl free radicals on MIL-101 (Cr) was proved by the simultaneous graft polymerization of 2-hydroxyethyl acrylate (HEA) onto the surface of MIL-101 (Cr) initiated by γ-irradiation. The grafting kinetics of HEA on MOFs was similar to the conventional graft polymerization, which indicated the irradiation induced grafting method can be used to modify MOFs just like the irradiation induced modification of polymer materials. The PHEA graft chains significantly increased the hydrophilicity of MIL-101 (Cr) and the contact angle of water on MIL-101 (Cr) decreased from 156.7° to 61.5°. Brunauer–Emmett–Teller (BET) surface area measurements were performed to investigate the effect of grafting modification on the specific area of MIL-101 (Cr). The results showed the specific area of the modified MIL-101 (Cr) increased 50% compared to that of as prepared MIL-101 (Cr), which should be attributed to the accumulation of PHEA graft chains on the surface of the MOFs.

X-ray diffraction (XRD) was used to investigate the crystal structures of the as prepared MOFs and the modified MOFs. The characteristic peak of the modified MIL-101 (Cr) was almost the same as that of as prepared MIL-101 (Cr), which indicated the nanopore structure of MOFs was not damaged by irradiation. In conclusion, HEA was successfully grafted onto the surface of MIL-101 (Cr) initiated by γ-irradiation. The specific area increased without affecting the nanoporous structure of MIL-101 (Cr). The surface of MIL-101 (Cr) converted from superhydrophobic to hydrophilic. The present work provides a new method for the preparation of hydrophilic nanoporous materials.

Synthesis of Amine-Containing Surfaces in Poly(Tetrafluoroethylene) by γ-Radiation

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Amine grafting polymers can be useful surfaces for cell colonization, they are usually prepared by plasma polymerization of alkylamine monomers. γ-radiation could be a good method to graft several monomers with amine groups in the desired polymer substrate as PE, PP, PET, etc. In this study, amine surface in poly(tetrafluoroethylene) (PTFE) was obtained by two different methods: a) grafting of acryloyl chloride by radiation direct method and preirradiation peroxidation method of acryloyl chloride in dichloroethane solution and further reaction with diethyldiamine; and b) preirradiation peroxidation grafting of acrylic acid (AAc) onto PTFE, acylation reaction with $SOCl_2$ and further reaction with diethyldiamine. The grafting of AAc onto PTFE was studied before by Sadurni *et al.* (2000). The grafting of acryloyl chloride onto PTFE was synthesized for the first time; the radiation direct method was the best method with higher grafting yield. The effects of the monomer concentration, absorbed dose, and reaction time were studied. The amount of amine groups were evaluated, gravimetrically and the density of amine groups in the surface by derivatization with 4-trifluoromethylbenzaldehyde (TFBA) followed by X-ray photoelectron spectroscopy (XPS) analysis. Samples were also characterized by FTIR, contact angle, SEM and AFM. Further studies will report the presence of a critical concentration of amine groups to adhere different types of cell lines.

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A03

Polycarbonate Chromatography Column to Be Used in a ^{99}Mo/^{99m}Tc Generator Irradiated in Saline Solution with EB and γ-Rays

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The technetium-99m generator (technetium cow or moly cow) is a device used to extract the metastable technetium isotope ^{99m}Tc from a source of decaying molybdenum-99. ^{99}Mo has a half-life of 66 hours and can be easily transported over long distances to hospitals whereas its ^{99m}Tc decay product (half-life of 6 h is inconvenient for transport) is extracted and used for several nuclear medicine diagnostic procedures, where its short half-life is well adapted. This device works as a closed system, where the principal component is a chromatographic column of acid alumina (Al_2O_3) as stationary phase. Currently this column is produced using borosilicate type 1 glass.

The goal of this study was to characterize the irradiated polycarbonate (PC) column in saline solution to simulate a ^{99}Mo/^{99m}Tc generator in real use conditions. PC column and PC samples were EB and γ-irradiated in saline solution with radiation absorbed doses up to 200 kGy. Samples were analyzed by electron paramagnetic resonance spectroscopy (EPR), infrared spectroscopy (FTIR), ultraviolet spectroscopy (UV), differential scanning calorimetry (DSC) and wide-angle X-ray diffraction (WAXD). Additionally, the γ-irradiated PC column in presence of saline solution was studied using high performance liquid chromatography (HPLC) coupled with fluorescence detection in order to investigate the chemical phase diffusion of bisphenol A (BPA). EPR results showed at X band region a strong singlet attributed to a phenoxyl radical in the irradiated sample at room temperature. Decay of radical occurs approximately within 40 days. UV spectra presented increase in relative absorbance at 400–450 nm with increasing radiation dose. Ionizing radiation caused greenness of the original clear PC samples. This discolouration confirms the formation of phenoxyl radicals. On the other hand, glass transition temperature decreased by 1% (5K) for the maximum radiation applied dose. Similarly, a small decrease on carboxyl group peak at 1770 cm^{-1} was observed by FTIR. No detectable change on crystallinity was observed by WAXD. For sterilization absorbed dose, results shown no significant changes on the studied properties that way can be recommend to use PC columns instead borosilicate glass column in the ^{99m}Tc generator. The protocol via HPLC with fluorescence detection used in this work can be employed to detect the chemical phase diffusion of BPA in saline solution at ppb concentration

EB Irradiation on Piezo-PVDF: Beneficial Effect for Harvesting Energy Application

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Poly(vinylidene fluoride) (PVDF), is one of the most attractive semi-crystalline polymer owing to its remarkable pyro-, piezo- and ferro-electric properties. These thermal and electrical properties result from an appropriate crystalline phase arrangement inside PVDF bulk. PVDF polymorphism is well-known and consists of four crystalline phases, named α, β, γ and δ phases. In β phase, PVDF chains are arranged in pairs adopting an all-trans planar zigzag conformation, resulting in a significant net dipole moment. Whatever the phases, poling is a necessary ultimate step to align whole microscopic net dipole moment to the direction of the electric field.

Since the discovery of the piezoelectric properties of PVDF in 1969, many research groups immediately understood the potential applications of the polarized β-PVDF as sensors and actuators. In the recent years piezoelectric PVDF membranes have experienced a resurgence of interest for energy harvesting. However, their use as electrical generators has remained rather limited due to their relatively low power output, despite the large reversible elastic deformation.

A03

Starting from polarized PVDF film, we have shown that irradiation energy doses lower than 100 kGy is a competitive way to modify structural components of the PVDF, e.g, its elasticity, without affecting the electro-active properties. The increase of crystallinity obtained for range doses lower than 25 kGy could be exploited to enhance the piezoelectric response after a further poling step. Moreover, the results suggest that irradiation doses higher than 25 kGy reducing the crystallites size affecting the piezoelectric response. A homemade pressure-cell system was realized to correlate the bending deformation on the PVDF membrane with the output voltage. FT-IR, DSC and XRD techniques give new insights on which crystalline part or structural change contributes at the surplus output voltage.

Co-Reduction Synthesis of Graphene/Au Nanocomposite from Graphene Oxide/Au^{3+} Solution upon γ-Irradiation

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A simple method for reducing graphite oxide (GO) using γ-irradiation is explored without using any photocatalysts or reducing agents. The obtained reduced graphene oxide (r-GO) is investigated by XRD, TEM and FT-IR. Various spectroscopic and imaging techniques confirm that most of the chemical functional groups present on GO are removed by irradiation, and Au nanoparticles are deposited on r-GO sheets which prevents the aggregation of Au nanoparticles. The nanoparticle size increases with increasing Au^{3+} doping level. Moreover, the catalytic activity of the r-GO/Au nanocomposites is also investigated.

A03

An Improved Method of Producing Adsorbent for Metal Removal Using Radiation Induced Graft Polymerization

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Vapour phase grafting of kenaf fibre with glycidyl methacrylate (GMA) using radiation-induced grafting was studied to develop an adsorbent for removal of metal from aqueous solution. The preirradiation of kenaf fibre was carried out at different doses from electron beam accelerator at various absorbed radiation doses (10 to 100 kGy). The grafting process was carried out in a chemical vapour deposition reactor operated at temperature of 40°C and gauge pressure of 0 MPa to -0.1 MPa with time range of 15 to 90 minutes. The percentage of grafting, P_g (%) was calculated based on quantitative Fourier transform infra-red spectroscopy (FTIR) analysis. The grafted fibre were confirmed using FTIR and scanning electron microscopy. The optimal condition for enhancing P_g was obtained at irradiation dose of 50 kGy, -0.025 MPa gauge pressure, and temperature and reaction time of 40°C and 30 minutes, respectively. Optimization of these parameters will be a guide for subsequent development of grafted copolymer for further functionalization for preparation of adsorbent. The effect in thermal stability of polymeric material after the incorporation of GMA was also investigated. It was found that incorporation of GMA increased the thermal stability of kenaf fibre. The adsorption capacity was assessed to evaluate the efficiency of the adsorbent towards aluminium removal. It was found that the adsorbent could remove more than 99% aluminium with the highest adsorption capacity of 4.98 mg/g.

Fabric Modification by Radiation Methods

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Our research groups is devoted to develop fabric modification by radiation methods, especially by radiation induced graft polymerization of functional monomers or together with nanoparticles.

The first research routine is based on radiation induced graft polymerization of the vinyl monomers. As a first step, by grafting the functional acrylate or methacrylate we can prepare superhydrophobic cotton fabrics which are durable for laundering and friction. Furthermore, by grafting and then amination or amidoxination we can prepare the metal ion exchangeable fabric for gold adsorption and reduction or uranium extraction from seawater.

The second research routine is based on radiation induced co-graft polymerization of the vinyl monomers and the inorganic nanoparticles, for example, functionalized TiO_2 nanoparticles or graphene oxide.

Very recently, we combined the radiation induced graft polymerization with the radiation induced reduction, which resulted in an antibacterial cotton fabrics grafted with pomegranate-shaped polymer wrapped in silver nanoparticle aggregations. This pomegranate-shaped silver NPAs functionalized cotton fabric exhibits outstanding antibacterial activities and also excellent laundering durability, where it can inactivate higher than 90% of both *E. coli* and *S. aureus* even after 50 accelerated laundering cycles, which is equivalent to 250 commercial or domestic laundering cycles.

The most advantage of the radiation methods in fabric modification is lying in the formation of the covalent bonds between the cellulous macromolecules and the graft chains or together with the nanoparticles, which is the key point for the laundering durability and permanent functionalization.

A04: Radiation for Environmental Protection I

Ionizing Radiation Induced Decomposition of Antibiotics in Waste Water

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Wide varieties of toxic organic compounds are entering the aquatic environment. The main sources of these impurities are the waste water treatment plants for domestic sewage. The co-occurrence of sublethal antibiotic concentration and high density of microbial population provides ideal condition for facilitating the selection and propagation of resistant bacteria in sewage treatment plants. To reduce the amount of harmful organic compounds entering into the receiving bodies of waste water a family of new technologies with the name advanced oxidation processes (AOP) is under development. In these technologies highly reactive, oxidizing radical intermediates (mainly OH radicals) are produced by various techniques, e.g., by ionizing radiation. Radiolysis provides the benefit to produce reactive oxidizing ($^{\bullet}OH$ and H_2O_2) and reduce ($O_2^{\bullet}$, e^-_{aq} and $^{\bullet}H$) species (or from a kinetic point of view highly reactive electrophile and nucleophile species) in situ from water.

Electron pulse radiolysis experiments were conducted using a Tesla Linac LPR-4 accelerator with kinetic spectrophotometric detection. A ^{60}Co facility with 11.5 kGy/h dose rate was used for γ-irradiation. LC/ESI-MS was used for final product analysis. The samples were also characterized by COD, TOC, TN and pH measurements and by complex toxicological analysis.

The oxidative and reductive decomposition of penicillin derivatives was studied, the change in the antimicrobial activity of the drugs was followed. The reaction mechanism of $^{\bullet}OH$ induced oxidation of penicillins indicates the existence of a short-living and a stabilized long-living $^{\bullet}OH$ adduct to the sulfur. The e^-_{aq} is accommodated on the carbonyl groups of the penicillin skeleton yielding ketyl radicals. Penicillins react with the hydrated electron somewhat similarly to a tripeptide. It appeared that excessive or insufficient absorbed dose is deleterious in relation to elimination of antibacterial activity. At low radical exposure the forming products exhibit enhanced toxicity and antimicrobial potency. The adverse effect at high radical exposure presumably arises from the forming polyhydroxylated phenolic compounds.

The $^{\bullet}OH$ induced decomposition of sulfonamide antibiotics in dilute solutions was also studied by a wide variety of analytical techniques. The degradation was shown to start with $^{\bullet}OH$ addition to the aromatic ring, the cyclohexadienyl type radical thus formed reacts with dissolved oxygen transforming to peroxy radical. This radical yields hydroxylated molecules by $HO_2^{\bullet}$ elimination, or it undergoes ring opening to aliphatic compounds.

It was shown that e^-_{aq} and $^{\bullet}OH$ are able to demolish the penicillin's β-lactam system responsible for their antimicrobial activity. However, careful optimization of the advanced oxidation process, determination of the dose necessary for decreasing the toxicity and improving the biodegradability is necessary. Based on complex investigations for both types of antibiotics the degradation with the formation of inorganic ions is multistep process, the molecules first are step-by-step oxidized and then mineralized.

Ionizing Irradiation-Induced Degradation of PPCPs in Aqueous Solution

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Pharmaceutical and personal care products (PPCPs), especially the pharmaceutically active compounds (PhACs) such as antibiotics and hormones have attracted great concerns worldwide for their persistence and potential threat to ecosystem and public health. PPCPs are being increasingly detected only recently and considered as potential hazardous to ecosystems owing to the rapid development of analytical techniques which enable quantifying PPCPs at trace levels and investigating their fate and transformation pathways.

Ionizing irradiation is a promising alternative for degradation of PPCPs in aqueous solution. The studies reviewed have demonstrated that ionizing irradiation effectively degrades a wide range of PPCPs in aqueous solution. Many PPCPs such as antibiotics and X-ray contrast agent could be removed completely by radiation. Solution pH is a key factor affecting PPCPs degradation. However, high doses are needed for mineralization and toxicity reduction. Development of the combined processes of ionizing irradiation with other techniques such as H_2O_2 and ozonation would be a solution to increase the rate of mineralization and reduce the cost.

In most cases, $^{\bullet}OH$ radicals are the major reactive species responsible for the degradation of PPCPs by irradiation. Identification of the intermediate and end products, addition of a radical scavenger and the application of pulse radiolysis technique are the most tested methodologies to explore the reaction mechanism of radiation-induced degradation and optimize the degradation efficiency.

The majority of studies on PPCPs removal using ionizing irradiation have been orientated towards the treatment performance and effects of operational parameters in pure water solution. Moreover, high concentrations of PPCPs were used in most studies for detecting those compounds easily, which can only reflect some situations such as the treatment of industrial pharmaceutical effluent and are far from the real situation in water matrix. From a practical point of view, studies on the decontamination and disinfection of the real effluent or water containing PPCPs by ionizing irradiation should be paid more attention and the transformation byproducts are of concern owing to their potential stability and toxicity. The bioluminescence inhibition assay with *Vibrio fischeri* has been used to evaluate the toxicological effect of PPCPs in aqueous solution after ionizing irradiation. Research on the toxic evaluation of parent compounds and their degradation byproducts using a variety of methods are needed in future studies.

Efficacy of Electron Beam Irradiation to Address Emerging Microbial Contaminants in Water Reuse Programmes

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Water availability is a major challenge facing municipalities around the world. To meet growing residential and agricultural needs, there are major water reuse programmes around the world. These reuse programmes span all the way from indirect potable reuse to direct potable reuse. The underlying hypothesis was that EB technology can breakdown the emerging contaminants of concern in water reclamation and reuse projects. We also hypothesized that the inactivation and elimination of contaminants by EB technology can be achieved cost-effectively. Having this technology in the "tool-box" of water reclamation technologies would open up innovative high-value, commercially-viable, and environmentally sustainable solutions and strategies for water reuse.

High energy electron beam irradiation was found to be effective in eliminating a variety of emerging microbial contaminants such as hepatitis A virus, norovirus, rotavirus as well as protozoa such as Cryptosporidium parvum. Additionally, EB was effective at achieving significant reductions of bacterial pathogens such as Shigella spp., Aeromonas spp., and Salmonella spp. Based on these studies, it was found that viral pathogens are the most resistant to EB irradiation and protozoan oocysts were the most sensitive. If 5 kGy EB is used for water reuse programmes, greater than 50-log reduction of bacterial and protozoan pathogens can be achieved. The log reduction of viral pathogens however was significantly lower ranging between 1 and 3 logs. These results suggest that EB irradiation technology can be major cost saving for water reuse programmes since it avoids the needs for other disinfection treatments and expensive membrane filters (to remove pathogens). The outcome of these analysis indicated that for large municipalities that require effluent treatment in the hundreds of millions of gallons per day, the minimum power requirement is at least 1 MW. Presently, commercial off-the-shelf (COTS) EB technology is available at significantly lower power ratings.

Toxicity Assays Applications for Assessing Acute Effects for Radiation Decomposition of Organics in Waters

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The knowledge for using electron bem irradiation for pollutants degradation is developing. Textile effluents and pharmaceuticals were the samples submitted to irradiations and to acute toxicity assays. An electron beam accelerator was the radiation source used for the treatment in batch experiments. Dafnids, rotifers and bacteria were applied for toxicity measurements. All the assays were performed at LEBA/IPEN (Environmental Biological Assays Laboratory). Doses required for decomposition of organics in water and related toxicity indicated that reduced colour of effluents with 2.5 kGy and 5 kGy. These doses were also suitable for toxic effects removal at pharmaceutical solutions (fluoxetine in sewage; propranolol and fluoxetine mixture and at fluoxetine and voltaren mixture). Part of real textile effluent (about 35% of samples) were very toxic (CE50 $<$ 5%) for daphnids and luminescence *Vibrio fischeri*. The surfactants contained at textile effluent were the most toxic compound. *Vibrio fischeri* luminescence was confirmed as one of the most sensitive assay, followed by *Ceriodaphnia dubia*, *Brachionus plicatis* rotifers and *Daphnia similis*.

A04

Radiation Technology Application in Environmental Protection

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Nitrogen oxides (NOx), sulfur dioxide (SO_2), volatile organic pollutants (VOCs), polyaromatic hydrocarbons (PAHs) and dioxins are still main air pollutants. They are mostly formed during fossil fuels combustion, solid waste incineration or at other industrial processes. In recent years, cargo ships are the major emission source of SO_2 and NOx emission generating very high concentrations of these pollutants in off gases.

Electron beam (EB) flue gas treatment technology for purification of gaseous effluents from coal fired boilers after testing in Japan, US, Germany, Poland, China and Bulgaria has been implemented in industrial scale in Pomorzany Power Plant, Szczecin, Poland. It is a dry scrubbing process with ammonia addition, high removal efficiency of SO_2 (>90%) and NOx (>70%) were obtained at 8 kGy absorbed dose, benign products were formed. EBFGT is also a very promising technology to remove SO_2 and NOx from flue gas generated by oil fired burner plants what was demonstrated at the pilot test carried out in Saudi Arabian oil refinery plant using a mobile accelerator. High removal efficiency of SO_2 can be easily achieved at low dose, however it needs very high dose (i.e., high energy consumption) to obtain high removal efficiency of NOx. EB technology combined with catalyst to increase removal efficiency of NO emitted from stationary source was investigated through computer modelling simulations. The feasibility to remove SO_2 and NOx from off gases generated from cargo ship by using EB technology was investigated, preliminary results showed that EB technology might be used to remove SO_2 and NOx from off gases emitted from cargo ship with presence of wet scrubbers instead of ammonia addition. NOx removal efficiency was increased from 3% (EB only) up to 62% (EB combined with 4.5% salty water scrubbers) at 8.8 kGy absorbed dose at 90°C for the initial concentration of NOx being 1500 ppmv with 500 ppmv SO_2 presence. EB technology might be used for PAHs and other organic pollutants removal as well. Recently emerging organic pollutants have been detected in tap water or ground water, their persistence cause people's concern. ICHTJ researchers have studied perfluorinated organic compounds (perfluoctanoic acid as a representative compound) destruction in aqueous solution by using EB or γ-irradiation. It showed that more than 80% PFOA was decomposed at 5 kGy dose under γ-ray irradiation in argon-saturated solution of pH 2.0 containing 20 mg/ℓ of t-butanol for initial concentration of PFOA being 1 mg/ℓ; under EB irradiation, nearly 100% PFOA was decomposed at 105 kGy dose. In order to get better understanding decomposition mechanism of PFOA under EB irradiation, a computer simulation was carried out. Good agreement was obtained between calculation and experimental results.

A05: Advances in Radiation Chemistry Research I

Basic Radical Reactions in Water Treatment by Ionizing Radiation

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In the so-called advanced oxidation processes (AOP) and in water treatment by ionizing radiation, which belongs to the class of AOP's, too, the main goal is to destroy, or at least to deactivate harmful water contaminants: pharmaceuticals, pesticides, surfactants, health-care products, etc. The chemical transformations are suggested to be initiated by hydroxyl radicals. However, some other inorganic radicals may also contribute to initiating the degradation.

The changes due to irradiation were followed by taking the UV-Vis spectra and by measuring the chemical oxygen demand (COD) before and after irradiation. The degradation products were identified after LC separation with MS-MS detection. To obtain information about the degradation, kinetics pulse radiolysis with kinetic spectroscopic detection was used. The spectra of the intermediates were calculated from the kinetic curves (radical concentration versus time, on the μs time scale) taken at different wavelengths. These spectra give information about the structure of the intermediates.

The kinetics and reaction mechanisms of a large variety of inorganic radicals with organic molecules were studied. It was shown that other inorganic radicals as $^{\bullet}OH$ also contribute highly to the initiation of degradation in most AOP's. Cl^- and HCO_3^- in the treated water reacting with $^{\bullet}OH$ transform to the $Cl_2^{\bullet-}$ and $CO_3^{\bullet-}$ oxidizing. Reactions of e_{aq}^- and $H^{\bullet}$ water radiolysis intermediates may also contribute to the degradation. In the primary reactions of all these radicals with organic molecules, carbon-centred radicals are produced. The reactions of the carbon-centred radicals with dissolved oxygen (DO) basically determine the oxidation rate. The peroxy radicals formed in the reactions of aliphatic carbon-centred radicals with DO may transform to peroxides and hydroperoxides, with the intervention of these intermediates gradual degradation takes place. Aromatic carbon-centred radicals (cyclohexadienyl radicals) in reversible processes react with DO, where the ring degradation is suggested to take place from the aromatic peroxi radicals. The primary carbon-centred radicals in uni- or bi-molecular processes may transform to other, e.g., oxygen or nitrogen centred radicals. These intermediates (e.g., phenoxy or anilino radicals) do not react with DO. Therefore, the initial degradation rate is low when, during the degradation reactions, there is a possibility for the formation of these radicals.

The carbon-centred radical formed in the reaction of a one-electron oxidizing radical with an organic molecule undergoes a second oxidation step when it reacts with DO. This reaction may be followed by further oxidations starting from the peroxy radical thus formed, or from the peroxide/hydroperoxide stabilization products. These reactions increase the degradation efficiency with a result that the one-electron oxidants induce 2–4 electron oxidations. When the radical does not react with DO, the degradation rate is low.

Synthesis of Novel Fabrics for Extraction of Uranium from Seawater

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The world's oceans contain more than 4.5 billion tons of uranium; however, access to this resource is limited by the ability to extract uranium from seawater efficiently. Lacing fabric substrates with chemical functionalities specific for uranium adsorption is one approach to meeting this challenge. Advanced adsorbent materials are being developed using polymeric substrates with high chemical stability, excellent degradation resistance and improved mechanical properties. Fabrics include polypropylene, nylon and advanced Winged Fibres from Allasso industries featuring extremely high surface areas for improved grafting density. Using a ^{60}Co γ-source and 10–32 MeV electron beam linear accelerator, the various fabrics have been irradiated over a wide range of dose rates, total doses and temperatures.

Innovative vinyl phosphate and oxalate exhibiting high distribution coefficients and selectivity for uranium along with excellent potential for free radical polymerization have been utilized in the functionalization of the fabric substrates. Azo compounds with higher selectivity have also been utilized but have required the use of a grafted chemical precursor. Attachment of the chelating adsorbent or its precursor to the substrate polymer is maximized through the optimization of numerous variables including monomer concentration, dose rate, total dose, solvent and temperature.

Following irradiation, fabrics are washed, dried and weighed to determine the degree of grafting (DoG). The presence of monomer in the fabrics is verified using numerous experimental techniques including X-ray photoelectron spectroscopy (XPS), scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS), and Fourier-transform infrared spectroscopy-attenuated total reflectance (FTIR-ATR). Zeta potential measurements allow for surface charge measurements to confirm the negative charge required for uranium chelation. The fabric capacity for uranium extraction was tested by rotating samples for 7 days in a rotary agitator with actual seawater spiked with 0.2 or 1.0 mg/ℓ uranium. The fraction of uranium in the solution which was removed due to uptake on the fabrics was found to rise with increasing DoG at both uranium concentrations. SEM-EDS measurements are used to map the distribution of adsorbed uranium on the polymeric fibres.

Current work includes optimization of grafting density in addition to material characterization on the molecular level and analysis of the sample microstructure. Further testing in synthetic seawater will be conducted to compare the selectivity of each adsorbent fabric towards uranium compared to that of other species, in addition to determining the loading and adsorption rates under various conditions such as pH, temperature and salt concentration. Experiments in real seawater will consider effects of organics on the adsorbent materials, test for durability and reusability and determine kinetics and efficiency of the uranium extraction as a function of degradation.

Ultrafast Electron Transfer Studied by Picosecond Pulse Radiolysis

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Furthering our knowledge on the reactivity of short-lived species in irradiated water at ultrafast timescales is necessary to understand the competitive reactions occurring within the first ps. The composition of aqueous solutions and the water/solid interface can potentially favour or inhibit one of these competitive ultrafast processes, such as electron hydration, electron hole recombination, proton transfer, or oxido-reduction of the solute. Pulse radiolysis measurements with 7 ps time resolution show that ultrafast electron processes occur in highly concentrated aqueous solution. The reactivity's of presolvated electron, pre-$OH^{\bullet}$ radical and pre-$H^{\bullet}$ atom radical are examined. By measuring the yield of the transient radical after the pulse it is shown that $H_2O^{\bullet +}$ radical undergoes an electron transfer and presolvated electron and pre-$H^{\bullet}$ atom are very efficient reducing species.

A05

Advances in Etched Ion-Track Polymer Membranes for Environmental and Microelectronic Applications

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Etched ion-tracks membranes are well-known and commercially available membranes for filtration which have, in the past decades, attracted a huge interest for applications in life sciences. More recently, since these membranes serve as template for nanowires or nanotubes fabrication, applications in microelectronics (e.g., MRAM for computers) have also been widely investigated. Control over the swift heavy-ion irradiation and subsequent etching condition enables the production of multiple or single channels of high aspect ratio. Playing on polymers chemical structure, crystallinity and track-etching strategies, channels of predefined sizes and geometries can be tuned such as cylindrical, conical or oblade-shaped channels, crossed-channels and so on. These track-etching technique presents the advantage to be industrially scalable. Among other examples, we will discuss how a large area fabrication of self-standing nanoporous graphene-on-PMMA substrate (interesting candidates for field-emission transistors) can be achieved simply.

Ten years ago, we have shown that, after a relatively short etching time, some track-etched nanoporous polymer membranes exhibited an EPR signal witnessing the presence of remaining radicals. These radicals, results of ion-matter interactions from previous irradiation, have been found reactive enough to initiate the radiografting of vinyl monomers. The grafted polymer chains are specifically localized on and all along the nanopores walls. This discovery has opened our applications field from polymer electrolyte membranes for fuel cells to the development of sensors of pollutants in waters.

In this talk, we will present our very recent achievements on etched ion-track polymer membranes for sensor applications in environment and microelectronics. The key of success is the use of a peculiar polymer, the poly(vinylidene difluoride) (PVDF). PVDF is a biocompatible and semi-crystalline polymer. Depending its crystallinity phase, it can also be piezoelectric. We will present how we have exploiting these properties for sensor applications.

Using Ionizing Radiation for Studying Radical Reactions with Nitroxides: Implications for their Biological Activity

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Radicals are part of the chemistry of life. The ever-increasing knowledge of the involvement of radicals in diverse pathological processes has expanded the search for more efficient antioxidants that can diminish radical-induced damage. Stable nitroxide radicals are receiving increased attention as potential therapeutic agents because of their pronounced antioxidative activity, low toxicity, and attenuation of oxidative and nitrosative damage in vitro and in animal models of inflammatory diseases.

We have used ionizing radiation for elucidating the kinetics and mechanisms of nitroxides reactions with radicals as well as with reduced metal ions and semiquinone radicals. Radicals which are neither good oxidants nor reductants such as carbon-centred radicals generally add to the nitroxyl group forming relatively stable adducts. The reactions of $^{\bullet}NO_2$, $HO_2^{\bullet}$ and peroxyl and thiyl radicals with nitroxides proceed via an inner-sphere electron transfer mechanism. The reactivity of nitroxides towards most radicals, excluding $HO_2^{\bullet}$ and peroxyl radicals, hardly depend on their structure. In the case of $HO_2^{\bullet}(pK_a = 4.8)$ the nitroxides reactivity decreases as the pH increases and, therefore, at physiological pH they are poor SOD-mimics.

The rate constant of nitroxides reaction with $^{\bullet}NO_2$ is extremely high (7×10^8 $M^{-1}s^{-1}$), and nitroxides catalytically prevent protein nitration, which is involved in diverse pathological processes. This has been demonstrated in vitro during the peroxidative activity of heme proteins in the presence of H_2O_2 and nitrite and in vivo using a mouse model of allergic asthma, which is an inflammatory disease, reflected by increased production of reactive oxygen and nitrogen species. The protective effects of nitroxides in suppressing the increase of main asthmatic inflammatory markers substantiate the key role played by reactive oxygen and nitrogen species in the molecular mechanism of asthma. Nitroxides are superior over common antioxidants, which their reaction with radicals always yields secondary radicals leading eventually to consumption of the antioxidant. Nitroxides act catalytically since their reactions with radicals form the respective oxoammonium cations, which are readily reduced back to the parent nitroxides by biological reductants.

The effects of the nitroxides are instrumental not only in protecting against oxidative and nitrosative damage, but also in elucidating the mechanisms underlying these processes.

Influence of N_2O and Ethanol on the Chemical Stage of Radiobiological Mechanism

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The biological effect of ionizing radiation may be rather strongly influenced by the presence of other substances in the corresponding medium during irradiation; see the problem of oxygen effect in tumor radiotherapy (at lower LET values). The radicals HO_2 arising in diffusing radical clusters formed mainly by densely ionizing ends of secondary electrons are responsible for the enhanced effect in damages of DNA molecules. Their frequency in the dependence on oxygen concentration will be presented, having been established with the help of our model based on the use of Petri nets. There are, of course, other substances (radiosensitive as well as radioprotective) that may influence the radiobiological effect and be practically applied too. We have chosen two of them: N_2O and ethanol (acting in opposite ways). Molecules N_2O react with hydrated electrons to form OH radicals which increase DNA damage while ethanol acts as scavenger of radicals and lowers DNA molecule damage.

To create the mathematical model which describes physical and chemical processes in the chemical stage of radiobiological mechanism we have used Continuous Petri nets. It enables us to describe and study the influence of both the main parallel processes: chemical reactions and diffusion of radical clusters. It is possible to study the time change of concentration of individual radicals during this diffusion process, which may be very helpful when the efficiency of different substances present in medium in the DNA damage (radiobiological effect) is to be studied. Concurrently, Petri nets enable us to simulate dependences of radical concentrations on concentration of oxygen, N_2O and ethanol which may be very helpful to study influences of those substances on DNA damage and find out their optimal concentration for radiotherapy and protection of cells against ionization radiation. We have started to study the corresponding problem earlier with the help of analytical model where system of differential equations has been used. The given model has been applied to the experimental data obtained for ^{60}Co radiation. The results of this model have been used for setting of basic parameters of Petri nets model.

EPR Characterization of γ-Irradiated Xerogels

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Silicate glass was considered as suitable material for dosimetric purposes, and the study of stable paramagnetic centres induced by radiation has proven its potential for radiation dosimetry. Despite its several advantages that make it especially attractive, silicate presents some disadvantages like heterogeneity of chemical composition and high melting temperature. These problems can be resolved by elaboration of silica glass at room temperature via sol-gel method, which was an excellent and economically process offering purity, homogeneity besides to control components and properties of this material.

In this study, the sol gel process preparation starts from a solution containing tetraethoxysilane (TEOS) precursor and consist mainly on two steps, hydrolysis and polycondensation. Hence, the sol to rigid glass conversion took place after loss of solvent, with drying gels at room temperatures and then γ-irradiated in order to induce paramagnetic centres. Therefore, we report in this study, the paramagnetic states induced after irradiation in iron doped and pure SiO_2 sol-gel glasses. The aim of the present work is to investigate the EPR properties of sol-gel silica glass and to ascertain its possible use for high dose dosimetry.

The EPR spectra of unirradiated silica, recorded at room temperature and at 140K exhibit a silent spectrum. However, major changes occur in the spectra of γ-irradiated samples are attributed to the formation of non-bridging oxygen hole centres and E' centres. The spectrum of iron doped silica recorded at 140K consists of four resonances: $g = 4.3$ attributed to ion Fe^{3+}, $g = 8.27$ and $g = 2.73$ associated to presence of iron clusters in pores, finally $g = 1.99$ may be due to defects of irradiation in sol-gel material.

The preliminary EPR analysis of radiation induced paramagnetic centres in sol-gel silica represents a relevant approach to dosimetry. According to the current results, complementary AFM and FTIR studies are in progress.

A06: Dosimetry and Standards for Radiation Processing

Process Control Methods in Radiation Technologies

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Radiation processing has become a well-known and well-accepted technology worldwide using different type γ-irradiation facilities, electron accelerators and X-ray machines. The technology is applied at various fields like radiation sterilization of medical devices, manufacturing of polymer products used in industry and health care, irradiation of various food and agricultural products, as well as the emerging technologies like synthesis of advanced materials and environmental protection. The successful implementation of these technologies depends very much on reliable quality assurance, i.e., the measurement of absorbed dose during process validation and control, the continuous check of machine parameters and the use of mathematical modelling in certain stages of the technology. It is achieved by using harmonized and standardized dosimetry procedures performed with different type and category product specific dosimetry systems. Dosimetry, as part of the total quality system provides quality assurance and documentation that the irradiation process was performed according to the preset specifications. Accurate and traceable dosimetry measurements, based on suitable calibration procedures, provide independent means for quality control in radiation processing.

In all validation steps (as described in ISO Standard 11137), i.e., during process definition, installation, operational and performance qualification, as well as in routine process control, various reference standard and routine dosimetry systems are applied for quality control. In the course of the presentation the main dosimetry procedures, required during the validation steps will be discussed. Thus the selection and use of reference and routine dosimeters for the characterization of the irradiation facility and the establishing of the irradiation technology as well as for routine process control will be highlighted through practical examples. Besides the challenges and solutions relevant to different irradiation facility designs and recent radiation technology requirements will be shown with respect to available process control methods.

Dosimetry and Process Control for Using Low Energy Electron Beams for Sterilization or Decontamination of Surfaces

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Low energy electron beams (100–200 keV) are used for sterilization or microbiological decontamination of surfaces in the medical device and pharmaceutical industry. This paper describes dosimetry methods used for validation and routine process control of these processes.

Dosimetry methods employed in high energy EB or γ-sterilization cannot be used at low energy EB, where the accelerated electrons are stopped within the dosimeter, and special methodology has been developed for this purpose. It is described how measurement traceability is maintained for dose measurement at low energy electron irradiation, and an uncertainty budget is also developed and described.

The basis for establishing a maximum acceptable dose and a dose needed for an effective process is given as well.

Is IQ/OQ/PQ Part of Irradiation Process Control?

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Regulations and ISO standards applicable for medical devices require that validation of a process shall be performed. In fact, both the U.S. Quality System Regulation 21 CFR Part 820 and ISO 13485:2012 have explicit elements requiring the manufacturer to perform tasks associated with IQ, OQ and PQ.

Only after performing IQ, OQ and PQ successfully with a desired result and established documents that verify each phase, can production get underway. This defined discipline for process validation has proven to be the ideal way to guarantee the best quality production and this, constantly over time.

During production, process control is the phase involved in ensuring the process is stable and consistently operating at the target level of performance with variations which have been set accordingly during OQ and PQ.

Relevant documents adapted to the radiation processing industry, such as ISO 11137-3, ISO14470, ISO/ASTM51649, ISO/ASTM51702, ISO/ASTM51608, ISO/ASTM52303, AAMI/ TIR 29 describe the purpose and the experiments to be conducted during IQ, OQ and PQ and routine control of the process of irradiation.

The purpose of this presentation is to show actual results of irradiation plant qualification following the mentioned standards/guides and an approach for routine process control. Preliminarily to those results, the dosimetry system calibration step and a dose measurement inter comparison conducted within the RLA 1013 004 ARCAL project, will be addressed since OQ/PQ results are mainly based on absorbed dose measurements.

Dosimetry Standards and Dissemination Systems for Radiation Processing in China

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In order to adapt the development of radiation processing and ensure that the product has been treated with an acceptable range of absorbed doses in China, a programme of high dose standardization was initialed in 1983. The high-dose standards and dissemination system has been established at NIM. The ferrous sulfate (Fricke) dosimeter is accepted as national reference standards, the ceric-cerous sulfate and potassium/silver dichromate liquid chemical dosimeters and alnine/EPR dosimeter are selected as transfer standards at NIM. The Fricke, potassium/silver dichromate, several kinds of radiochromic films (RCD), cellulose triacetate (CTA) and polymethylmethacrylate (PMMA) dosimeters have been recommended as routine dosimeters for radiation processing in China. A series of national standards, verifications and technical norms have been enacted and issued on the dosimetry for radiation processing and on the approval of irradiation facilities. This programme plays an important role in the dose measurement standardization and product quality assurance for radiation processing. This paper presents a brief overview of dosimetry activities for radiation processing carried out at NIM during the last 10 years. Calibration of systems with the Fricke reference standard and comparison of absorbed dose results obtained from NDAS program with potassium/silver dichromate dosimeter and alnine/EPR dosimeter for radiation processing in China are also discussed.

EPR Dosimetry Systems; Assessment and Developed in NCRRT

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During the last two decades, a team of NCRRT researchers developed and assisted many dosimetry systems depending on the electron paramagnetic resonance (EPR) analyzing method. EPR dosimetry is characterized by its non-destructive read-out and the possibility of dose archival. Recently, monosodium glutamate powder and prepared rods containing different concentration of it (3×10 mm) were studied to be a radiation sensitive dosimeter measured by ESR method of analysis. The dose range from 10–90 kGy tested for powder, whereas, rods are useful in the dose range from 10–120 kGy.

NCRRT researchers studied different substances evaluated as; taurine, strontium carbonate, riboflavin, strontium carbonate, anhydrous strontium sulfate, 2-methylalanine, magnesium lactate, ammonium oxalate, and arginine mono-hydrochloride. The response of taurine to γ-radiation doses in the range from 0.1 to 50 kGy was investigated, as well as that in the range from 1.0 to 20.0 Gy using numerically enhanced EPR taurine spectra. The radiation-induced defects in strontium carbonate ($SrCO_3$) rod dosimeter in the dose range of 2.5 Gy–25 kGy was investigated using EPR resonance technique. The un-irradiated riboflavin (RF) exhibits a very weak EPR signal ($g = 2.00950$) and upon γ-ray exposure the signal increases up to an absorbed dose of 50 kGy. Anhydrous strontium sulfate ($SrSO_4$) has shown a promise candidate as a dosimeter for low dose applications producing unique EPR signals with γ-rays which it has a linear response relationship ($r_2 \approx 0.999$) in the range of 1–100 Gy. The dosimetric characteristics of γ-radiation induced free radicals in 2-methylalanine (2MA) pellet dosimeter are investigated using EPR in the high-dose range of 1–100 kGy. The EPR spectrum of irradiated magnesium lactate (ML) rods was characterized by a quartet signal with the spectroscopic splitting g-factor of 2.0048700003 at 0.4 mT. The useful dose range of the rod dosimeter was 100 Gy to 80 kGy. The dosimetric properties of the of ammonium oxalate $(COONH_4)_2H_2O$ studied under low and high radiation doses. The EPR spectra of ammonium oxalate have the spectroscopic splitting g-factor of 2.00095 for $C_2O_4^-$ radical detected as EPR signal. The dose-response curves have very good linearity in the range 10–1000 Gy for low doses and show slight sub-linearity in high dose region up to 25 kGy. Arginine mono-hydrochloride rods (3–10 mm) were irradiated with ^{60}Co γ-rays to study radicals for dosimetric materials with EPR. The rods have significant signal which develops upon irradiation and the intensity of signal increases upon the increase in irradiation dose, in the dose range from 5 to 120 KGy.

More and more articles ware published by the NCRRT researchers group dialing with this issue represents the unique analyzing method of using EPR in the field of dosimetry.

A07: Advances in Radiation Chemistry Research II

The Radiation Chemistry of Organized Systems: Basic Studies and Implications

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The development of new approaches to radiation stabilization and radiation processing in various fields should be essentially based on consideration of the efficiency and spatial selectivity of the radiation-induced events in complex molecular systems and polymers. In fact, as shown in a number of recent studies, the radiation chemistry of such systems may be controlled by rather subtle effects, e.g., molecular packing determined by relatively weak interactions, conformation, supramolecular structure, dynamics on interfaces, etc. It implies that, in addition to understanding the radiation-chemical processes at the molecular level, one should consider the effect of system organization on the primary radiation-induced processes and kinetics of postirradiation reactions.

This lecture will present an overview of the modern concept of radiation chemistry of organized systems and illustrate its basic aspects and implications with results on different systems (from the simplest intermolecular complexes to nanocompsites) obtained in our laboratory during the past decade. Experimental characterization of the radiation-induced effects and structural changes was carried out using various methods, including EPR, UV/VIS, and FTIR spectroscopy, TEM and XRD analysis and complemented by theoretical simulations, when applicable.

The illustrative examples briefly covered in this lecture will include i) radiation-chemical transformations of frozen intermolecular complexes; ii) specific features of the radiation-driven processes in room-temperature ionic liquids (RTIL); iii) mechanism of the radiation-induced degradation of crown-ether based systems. Particular attention will be paid to nanostructured systems. A new method of controlled single-stage radiation-chemical synthesis of metal-polymer nanocomposites from the inter-polyelectrolyte complex films developed in our laboratory will be presented. This method makes it possible to obtain the composite films containing metallic or bimetallic nanoparticles with various size distribution and spatial organization using X-rays or fast electron beams. The results obtained with X-ray irradiation of nanostructured systems demonstrated a prominent effect of "radiation-chemical contrast" with possible applications for selective modification of nanocomposites and targeted sensitization (e.g., in radiotherapy).

Finally, the implications of the radiation chemistry of organized systems for various existing and emerging technologies (ranging from nuclear waste treatment to fabrication of new nanomaterials and nanolithography) will be outlined.

Interfacial Radiation Chemistry in Nuclear Technology

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Radiation effects on materials constitute a unique and often crucial feature in the nuclear industry. The effects can be either direct, due to radiation energy deposition in the material, or indirect, due radiation energy deposition in the surrounding media subsequently transferred to the material via chemical reactions. In the majority of nuclear technological systems such as nuclear reactors, fuel reprocessing plants and geological repositories for used nuclear fuel, the surrounding medium exposed to ionizing radiation is water. This is one of the reasons why the radiation chemistry of aqueous solutions has been studied so extensively. However, even though processes occurring in aqueous solutions are extremely important, the most crucial processes from a practical point of view are those occurring at the interface between the aqueous phase and solid materials as these can strongly influence the performance and the integrity of the facility. Of particular concern are corrosion processes induced by oxidative radiolysis products. In most cases the solid material of relevance is metallic or ceramic (primarily UO_2 in nuclear fuel). Hence, the surface of the material is an oxide. It has been reported that the yields (G-values) of the radiolysis products can change significantly in the vicinity of oxide surfaces. The rationale for this phenomenon is still debated. In addition, oxide surfaces have been shown to catalyze several reactions involving the molecular aqueous radiolysis products (H_2, H_2O_2 and O_2). Consequently, it is of utmost importance to gain fundamental understanding of the radiation driven processes of interfacial systems. In this paper, interfacial radiation chemistry will be discussed in general and the reactions of molecular radiolysis products catalyzed by oxide surfaces in more detail.

The oxide materials that have been studied are UO_2, Cu_2O and CuO of relevance in geological repositories for spent nuclear fuel according to the KBS-3 concept (copper coated canister), ZrO_2 of relevance in nuclear reactors (fuel cladding) and numerous other oxides that were mainly studied in order to understand the influence of fundamental oxide properties on the catalytic properties of the surface.

The experiments show that the catalytic decomposition of H_2O_2 yielding O_2 and H_2O as final products proceed via the intermediate formation of surface bound hydroxyl radicals. This process is catalyzed by most oxide surfaces. For irradiated systems it is also obvious that radiolytically formed hydroxyl radicals adsorb to oxide surfaces present in the aqueous phase. Specific studies of metallic copper in water have shown that copper irradiated in anoxic aqueous solution undergoes significant corrosion and takes up more hydrogen than copper exposed only to water during the same period. Other experiments reveal that H_2 and O_2 produce H_2O_2 at room temperature in aqueous solution containing oxide surfaces.

In conclusion, oxide surfaces catalyze a number of reactions that are usually not accounted for in homogeneous aqueous radiation chemistry. The molecular radiolysis products yield surface bound radicals of unknown stability. To fully understand present and future systems of relevance in nuclear technology, we must strengthen our knowledge in interfacial radiation chemistry.

Radiation Sterilization of Devices and Scaffolds for Tissue Engineering

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A sterile medical device is one that is free of viable microorganisms. This can be achieved through: a terminal sterilization process, sterilization of some components, a combination of chemical/physical sterilization and aseptic processing. The choice of a sterilization process and the sterility assurance level (SAL) should be addressed early in the development of the product and process design requirements in conformance with an integrated quality and risk assessment management system. For radiation sterilization, many standards are proposed to validate the process, and the substantiation of this sterile claim over time is through the dose audit process.

For the sterilization of all medical devices the most rigorous SAL (10-6SAL) should be selected and used based upon the ability of the product to function after it undergoes the sterilization process. But, many of the proposed scaffold materials do not withstand high doses to reach a 10-6SAL; so a lower SAL should be investigated on a risk based assessment, that involved the following criteria according the pretended use: Products intended to come into contact with breached skin or compromised tissue; Invasive products that enter normally sterile tissue; Products with claims of sterile fluid pathways; Surgically implanted devices; Products not intended to come into contact with breached skin or compromised tissue; Topical products that contact intact skin or mucous membranes, among others.

Sterilization by irradiation has shown a strong applicability for a wide range of products, such as single-use medical devices, tissue-based devices, combination devices, implantable devices and pharmaceuticals. Most of them are sensitive products, but, due to the new standards approaches, radiation sterilization has proven itself to be an effective and flexible method as indicated by its acceptance in the different pharmacopoeias and sanitary authorities.

A07

Effect of Sterilization by γ-Irradiation on Biocompatibility of Starch-Based Polymers and Composites Suitable for Stem Cell Growth

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Studies with biodegradable starch-based polymers have recently demonstrated that these materials have a wide range of properties, which make them suitable for use in several biomedical applications, ranging from bone plates and screws to drug delivery carriers and tissue engineering scaffolds. A novel non-toxic biodegradable starch based polymer was developed for use in tissue engineering applications. The starch and its blends consisted of: 100% starch; starch mixed with 10% cellulose acetate, 10% acrylic acid and 5% carboxy methyle cellulose; and starch mixed with 10% cellulose acetate and 10% carboxy methyle cellulose. Scaffolds were sterilized by ionizing radiation and cells were allowed to grow on the designed scaffolds. Biocompatibility evaluation of such blends was carried out using Hep-2 cells, which were cultured in direct contact with the different starch blends for 72 hours and observed in light and scanning electron microscopy (SEM). Viability was assessed using the light microscope, DNA content, nitric oxide content, lipid perocidation and MTT assay. Also, the effect of low level laser energy (LLLI) on enhancing the proliferation of cells on such scaffolds, were examined, where cells were exposed to He:Ne laser at doses 1, 2.5 and 5 J/cm^2 every daily for a duration of two days. Both types of starch-based polymers exhibit biocompatibility that can allow for their use as biomaterials. Starch mixed with 10% cellulose acetate and 10% carboxy methyle cellulose blends were found to be the less cytotoxic for the tested cell line, although cells adhere better to starch cellulose acetate surface. Exposure to 2 J/cm^2 He:Ne laser greatly enhanced cell proliferation on all of the given scaffolds.

Radiation Chemical Studies Leading to the Development of Selenium Radioprotectors

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Radiation chemistry, a discipline involving study of chemical changes induced by ionizing radiation, has been the subject of interest for both researchers and technologists. Extensive research carried over the last few decades has translated into applications in the areas of advanced materials, nuclear fuel cycle, radiotherapy, sterilization, waste treatment, water purification, etc. Radiation chemistry of water as one of the important areas of research, provided understanding of the primary processes of water radiolysis, the same has also led to the progress of another related field, radiation biology. Hydroxyl ($^{\bullet}$OH) radicals, a powerful oxidant generated during water radiolysis, trigger sequences of events in the living cells causing several changes including mutations in DNA and cell death. While this formed the basis of radiotherapy for cancer treatment, the same became a matter of concern due to unwanted normal tissue radiation damage. In order to minimize this unwanted radiation damage to the normal tissue, radioprotectors are employed. Search for radioprotectors began following the Second World War and after screening several thousand natural and synthetic sulfur compounds, only one compound, amino thiol known as, "amifostine" has been approved for clinical use.

Our recent experience in the research area of radiation chemistry of selenium compounds, prompted us to find a new direction of developing radioprotectors from organoselenium compounds. Selenium as a member of chalcogen group shares similarities with sulfur and is a micronutrient and a constituent of redox active selenoenzymes like glutathione peroxidise. A number of selenium compounds such as selenoethers, diselenides, monoselenides have been synthesized and screened for radioprotection. Since $^{\bullet}$OH radical reaction is the primary process in radiation damage, the reactions of selenium compounds with $^{\bullet}$OH radical were studied in real time scales. For these studies, pulse radiolysis, a time-resolved linear electron accelerator based technique, used to follow chemical reactions in nanoseconds, was employed. The results indicated that in these compounds, selenium is the active centre for the attack of $^{\bullet}$OH radical and the reaction leads to formation of selenium centred radical cation, which interacts with the nearby hetero atoms through non-bonding interactions. Depending on the strength of interactions, the radical actions are converted to oxidized products, which played a crucial role in deciding whether the selenium compound can be explored as a radioprotector or not. Similar studies on several substituted selenocarboxylic acid derivatives suggested that a diselenide having propinoic acid substitution is structurally best suited for developing as radioprotector. Accordingly, diselenodipropionic acid examined in vivo systems was found to be a good organ specific radioprotector. Some of these results will be presented in the lecture.

The IAEA Research on Radiation Sterilization in Tissue Banking

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The IAEA programme on radiation and tissue banking is a major effort to establish and improve tissue banks in Member States (MS). Started in 1971, it became supported by IAEA's Department of Technical cooperation in 1982, and there are a number of running projects in this area coordinated by the Agency. Less known is that, apart from capacity building by the TC, IAEA's Department of Nuclear Sciences and Applications carried out Adaptive Research and Development projects related to tissue sterilization. These two directions of work reinforce each other and result in better Tissue Banking services in MSs. IAEA Coordinated Research Project (CRP) E31006 on "Safety and optimization of radiation sterilization in tissue banking: Studies on functional properties of irradiated tissue grafts" was started in 2010 and completed in 2015. Sixteen organizations, represented by Chief Scientific Investigators: Paulina Maria Estela Aguirre Herrera (CHI), Dr Emma Castro Gamero (PER), Mark Forwood (AUS), Clara Linda Guerrero (COL), Marisa Herson (AUS), Eulogia Kairiyama (ARG), Artur Marek Kaminski (POL), Astrid Ann Lobo Gajwala (IND), Jan Koller (SLO), Menkher Manjas (INS), Monica Beatriz Mathor and Wilson Aparecido Calvo (BRA), Peter Myint (UK), Isabel Maria Otero Abreu (CUB), María del Carmen Salidas Farinella (URU), Suzina Sheikh Ab. Hamid (MAL), Sven Scheffler (GFR) contributed to this project.

The use of tissue allografts in surgical procedures has increased tremendously over the last two decades. Radiation has been used to sterilize tissue allografts on a large scale. Controversies exist regarding the optimal dosage required since radiation may also compromise tissue allograft integrity and/or its biological function. Tissue banks use radiation doses just based on empirical and/or historical data, or use a fixed dose of 15 or 25 kGy for all tissue allografts. Moreover, radiation conditions differ very strongly from institute to institute which may strongly influence the efficacy of the radiation treatment. In order to improve the knowledge on radiosterilization of tissue allografts "new" and additional studies were designed and conducted under controlled and validated conditions. This "new knowledge" will lead to an optimization of the radiation sterilization process/procedures.

Five main categories of research topics were studied: Bone, Demineralized bone, Cartilage allograft, Skin and Amnion. Bone: Adoption of sterilization doses below 15 kGy improves tissue quality and surgical outcomes. Demineralized bone (DMB): Sufficient osteo-induction was observed after experiments using DBM treated at 15 kGy radiation dose. Cartilage: Present studies demonstrated that optical coherence tomography (OCT) is a suitable non-destructive technique to evaluate costal cartilage change after sterilization by ionizing radiation. Skin: Most sensitive tissue to structural changes induced by radiation proved to be animal skin, least sensitive human skin. Irradiation dose up to 25 kGy had minor impact on the ultrastructure of the irradiated skin and its functionality (evaporation index).

It can be concluded that since 2010 significant progress has been made by the participating tissue banks/institutes leading to the production of safer allografts both with respect to its functionality and sterility.

A08: Radiation Sources and Facilities: Panel Discussions

A08

Review of the Two New Rhodotron Accelerators: The Compact 10 MeV TT50 and the High Energy 40 MeV Rhodotron

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Emerging applications drive development of new innovative accelerators. IBA is currently developing two new accelerators. The first new accelerator is a compact electron beam accelerator called the TT50 allowing to produce beam up to 10 MeV. This accelerator is perfectly suited for industries sensitive to cost such as cargo screening, medical device sterilization or applications requiring mobile systems.

The second new product under development is a high energy Rhodotron able to reach 40 MeV and 125 kW of beam power. These specifications makes ^{99}Mo production using particle accelerators very competitive. Development status, innovations and target performances will be reviewed.

A08

A Billion Curies and Counting: Ensuring ^{60}Co Supply and Disposal for Decades to Come

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Nordion has been a leader in the production of ^{60}Co, used for prevention and treatment of disease, since the inception of the technology in the 1950s. This product has become a critical component of healthcare, impacting the daily lives of millions of people around the world.

Since the production of the first C-188 ^{60}Co source in 1964, Nordion has shipped more than one billion curies of Cobalt for use by the γ-processing industry. During this 50 year period, there have been significant changes in technology, regulation and the global supply chain. Our approach to managing the full lifecycle of the C-188, from sourcing to production to transportation to disposal, has allowed us to adapt to these changes and continue to provide a reliable supply of Cobalt to a global customer base

Today, we face a changing reactor landscape and new industry dynamics that offer both challenges and opportunities. Our Extend, Expand, Develop strategy is aimed at exploring a wide array of possibilities for strengthening the supply chain for the coming decades. We now have more than 20 active projects under way, from the development of new technology platforms to enhancement of existing partnerships, as well as the creation of new ones. We also continue to make use of established paths for disposal of spent sources, while pursuing other solutions in order to provide the best options for the industry.

This presentation will describe the evolving industry landscape as we see it, and provide an update on Nordion's efforts and successes around securing supply of ^{60}Co and managing the complete lifecycle for the long term.

How to Apply Radiation Technology for Pollution Control

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Since the 1980's, radiation technology has been introduced to pollution control, and over the past few decades this technology has been developed aiming at ensuring the safety of gaseous and liquid effluents discharged to the environment. It has been demonstrated that flue gas treatment (SOx and NOx removal), wastewater purification and sludge hygienization by radiation can be effectively deployed to mitigate environmental degradation. They even showed promising results through the operation of several pilot scale plants and industrial scale implementation, however, the technology was boggled and it needs to achieve a breakthrough. There are several drags to implement larger scale applications. Unlike other industrial applications, the environmental plant should operate all the year round without stopping. Once it stops, the waste (stack gas or wastewater) will discharge without any treatment, and the stand-by system costs too much. Thus, technical upgrades to manage the plants in such cases are required. Radiation technology, like other technologies, also has strong competition in market with conventional pollution treatment technologies. And hence, it is necessary to decrease the capital cost with the operating cost to have competitiveness in waste treatment cost. Nowadays, radiation processing equipment is getting more powerful and reliable, and ready to apply for pollution control, but requires a systematic operation for preventing the entire plant shutdown. To avoid tough competition, it is better to find niche applications where radiation technology can do better, such as removal of EDCs and pharmaceutical residues in domestic wastes, VOCs removals from industries or sludge hygienization. Computational methods, mobile EB and other effective ways to confirm laboratory results will help for easy scaling to industrial implementation.

ILU Industrial Electron Accelerators

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ILU electron accelerators designed and produced in Budker Institute of Nuclear Physics are working in industry and in research organizations. ILU-8 and ILU-10 machines have single-cell cavities, their maximum energies are 1 MeV and 5 MeV, maximum beam powers are 20 kW and 50 kW respectively. The recently developed ILU-12 and ILU14 machines have multicavity accelerating structures, their energy ranges are 5–7.5 MeV and 7.5–10 MeV, maximum beam power of ILU-14 is 100 kW. Radio frequency (RF) generators of the ILU machines are based on pulse vacuum triodes. Compact accelerator ILU-8 with energy up to 1 MeV is using mainly for wire irradiation, it has local radiation shield. All other ILU accelerators can be supplied with X-ray converters and can work in X-ray generation mode. Powerful ILU accelerator are used for wire, cable and pipe modification as well as for medical device sterilization and food irradiation.

EB Technology vis-a-vis γ-Radiation for Irradiation Sterilization: Emerging Scenario

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Irradiation sterilization as a green and safe sterilization method is widely used in the treatment of food, medical products, herbals and agricultural products worldwide. The main technologies for irradiation sterilization are γ-radiation and electron beam technology which includes EB and X-ray. Technology based on ^{60}Co was developed more than half a century ago, but following the continuous concerns on the radiation safety, nuclear security, radioactive waste and the supply of ^{60}Co sources, the development of γ radiation for irradiation sterilization faces more and more challenges. Electron beam based technology was developed much later relative to γ technology. As the need of alternative methods which do not use radioactive material for irradiation sterilization, EB technology has developed very rapidly in the last decade.

The presentation provides a general analysis of the advantages and drawbacks on different aspects such as regulation requirement, safety and security, products scope, economic competitive for both γ and EB technologies and will provide some suggestion and outlook for this emerging scenario of irradiation sterilization.

γ-Irradiator Technology: Challenges and Future Prospects

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γ-irradiator technology has served the bulk irradiation industry very well. Sterilization of medical disposables has been the most popular application followed by irradiation of food and other products. However, it has faced number of challenges in its journey so far. The initial irradiators utilized ^{137}Cs sealed sources in highly soluble chloride form. Wet storage irradiators had risk of contamination due to ^{137}Cs sources. There were incidents of irradiator facility and surrounding soil contamination due to source leakage. Availability of ^{60}Co in metallic form came handy to surmount this challenge. Over-exposure of plant personnel while carrying out maintenance has been reported. With the improvements in safety systems, this challenge was adequately tackled. Later, shortages of ^{60}Co in addition to high prices coinciding with availability of the challenger linear accelerator technology became the biggest challenge. Higher capital cost in addition to higher running cost of the LINACs was though a deterrent. Also, non-availability of reliable power supply in different parts of the world was an additional factor in accelerators not replacing γ irradiators at faster pace.

The most recent challenge to γ irradiator technology has come due to the heightened security risk the world is facing now. There are fears being raised regarding security of the high intensity radioactive sources in such irradiators. The security challenge is due to fear of the sources falling into the wrong hands. This possibly could happen when sources are in installed position or more so during their transportation. Such fears have forced the authorities to strengthen regulations. Shipping companies have become reluctant to carry radioactive materials, particularly when trans-shipment is involved. There are number of instances of denial of shipments making the situation worse. The maximum activity which can now be carried in a Type B(U) container is also limited to only 30 kCi of ^{60}Co whereas the requirements in industrial irradiators is much higher which makes the transportation by air exorbitantly expensive. The other requirement of regulatory body to obtain guarantee of return of sources to the original supplier is an additional impediment. To prevent source theft when it is in installed position, hardening of facilities or devices needs to be carried out so that response time for the security agency in case of theft attempt is shorter than what is needed by the adversary to remove the sources from the device and shift those to a makeshift container. Lastly, challenge due to possible dismemberment of installed sources which can result in large areas becoming inaccessible due to contamination is forcing operators to think hard before making a choice.

Accelerator technology being "On-Off", does not have such drawbacks. Because of this, LINACs have gained much higher importance in recent times. However, LINAC's lower efficiency of conversion of energy to electromagnetic radiation and its dependence on availability of economic and reliable power supply will eventually decide the time at which it replaces the γ irradiator technology fully in any particular part of the world.

A09: Preservation of Cultural Heritage

Disinfection and Consolidation of Archived Materials and Cultural Heritage Artefacts by Radiation Processing Techniques

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Degradation of organic and especially cellulose based heritage is caused by both endogenous and exogenous factors. One of the most common exogenous factor is moisture, and the variation of the equilibrium moisture content of the material can initiate the development of mold in the substrate. Mold not only affects cellulose materials, but is also impacts occupational health and thus should be rendered inactive as soon as possible. Doing nothing is not an option because active mold (even dormant) may deteriorate cellulose based heritage easily, while its wake-up call, i.e., an atmospheric moisture increase, can occur easily.

Much work has been performed on the application of γ-radiation and therefore it is well accepted in, e.g., the food industry and for medical device sterilization. However for cultural heritage application, discussions are still on-going as ionizing radiation may be capable of deteriorating organic materials. Compared to conventional disinfection with chemicals, γ-radiation can be seen as a clean disinfection method as no harmful volatiles are emitted after the treatment with full effectiveness on deteriorating the mold species.

In the past decade, many heritage science research programmes world-wide were dedicated to the application of ionizing radiation for disinfection and conservation. The research varied from optimization of the treatment to understanding of deterioration mechanisms, and in 2012 for the first time, an IAEA supported event was held in São Paulo, Brazil. The IAEA now supports a new research network dedicated to this topic aiming to solve final research gaps and produce well accepted recommendations.

This paper reviews not only the state-of-the-art of international developments on the application of ionizing radiation for cultural heritage for both disinfection and conservation, but includes a summary of show-cases. For example, the disinfection of the Library collection of the Peace Palace, the Hague (Netherlands) and conservation of a XVIIIth century parquet, Grenoble (France). Finally a novel book dedicated to the topic of this presentation, supported by the IAEA, shall be introduced.

Irradiation Method in the Protection of Cultural Heritage Objects Endangered by Massive Biodegradation

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Cultural heritage artefacts of organic origins are susceptible to deterioration by the action of insects, moulds, fungi and bacteria. The infestation of museum store rooms, collections and sacral places is a serious permanent worldwide problem to the safekeeping of such objects. Protecting cultural heritage objects against biodeterioration becomes especially urgent when provoked by sudden changes of their stable and optimum storage conditions, caused either by natural catastrophes (floods, earthquakes, tempests, etc.) or by human activities (wars, riots, street unrest, etc.). The emergency recovery of many objects in the course of a rescue operations can bring infested and non-infested objects into contact, engendering an abrupt development of pests and endangerment of whole collections.

The commonly used methods for suppressing massive biocontamination (capable of fast processing of large numbers of objects), are treatment with poisonous gasses and treatment with ionizing radiation. While the use of ethylene oxide gas is now severely restricted, irradiation has proven an effective physical, noncontact method of preservation, applicable to massive treatment of cultural heritage objects.

In its ~ 50 years of application to cultural heritage preservation, the irradiation method has most often been used for disinsection, i.e., eradication of insect pests from objects. In the course of safekeeping, massive treatments of entire museum collections during regular and/or urgent maintenance and clean-up procedures provide examples of especially appropriate applications of irradiation method. Likewise, in cases of simultaneous endangerment of many objects by mold, literally for entire collections caught up in catastrophes, the irradiation method has proven to be the method of choice. Professional literature presents some especially successful cases of massive decontamination by irradiation and it will be briefly presented in the lecture.

Croatian experience in the field gained at the irradiation facility of the Radiation Chemistry and Dosimetry Laboratory of the Ruđer Bošković Institute in Zagreb during the past 25 years will be illustrated by two groups of examples of successful application of irradiation to the protection of large numbers of cultural heritage objects endangered by massive biocontamination: a) Massive radiation desinsection in the process of maintenance of museum collection and interventive treatment of an entire polychromic altar; b) Radiation treatment in the massive process of rescuing and protecting art objects endangered during the war in Croatia (1991–1995).

In co-operation with the Croatian Conservation Institute, one third of evacuated objects, mostly polychromic wooden sculptures, parts of altars and other wooden pieces, comprising almost 1500 complete altars, were irradiated for disinsection, or disinfection by the RBI facility. Besides halting degradation, irradiation was used as the first step of conservation to enable safe object storage without the risk of cross-contamination before final conservation and restoration.

Radiation Processing for Cultural Heritage Preservation: Romanian Experience

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Radiation sterilization was taken into consideration as a mass decontamination techniques for the biodegradable cultural heritage (CH) as soon it was spread in the medical field. Earlier experiments showed the advantages and disadvantages, namely "side-effects" on the CH materials. More than 50 years later, the suitability of ionizing radiation treatment for CH items is still under debate. The main reason is that science and industry were not yet able to provide another mass decontamination technique with higher efficiency and effectiveness.

For wood items there is a general agreement that the irradiation dose needed for insect eradication will not produce any damage, even in case of painted wood. For cellulose in paper there is a reduction of the degree of polymerization (DP) at higher doses required for stopping the fungal attack but this should be taken into consideration against the purpose of the treatment. Emergency or salvage treatments are required for mitigation of consequences of accidents or bad storage conditions. In some cases (archives) the value of the written information is higher than the historical value of paper artefact. For other materials (textiles, leather, parchment) there are less published investigations on the effects or ionizing radiation. As a general rule, irradiation is not needed when there are only few CH items affected by biological contamination. The conservators and restaurateurs can handle the problem by classical means. The need for irradiation appears when there are large collections (hundreds, thousands or more items) heavily affected by biological attack.

Following new literature reports there is a slow increase in the quantities and kinds of irradiated CH items in different countries of the world. In Romania, IRASM γ-irradiator of IFIN-HH is receiving an increasing number of requests for CH irradiation, mainly because an intensive research programme on this topic and a close contact with the CH owners or administrators. After more than 10 years of CH irradiation, IRASM facility can advise the CH owners about choosing the irradiation dose and how to evaluate the irradiation side effects (if any). Beside the review of the scientific results obtained in Romania and abroad, this paper will present some examples from Romanian experience.

Development of New Radiation-Curing Monomers-Resins Systems for the Consolidation of Wooden Cultural Heritage Artefacts

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The styrene unsaturated polyester resin is implemented so far by ARC-Nucléart Conservation Centre for the consolidation of degraded wooden artefacts from cultural heritage, following a process so-called "Nucléart" by liquid state resin impregnation under vacuum/pressure, and in situ polymerization of the resin under γ-irradiation. However, this method is irreversible due to the cross-linked solid state resin which is insoluble in any solvent, and moreover, the consolidation of wood by such 100% reactive resin fills almost completely the wooden pore structure, creating in fact a wood-plastic composite which has a density much higher than untreated wood. These features are the drawbacks of the method because in conservation-restoration of art objects, the two well-known criteria among others are the reversibility of the products and the minimal intervention in order to avoid the denaturation of the original and unique object.

Having proven during many decades its effectiveness for saving from destruction numerous highly degraded artefacts, another drawback of the actual process is the more severe regulation in terms of safety, toxicity when using the styrene monomer, without considering its high vapour pressure and its residue in treated artefacts even after long periods of storage or display. For these different reasons, the aims of our research are the improvement of our radiation method in two directions: the application of already available styrene-free resins, and the development of hydroxyl-acrylic monomers which polymers are in principle reversible, respecting one of the most important criteria in conservation. In this paper, we will describe first the irradiation conditions to overcome the inhibition effect of oxygen on the complete curing of the resin or monomers, the formulations of monomers in order to obtain polymers with the most appropriate T_g (around 40° to 60°C), and their polymerization in selected solvents in order to modulate their content in the wood. Structural characterizations are carried out by using FTIR and solid state NMR spectroscopies. The second part of our work will present the impregnation of two species of wood, beech and fir, by styrene-free selected resin and by monomers. They are characterized by various techniques such as colourimetry, dimensional changes, radiography, computerized tomography, and mechanical resistance. Last but not least, the interaction (or not) of the resins or monomers with various polychromies (pigments, colourants) has to be checked, and it is important to assess the feasibility of their implementation in consolidation of samples of sacrificed artefacts presenting gilded or polychrome surface layers.

Application of Ionizing Radiation for Cultural Heritage

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Ionizing radiation has specific and indisputable advantages over classical procedures for conservation and preservation in cultural heritage, such as no risk for the operators, no toxic residues and hence no risks for curators, visitors or the environment. This technology can replace the traditionally used toxic or carcinogenic gases such methyl bromide or ethylene oxide, eliminating the associated health problems and environmental pollution. Large amount of biodeteriorated objects can be treated in a short time with excellent reliability, using controlled and codified procedures. The evaluation of the often nonreversible physical-chemical modification induced by ionizing radiation on treated materials, namely side-effects, represent an important goal to guarantee the safeguard of the artefacts and the reliable diffusion of this technology. Irradiation procedures and characterization methodologies will be assessed for the conservation and preservation of archive materials and for the consolidation and protection of porous artefacts. Defined irradiation conditions (in terms of irradiation dose and dose rate, environmental atmosphere, pretreatment of the cultural heritage object) and the proposal of shared guidelines are extremely desirable. ENEA activities regarding the application of ionizing radiation in cultural heritage performed at Calliope plant are focussed on conservation and preservation (biodeteriogen eradication in archived materials) and on consolidation and protection (degraded wooden and stone porous artefacts consolidation). The biocide effect of γ radiation has been confirmed on selected papery materials at dose effective for the treatment and the harmful effects on the irradiated materials have been demonstrated.

With the aim to be effective for disinfestation, microbiological studies about the dose rate and atmosphere (air and inert gas) effects on γ-irradiated archived materials have been performed. Irradiation side-effects on paper have been also investigated by chemical and spectroscopic techniques (DP, FTIR, ESR). Different atmospheric and biological agents induce severe and somewhat irreversible degradation phenomena on wooden or stone artefacts (i.e., porous materials). Consolidation and surface protection of these degraded objects is usually obtained by the application of natural or synthetic consolidating agents but the penetration inside the porous material it rather difficult, limiting the effectiveness of the treatment. Impregnation of cultural artefact with a diluted solution of consolidant precursors (i.e., low-sizes monomers or oligomers) followed by radiation induced in situ polymerization represents a very promising solution to achieve actual bulk strengthening. Formulation of different polymeric composition for the consolidating agents to improve their strengthening efficacy and safeguard towards the cultural object has been investigated, modifying their features by γ irradiation and aiming to increase their functional, chemical and time stability. Particular attention has been paid on the solvent compatibility, aiming at employing environmentally friendly and human nontoxic substances. Characterization by means of different techniques (optical measurements, FTIR, ESR, NMR, mechanical tests) has been carried out to evaluate side-effects and the postirradiation behaviour. Standardization of irradiation procedures and methodologies by a correct choice of irradiation parameters and their reliability and reproducibility has been verified and supported by dosimetric measurements.

Uses and Prospects in γ-Biocide Treatments for Cultural Heritage

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Biocide treatment by γ-irradiation for wooden and archival items has been proposed more than 50 years ago, but, despite some resounding success and a demonstrated real efficiency, it is still of limited uses for heritage conservation. Indeed, if such denoted "nuclear" process can scare the less scientific public, more rational reluctance due to fear of negative effects induced by ionization in irradiated material have been expressed. Despite such, secondary effects are usually insignificant or very low, γ irradiation has been (and is still) often understood by many curators as resulting in a strong and irreversible degradation, comparable to well-known ultraviolet exposure ageing. Of course, as with any process in which we ask to be active — in this case to kill biodegrading species — it is impossible to ask for absolute harmlessness. Any biocide process, as innovative or not as it is, can be problematic. Anoxia is known to induce colour changes of some dyes. Ethylene oxide, not only being very dangerous, is very reactive. Temperature treatments can cause mechanical tensions and so on. In choosing between different ways to manage pest infestation, curators have to evaluate a balance between benefits and drawbacks, selecting the best compromise regarding the conservation issue (including the benefits and drawbacks of "doing nothing").

In this context, advantages of the γ irradiation are various. Beyond its proven effectiveness on any kind of living organism, whatever the life stage, this contactless technology meets very well the concept of minimum intervention, being able to insure the required successful conservation with very low impact, only "changing as much as necessary but as little as possible". The ability to treat by mass, even through packaging, and the absence of other associated heat effect or residue in processed materials are two other desired qualities. But it is definitively its reliability, besides its efficiency, which distinguishes γ irradiation, thanks to γ penetrating power and the facility to ensure that biocidal conditions are achieved everywhere in the volume.

In the other hand, possible secondary effects need to be evaluated carefully. Material behaviour under irradiation is studied in the field of heritage, as well as it is widely investigated in many areas (nuclear, space, medical, etc.). Effects depend largely on the type of material and on the absorbed dose. Very few materials are known to be incompatible with γ-irradiation biocide treatment. The possible interaction with informative properties of patrimonial goods (DNA information, dating parameters) is another relevant issue.

ARC-Nucléart, Grenoble, France, makes use of γ irradiation for more than 45 years for cultural heritage. While insects are most often targeted, mass treatment of fungal species contaminated collections are more and more demanded. It seems that during the last 10 or 15 years, it is also increasingly used around the world.

We will give an overview of the latest developments of this technique, both in actual use in France, and in the studies that are ongoing to quantify so-called secondary effects.

A10: Development in Electron Accelerators Technology

Addressing Challenges Posed by Electron Beam Irradiation through Innovation

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Over the past decade, the use of electron accelerators for sterilization and disinfection has made considerable progress and the offer has greatly diversified. The challenges that γ-technology is facing has also raised considerable interest in EB and X-ray technology as a possible alternatives to the use of radioisotopes.

However, commercial operation of electron accelerators faces several challenges. The penetration depth of electron beams, even at 10 MeV, does not permit processing all commercial packages that are encountered. Companies operating a single EB machine are often confronted with downtime that results in production delays due to the time necessary for repairs.

The presentation will introduce an innovative solution that overcomes these challenges and was designed and proven through a long and broad experience of using and manufacturing electron accelerators. This solution is based on an optimal mix of electron accelerators types (Linac and HFHV), different energies (10 MeV and 5 MeV) and different types of ionizing radiation (EB and X-ray). A recent example of successful use of this combination will be shown.

Illinois Accelerator Research Center

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The Illinois Accelerator Research Center (IARC) hosts a new accelerator development programme at Fermi National Accelerator Laboratory. IARC provides access to Fermi's state-of-the-art facilities and technologies for research, development and industrialization of particle accelerator technology. In addition to facilitating access to available existing Fermi infrastructure, the IARC Campus has a dedicated 36 000 sqft heavy assembly building (HAB) with all the infrastructure needed to develop, commission and operate new accelerators. Accelerator infrastructure available for use in collaborative efforts will be detailed. Connected to the HAB is a 47 000 sqft Office, Technology and Engineering (OTE) building, paid for by the state, that has office, meeting, and light technical space. The OTE building contains the Accelerator Physics Center, and with nearby Accelerator and Technical divisions, provides IARC collaborators with unique access to world class expertise in a wide array of accelerator technologies. IARC scientists and engineers from Fermilab and academia work side by side with industrial partners to develop breakthroughs in accelerator science and translate them into applications for the nation's health, wealth and security. Some of the current collaborative efforts will be detailed.

A Compact Superconducting RF Accelerator for Electron Beam and X-Ray Irradiation

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As commercial and industrial applications of electron beam and X-ray irradiation have developed, new applications have emerged that require very high beam power to create the required radiation field. These new applications require dependable, efficient, high energy, high power electron accelerators.

Recent developments in superconducting radio-frequency (SRF) technology can now enable accelerators with lower costs and improved performance. Cryogenic heat loads are dramatically reduced through use of new materials and improved component designs. New cooling methods allow the replacement of complex systems requiring cryogenic fluids with simple robust systems with no fluids. New RF sources can greatly reduce the cost of RF power. Each of these developments has been individually proven and an effort is underway at the IARC at Fermilab to integrate them into the first prototype of an entirely new class of industrial SRF-based accelerators. These accelerators will enable robust, turn-key operation with very high electrical efficiency. The accelerator prototype under design will be capable of 10 MeV beam, CW operation, and 250 kW of electron beam power. These modular systems are small enough to be palletized and transported to the point of use. Their high electrical efficiency mean that portable power generation systems can be enable their use in mobile applications.

The goal is a compact, cost effective, high power accelerator suitable for many of the applications covered by this conference. Fermilab is actively working to build the prototype and identify partners for commercialization. The end product will be a commercially available, robust, turn-key system for applications requiring reliable electron beam or X-ray irradiation.

Low-Energy Electron Irradiation for Novel Applications in Medical Production and Pharma

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Currently most γ or high energy EB ionizing irradiation processes for medical and pharmaceutical production are provided by external services. Only a few applications rely on low energy electron irradiation: e.g., syringe tub sterilization at high throughput filling lines. But more complex and expensive logistics as well as demands for flexibility in small customized production batches calls for an irradiation processes integrated into the production chain. The simple implementation of irradiation technologies into typical production environments. is hindered by the limited penetration depth of low energy electrons and the expense of multisource arrangements needed for 3D-objects. Therefore, Fraunhofer FEP and partners has developed a new low energy electron irradiation application available for production integrated solutions. To avoid multisource arrangements for homogeneous irradiation of 3D-objects, a toroidal shaped electron beam source was developed. By using high-voltage glow discharge for electron generation, a compact and robust electron source for energies up to 150 kV was born. Original targeted for treating bulk goods, a single source is perfectly adapted for surface modification or sterilization of 3D products like implants, or continuous feed material like tube packaged parts. First experimental results of operation, the electron generation principle and the first application (seed treatment) will be presented.

Liquids irradiation traditionally requires high energy irradiation because of the penetration depth requirements. Especially in the case of vaccine production, virus inactivation by irradiation is very interesting because of the high efficiency in antigen conservation. But high energy irradiation at external facilities is not practicable because of the strong safety requirements. Within an ongoing Fraunhofer funded project, an interdisciplinary team developed a low energy irradiation method for virus containing suspensions to produce inactivated but still very efficient vaccines. Actually results about irradiation technology and vaccine testing will be presented. The new inactivation technology will make vaccine production faster and cheaper with higher efficacy at the same time.

Together with some actually additional development directions like:

- Miniaturized electron beam sterilization compartment for on-site sterilization of packaged products;
- Electron beam modification of cell-therapeutic substrates;

we can show an enormous potential for low electron irradiation processes in medical and pharmaceutical production.

More flexibility in small batch production and a close production chain inside the facility increase the safety level and the production efficiency at the same time. Low energy electron irradiation will play an important role in this paradigm change over the next years to fulfil the requirements of more than just the healthcare industry.

DC ELV Accelerators: Development and Application

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ELV accelerators are widely used for electron beam processing. The use of these machines enabled developing the manufacture of a wide range wires, cables and heat-shrink goods, films, bands and so one. All of them are of high security and reliability during operation as under standard and extreme operating conditions. ELV are DC electron accelerators with high electron beam power. The conversation efficiency of electricity to electron beam power is also high. The Budker Institute of Nuclear Physics (Novosibirsk, Russia) had started activities with ELV accelerators in the 1970's, at the request of former USSR cable industry. Since then, over 140 accelerators were delivered inside Russia and abroad.

The ELV accelerator can be equipped with a wide set of supplementary devices extending the application range. There are systems of ring and double side irradiation, 4-side irradiation system, extraction device for focussed electron beam, transportation systems for cable, film and grain. There are special devices to improve of dose uniformity during film and band irradiation. ELV accelerators can be easily integrated in the technological processing given its computerized control system. We study the requirements of accelerator market and follow the requests of electron beam technologies users. The normal operating lifetime of accelerators is some tens of year. Very often the modification of an accelerator for users is more attractive in comparison to the capital cost of installing a new machine. So very often old accelerators have upgrades and continue in operation.

The development of ELV accelerators is concerning with: stability in operation, new energy region (the minimum energy became 200 keV instead of 400 keV. Accelerators with energy less 1.0 MeV can be assembled inside the steel local shielding. There was developed the system after warranty service of delivered accelerators. We are manufacturing ELV accelerator both inside BINP and in collaboration with South Korean and Chinese firms. An accelerator with 400 kW electron beam power was developed and manufactured together with EB-TECH Co.

Electron Treatment of Seed

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Providing the world's growing population with nutritious food is an enormous challenge, that solution starts very early in food production. Beside the known chemical seed dressing there is another way for killing pathogens. Electrons are a versatile tool for numerous applications in all fields of industry. Beside the known and established processes in medicine and pharma, the electron treatment of seed becomes more and more important. This environmental friendly, purely physical disinfection of seed, is based on the biocidal effect of accelerated electrons.

The penetration depth of the electrons into every single seed grain can be adjusted via the kinetic energy of the impinging electrons. Thus, the sterilizing effect can be restricted to the surface, pericarp and tegument, without affecting the seed embryo inside the seed grain.

The Fraunhofer FEP developed a technology that allows treating seed in air in a continuous process. Thus, two large plants with throughputs up to 30 tons of cereals per hour were constructed and successfully established in Germany. Large field tests, among others by federal institutes, shows the success and comparability in field yield to conventional seed dressings, without the disadvantages of chemical treatment, like the environmental effects, dressing dust and the high costs of the chemicals. Beside the treatment of cereal seed, FEP and its partners proofed the feasibility of killing bacteria such as *E. coli* on sprouting seed. Due to the current demands, and following on the heels of the EHEC crises in 2011, there is a growing demand for safe pathogen killing measures.

Infected seeds were treated with electrons and their resulting germination force, germination rate and pathogen loads are investigated. More than 90% of the fenugreek and clover samples and more than 80% of the mung bean samples are sterile, proved with fluid turbidity tests, after electron treatment. Not to influence the embryo, can be proved by testing germination rate and germination force. Both are kept unchanged. Tests show that the treatment of sprouting seed (Mung bean, clover and fenugreek) to reduce bacteria load is possible, without influencing the embryo.

A11: Safety and Security Perspectives of Radiation Facilities

Upgrading Safety and Security of γ-Irradiation Facilities: Possibilities and Limitations

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Improvement of safety and security are important goals of γ-irradiation facility upgrades, besides improvement of more economical and product quality related features. Safety of γ-irradiators comprises three complexes which may require upgrades:

- Shielding of radiation when in operation and in stand by;
- Protecting people from entering or staying inside the irradiation room;
- Preventing of dispersal of radioactive material.

A more general problem with respect to safety is safety culture, which is on very different levels at different places in the world. This is not limited to radiation protection but is a problem also in other fields of commercial and daily life (road traffic, electricity, health and safety at work). Here "upgrades" may be required as well.

Fortunately, respect from radioactivity increases safety attitude, at least at the beginning. Limiting factors not only for upgrades but sometimes also for the safety level of new installations are:

- Lack of financial resources;
- Lack of know how;
- Lack of safety culture;
- "cheap – cheaper – cheapest" business culture.

Security is all about preventing theft of radioactive sources for terroristic goals and other abuse. Here it may be easier to overcome a possible lack of financial resources or of know how due to the interest of the international community to eliminate terroristic threats.

A11

Safety Improvements of an Industrial Irradiation Facility

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The operational experience feedback is a powerful tool to implement corrective actions after an incident. These corrective actions, discussed and adequately defined with the regulator, consist in a powerful way to improve the safety of a facility.

Belgium hosts two ^{60}Co industrial irradiators that have now been used for more than 30 years. During this period, the facility dealt with a few incidents that have driven improvements through implementation of adequate corrective actions in the existing design and processes.

The licencee promoted transparency towards the regulator (Bel V and the FANC) and declared all technical events related to safety and radioprotection. The licencee has proposed technical and organizational solutions that were reviewed independently by Bel V to avoid the recurrence of similar incidents. Short term improvements were immediately set-up after the incidents. Mid-term improvements were also implemented. For more complex issues such as the removal of broken sources, a long term planning was established, requiring the participation of a large number of stakeholders: transport, safety authorities, waste disposal facility, etc. For this type of issue a long term approach was favoured.

The will of the licencee to declare incidents to safety authorities and to implement adequate corrective actions in agreement with the safety authorities, allows a regular improvement of the facility in order to keep it up to date with safety standards and best practices.

This proactive management of incidents and corrective actions has also strongly increased the safety culture awareness of the operators.

Upgrading and Continuous Improvement of ININ γ-Irradiation Facility

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The highlights of the updated activities at the ININ γ-irradiation plant facilities and improvements as well as in the irradiation process, to make it a multipurpose plant with greater capacity for products processing are shown in this work. The ININ γ-irradiation plant has a 6500 JS irradiator originally designed for processing medical disposables. Since its start in 1980, the irradiation plant has been increasing their annual hours of operation and as a result their number and diversity of clients from the food industry, pharmaceutical companies, medicines and medical devices manufactures and health care products, to such an extent that by the year 2000 and 2011 had seen the start of operations in the country, respectively, of two new irradiation facilities from private capital. The importance of implementing and maintaining a certified quality management system, improving ergonomics, establishing a preventive maintenance system and critical spare parts inventory, maintaining the operating licence as a result of good radiation safety practices, and good customer relationships to support compliance with their regulations are remarked. Results are also presented in improved uniformity of dose delivery, dose catalogue offered to clients, ^{60}Co reloads (with corresponding activities) and annual processing capacity obtained.

A11

Enhancing Nuclear Security System of Irradiation Facility SIBO INRA/Tangier Morocco

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Around the world, radioactive sources have been widely used for decades to benefit humankind — to diagnose and treat illnesses, monitor oil wells and water aquifers, irradiate food to eliminate microbes, and many other uses. However, the malicious use of radiological sources poses a significant threat globally. As irradiation facility for research, the goal of this paper is to show a case study of application of nuclear security and nuclear security culture code of contact in irradiation facility using ^{60}Co. We will show the necessary work done to achieve the goal protecting the radioactive material and continue working in safe conditions. This objective could not have been achieved without the collaboration of all departments involved in security and nuclear safety.

In all irradiation facility in the world the level of this control is always implemented to achieve safety procedures in usual work on this field. In this work we applied the nuclear security and nuclear security culture procedures in order to define the type of system used to achieve the global objective in accordance with Global Threat Reduction Programme to reduce the threat of a radiological dispersion device (RDD) in collaboration with the US Department of Energy's National Nuclear Security Administration (NNSA).

This work has been done with other operation in the same facility as local upgrading of ^{60}Co in our irradiator in Tangier and upgrading of safety and technical system of the irradiator made in collaboration with IAEA, detail of this works are presented in others scientific papers.

The objective of this paper is to share a local experience in upgrading security with return of experience in practice and very good collaboration with general direction of national security and all departments involved in security and nuclear safety

A11

Development and Application of Electron Linear Accelerator of CIAE

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As an artificial radiation source, the electron linear accelerator is not only widely used in basic science research, but also more and more used in industry, agriculture, medical and environmental protection and other fields. The CIAE began to engage in research and development of electron linear accelerators from its early establishment, and has converted the research outcomes successfully into products and services in the cause of China's prosperously development.

These outcomes are mainly divided into two categories. The first category is the non-destructive testing (NDT) electron linear accelerator (LINAC). In the 1990s, CIAE successfully developed China's first NDT electron LINAC, then successively developed a series of accelerator products with different X-ray beam energy like 2 MeV, 4 MeV, 6 MeV, 9 MeV, the detection thickness of equivalent steel reach to 380 mm, mainly used in the verification of weld joints of thick-walled pressure vessels, pipes, boilers, valves equipped in petrochemical industry, thermal power plant and nuclear power plant, testing of the defect of key components of the high-speed train, rocket engine and so on. The national standards of NDT electron LINAC was drafted by CIAE and the corresponding international standard project launched to International Electro-technical Commission (IEC) from CIAE has been started and is progressing well.

The second category is electron LINAC for radiation processing. The first radiation facility based on high-power high-energy electron LINAC developed by CIAE was put into trial operation in 2007. The electron beam (EB) energy of this accelerator is 10 MeV, and the power exceeded 15 kW, which was the highest power of the same type around that time. Currently, the EB power of this type has reached 20 kW, and was capable of stable operation. Number of radiation processing enterprises has purchase this type of accelerators, which are used for garlic, tea preservation and pet food, seasoning sterilization.

In China, R&D direction of NDT electron LINAC is miniaturization and digitalization, while for irradiation accelerators, scientists and engineers are striving to improve the EB power or X-ray-conversion efficiency.

A12: Radiation for Environmental Protection II

Virucidal Potential of γ-Radiation

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Enteric viruses are a major cause of water- and food-borne human diseases. These type of viruses primarily infect the intestinal tract through ingestion of contaminated water or food. Enteric viruses, like norovirus (NoV) and adenovirus (AdV), can enter the environment through the discharge of waste materials from infected individuals and be transmitted back to susceptible individuals. The stability of these viruses and their presence in water and food can thus cause serious implications on public health. In this scenario, γ-irradiation could be an efficient technology to achieve elimination of viral pathogens.

The goal of this study was to investigate the inactivation by γ-irradiation of murine norovirus type 1 (MNV-1), as a NoV surrogate, and human adenovirus type 5 (AdV-5) in six different aqueous substrates and two types of fresh berry fruits. Phosphate buffer saline (PBS), demineralized water, tap water, fetal bovine serum (FBS) and aqueous solutions of 10% and 50% FBS as well as fresh strawberries and raspberries, were inoculated either individually with MNV-1 and AdV-5 or with a viral pool of both viruses. The spiked samples were irradiated in a ^{60}Co chamber at several doses, 0.87 up to 11.35 kGy, at a dose rate of 1.6 kGy/h. For fresh berries samples, the viruses were recovered from spiked samples and then purified and concentrated by low speed centrifugation. The infectivity of viral particles of MNV-1 and AdV-5 was tested by plaque assay using Raw 264.7 and A549 cells, respectively. D10 values and virucidal efficiency of γ-irradiation were estimated for each virus and substrate.

A reduction on MNV and AdV titers of 4 log10 PFU/ml was achieved after irradiation at 3 kGy on PBS, demineralized and tap water suspensions. However, it was found that MNV-1 and AdV-5 were approximately 3 times more resistant to γ-radiation when irradiated in FBS suspensions. Concerning the obtained results for fresh berries, a reduction on MNV-1 and AdV-5 titers of 2 log10 PFU/g was achieved after irradiation at a dose of 4 kGy. Non-linear inactivation survival curves were obtained for both virus in fresh berries, leading to the detection of infective viral particles at a dose of 11 kGy.

MNV and AdV indicated to have the same radioresistance when irradiated in a viral pool or in individual viral suspension for all tested matrices. The viral inactivation by γ-radiation was found to strongly depend on the substrate where the viruses are suspended. The study of viral behaviour in different substrates could open new insights on the inactivation mechanism caused by γ-irradiation. The selection of the γ-radiation dose for the disinfection treatment of berry fruits, must achieve the balance to guarantee food safety and preserve food quality. The irradiation process presented virucidal potential. This technology can be an effective virus mitigation tool to treat polluted waters, which are the major vehicle of contamination for minimally processed food products.

Removal of Wastewater Pharmaceutical Chemical Contaminants Using AOPs

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Quantitatively removing all remaining traces of pharmaceuticals such as antibiotics and estrogenic steroids from effluent wastewater is essential before its further use or release into the environment. In particular, the presence of antibiotics and even their metabolites in wastewaters can enhance the proliferation of antibiotic-resistant bacteria such as MRSA and ND-1. Unfortunately, conventional primary and secondary water treatments that rely mainly upon adsorptive and chemical-physical processes have been demonstrated to be insufficient for quantitative large-scale treatment. These removal treatments are considerably complicated by the presence of much higher levels of other water constituents such as dissolved organic matter (DOM) and carbonate.

Therefore, to prevent increasing levels of antibiotics entering environmental waters, additional treatment using radical-based, advanced oxidation processes (AOPs), are being considered to augment our traditional water treatments. In real-world waters most AOPs utilize the hydroxyl radical ($HO^\bullet$), which can be created using a variety of techniques including combinations of ozone, hydrogen peroxide and UV-light: O_3/H_2O_2, O_3/UV-C, and H_2O_2/UV-C. Other AOPs that produce a mixture of reducing and oxidizing radicals include the light irradiation of titanium dioxide, sonolysis, or the irradiation of water via electron beams or γ-rays. Once these radicals are generated, the dissolved oxygen present will predominately react with the reducing hydrated electron or hydrogen atoms produced. However, the deliberate addition of a compound such as persulfate to these waters can augment $HO^\bullet$ reactions through the concomitant production of the sulfate radical ($SO_4^{-\bullet}$) by the reaction of both these two reducing radicals. While this is a promising enhancement in the AOP treatment methodology the effectiveness of the sulfate radical augmentation approach must be fully established before its use at large scale. In particular, the cost-effectiveness of this approach will depend upon the reactivity of the sulfate radical with other water constituents.

Therefore, we have performed electron pulse radiolysis measurements to determine reaction rate constants for hydroxyl and sulfate radicals with a large number of DOM fractions from various sources. The sulfate radical rate constants were found to be effectively independent of the DOM aromatic/aliphatic constituent fractions, and in general about an order of magnitude slower than determined for the analogous $HO^\bullet$ radical reactions. The slow reactivity of the sulfate radical with DOM is encouraging, as it would allow a greater fraction of these radicals to react with the contaminants present at much lower concentrations. To further investigate this, we have also now performed preliminary measurements on the use of sulfate radicals to remove low-levels of β-lactam antibiotics in the presence of different DOM species. Kinetic and efficiency data for penicillin-G in the presence of varying ratios of Suwannee River fulvic acid and Elliot Lake humic acid have been determined and will be reported.

Applications of Radiation Technology in Control and Treatment for Environmental Pollution

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Radiation technology including electron beam and γ-ray irradiation has great potential in the field of environmental protection due to its special characteristics. The investigations and applications of radiation technology in the treatment of wastewater, waste gas and solid waste are introduced in this paper, including the treatment of printing and dyeing wastewater, paper mill wastewater, nitroanilines, halogenated flame retardants, endocrine disrupting chemicals, algal toxin, volatile organic contaminants and sludge, etc., and the removing of SO_x and NO_x in coal-fired and automobile exhausts. The degradation efficiency of these organic pollutants by electron beam or γ-ray radiolytic degradation is discussed in various conditions, such as different initial concentrations, irradiation doses, pH values, solvents, radiolysis systems and the addition of H_2O_2, etc. Besides, the radiolysis products of certain pollutants are listed and radiolytic degradation mechanisms of these organic pollutants are illustrated. These results demonstrate that radiation technology is an effective method to degrade the organic contaminants, especially the persistent organic pollutants, hydroxyl radicals and hydrate electrons play significant roles in the radiolysis of organic pollutants. In addition, the limitations and the future tends of radiation technology applied in the environmental protection are also discussed.

Application of Mobile Electron Beam for Remediation of Soil and Groundwater Contaminated with Leachate from Animal Carcass Burial Sites

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Leachates of livestock burial sites have raised a concern regarding their potential impact on the environment and public health in Korea. They contain high concentrations of organic and inorganic contaminants, and pathogenic microorganisms such as *Campylobacter jejuni*, *Salmonella spp.*, *Clostridium perfringens*, and *Shigella spp*. Several studies have attempted to remove contaminated groundwater by leachates, but an effective method has not been found. Thus, the objective of this study was to treat leachates from livestock burial sites using a combined process of pretreatment and an electron beam. The pretreatment system consists of two columns: activated carbon and zeolite. Leachates used in this study were collected from groundwater near a livestock burial site located in Gyeonggi-do, Korea. The removal efficiencies of suspended solids and total organic carbon were 98% and 77% by an activated carbon process, respectively. NH_3-N was removed about 80% through the zeolite process. In addition, microorganisms showed a removal efficiency of 99.99% using an electron beam at an absorbed dose of 2 kGy. Consequently, the combined processes of pretreatment and an electron beam can be applied to the remediation of groundwater contaminated by leachates.

Electron Beam Treatment for Potable Water Reuse: Removal of Bromate and Perfluorooctanoic Acid

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Water availability is a major problem facing many regions around the world. To meet growing residential and agricultural needs, effective technologies have to be adopted to address microbial and chemical contaminants as part of water reuse programmes. The underlying hypothesis was that electron beam (EB) technology can breakdown the emerging contaminants of concern in water reclamation and reuse projects. We also hypothesized that the inactivation and elimination of contaminants by EB technology can be achieved cost-effectively. Having this technology in the "tool-box" of water reclamation technologies would open up innovative high-value, commercially-viable, and environmentally sustainable solutions and strategies for water reuse.

In this study, EB irradiation was investigated as a method for removing bromate and perfluorooctanoic acid (PFOA) from a synthetic water designed to simulate a treated wastewater intended for potable water reuse. In the absence of oxygen, an exponential model was able to relate bromate concentration to absorbed dose. However, a more complex model was needed to describe PFOA defluorination, so a model was developed that assumed formation of one partially defluorinated intermediate and this model was used to describe the relationship between free fluoride concentration and absorbed dose. Nitrate negatively affected the removal of bromate and the dose constant was inversely proportional to the nitrate concentration as predicted by a simple model that assumes the presence of radical scavengers. In contrast, the presence of nitrate improved the degradation of PFOA, possibly due to formation of oxidizing radicals or by other reactions of nitrate degradation products. Fulvic acid and alkalinity exerted negligible influences on bromate removal. Fulvic acid dampened the defluorination efficiency, probably due to the scavenging of oxidizing radicals such as the hydroxyl radical ($^{\bullet}$OH). Alkalinity was found to accelerate PFOA defluorination, possibly because of the formation and reactivity of the carbonate radical ($CO_3^{-\bullet}$). As pH increased from 5.0 to 7.3, the dose constant for bromate removal increased from 0.45/kGy to 0.69/kGy, but it barely changed when pH was further increased to 9.0. In the presence of oxygen, both contaminants were degraded less efficiently and showed more complex patterns of degradation. Pretreatment to remove dissolved oxygen would probably be needed to apply EB in practice for degradation of bromate and PFOA.

Changes in the Biological Degradability and Toxicity of Sulfonamide Antibiotics in Activated Sludge and River Water due to Ionizing Radiation Treatment

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During conventional wastewater treatment, the removal of pharmaceutical compounds is usually inadequate as most of the xenobiotics show high resistance to biological decomposition by activated sludge. This deficiency can be counteracted by application of ionizing radiation treatment that leads to oxidation of organic molecules mainly by reactions of hydroxyl radicals. Oxidation may result in a complete solution to the final disposal of pollutants with no further purification steps required, but may also contribute to formation of biodegradable, less harmful transformation products.

The biodegradability and toxicity have been examined on 10^{-4} mol/dm^3 sulfonamide antibiotic solutions with considerably different chemical structure (sulfanilamide, sulfaguanidine, sulfathiazole and sulfamethoxazole) and their products at different stages of oxidative decomposition. The biodegradability in activated sludge and freshwater has been specified by the ratio of the biological and chemical oxygen demand (BOD/COD), while the toxic properties have been evaluated by activated sludge respiration inhibition tests and acute toxicity experiments done on *Vibrio fischeri*, *Pseudokirchneriella subcapitata* and *Daphnia magna*. Test organisms were placed under the exposition of same loads of test substances and the interfering effects of H_2O_2 forming during irradiation procedure have been eliminated.

Initial sulfonamide solutions inoculated with activated sludge showed low BOD/COD (0.16–0.21), while complete resistance has been observed when river water was used as inoculum. The biodegradability continuously increased as a function of absorbed dose in both matrices and ready biodegradability (BOD/COD ~ 0.7) has been reached at 1.5 kGy and 2.0 kGy in case of activated sludge and river water, respectively. This difference in absorbed doses means that higher degree of oxidation is needed, when sulfonamides are subjected to river water community, to achieve same biodegradability level under same time as in case of activated sludge. Nevertheless, already a few tenth kGy of absorbed dose led to increment in biological availability. Activated sludge respiration inhibition tests showed no toxic effects of both initial and treated solutions. Growth inhibition on *Pseudokirchneriella subcapitata* has been reduced during treatment. *Vibrio fischeri* was susceptible to treated solutions, as the inhibition increased in case of sulfamethoxazole and sulfathiazole. Mortality of *Daphnia magna* considerably reduced in treated solutions, with the exception of early products of sulfathiazole.

It can be concluded that biological treatment at conventional wastewater treatment plants is not adequate for removal of sulfonamide antibiotics. Nevertheless, ionizing radiation led to formation of products biologically degradable by activated sludge.

A13: Advanced Nano Materials

Radiation Synthesis of Nanosized Drug Delivery Devices

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The radiation chemistry of polymer aqueous solutions is a successful synthetic methodology for large scale production of nanosized drug delivery systems. That is particularly true for nanogel drug carriers. Nanogels are fascinating nanoparticles that, for their tunable chemical structure and swelling ability by water molecules, can be designed to be biocompatible, to offer conformable cavities to incorporate bulky therapeutic proteins, but also small hydrophobic pockets to host barely polar molecules, which is the case of most medical drugs. They can display reactive groups to conjugate targeting ligands, such as monoclonal antibodies, peptides and oligonucleotides. These nanoparticles can be used to target specific cells and cellular microenvironments with high specificity and affinity. They can also incorporate chelating agents that bind radioactive ions, either for bio-imaging or therapeutic purposes. The possibility of producing nanogels as aqueous dispersions, without going through a drying step for purification since no recourse to organic solvents and surfactants is made, is the best guarantee for preserving their size, hence functionality.

Water radiolysis provides a means of generating initiating radicals at the desired rate. These radicals can either recombine or react with the polymer solute, transforming the otherwise chemically inert macromolecule into multiradical species. Radicals formed on the polymer can either react with molecular species present or formed in solution, or combine with other macroradicals. Intramolecular combination creates permanent loops and cross-linking points within the same chain, transforming the linear or branched polymer chain into a nanoscalar network. Intermolecular combination, binding polymer chains together, contributes to increase the nanogel size and molecular weight. By tuning the irradiation conditions we expect to be able to tailor both particle size and chemical composition. In order to establish relevant process-structure-property relationships, irradiations are performed with pulsed electron beams varying the irradiation conditions and system composition. The efficiency of the polymer in scavenging the initiating radicals is estimated. The produced nanogels are characterized for their composition and particle size. The possibility of generating nanogels with controlled hydrodynamic diameter in the range from 20 to 200 nm and relatively narrow particle size distributions (PDI$<$0.3) is demonstrated. Irradiation conditions that favour intra-molecular cross-linking are identified, the most important parameter to control being the polymer molar concentration. Functional groups are generated on the polymer by the reaction of some macroradicals with molecules that may be produced in situ by irradiation (e.g., H_2O_2, O_2) or purposely added to the system (unsaturated monomers). These groups are used to bind therapeutic biomolecules, that can be protected by the nanogel from degradation when in solution and be exposed to their receptors when the nanoparticles experience a change in their microenvironment (e.g., at the cell membrane).

The easy of manufacture and purification of the base nanogels, the possibility to use them as substrates for different therapeutic strategies by attaching specific ligands and drugs, and their properties when evaluated in relevant cellular and animal models represent today a very promising prospect for translation into clinical use.

Protein-Based Nanoparticles Prepared by Radiation-Induced Cross-Linking

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The powerful of ionizing radiation of electron beam or γ-sources to cross-link polymers has been largely demonstrated. Preparation of cross-linked hydrogels for wound dressing by this technique has important advantage to other chemical process. In addition, ionizing radiation technology has the ability to generate intermolecular or intramolecular cross-linking. Conversely, for several decades have been demonstrated that irradiation of protein solutions generates mainly degradation products. Only protein solutions in frozen state can be sterilized by γ-rays avoiding protein degradation.

Low amounts of polar solvents can be added to protein solutions without produce denaturation. By dynamic light scattering (DLS) it is possible to follow the protein aggregation process in solution; however, this effect is reversible. In this work, novel methods of Albumin NPs (Alb NPs) and core/shell gold/Albumin NPs (Au/Alb NPs) preparations are shown by radiation induced cross-linking.

Albumin dissolved in ethanol/water solutions were irradiated with ionizing radiation sources (γ-rays or electron beam). In both cases NPs were obtained after irradiation with at least 2 kGy [1, 2]. NP size can be modulated with the ethanol concentration. In the same way, core/shell Au/Alb NPs has been prepared by a similar technique. In this case a multilayer of cross-linked Albumin coated the Au NPs.

NPs were characterized by different techniques such as DLS, UV-visible and infrared spectroscopy, transmission electron microscopy and atomic force microscopy. NPs sizes were in the range of 20–40 nm for Alb NPs and 60–80 nm for Au/Alb NPs. In the last case, TEM images showed that the NPs have spherical shape and the presence of a low-density halo around the metal core confirms the presence of Albumin. Using an antigen-antibody recognition analysis was able to demonstrate the biospecificity of the NPs surfaces.

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A13

Molecular Design and Synthesis of Different Polymer-Based Nanoparticles as Nanocarriers Using Irradiation Techniques

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Significant progress has been made during the past decade in preparing polymer-based nanoparticles (NPs) as nanocarriers for a wide range of applications. One of the next critical challenges is developing a green, robust and versatile method using irradiation techniques which allows the synthesis of different polymer nanoparticles into functional structures tailored for each specific purpose. In this work, we proposes the molecular design and irradiation-assisted synthesis for the creation of polymer-based nanostructures, i.e., amphiphilic polymer core-shell NPs, inter-polymer complex NPs, polymer-capped metal NPs and hydrid NPs to be applied as nanocarrier for drug delivery, agrochemical entrapment, paint and coating additives. According to the different molecular structures, radiation-induced degradation, grafting and polymerization were carried out in particular water-based system at room temperature. Subsequent γ-ray and electron beam irradiation doses ranging from 5 to 100 kGy were selected and controlled to achieve nanocale structure with the size of 10–300 nm. The amphiphilic core-shell water-soluble chitosan NPs ($\sim$ 120 nm) could encapsulate Berberine and Paclitaxel anticancer drugs with the drug content of 37% (w/w). Chitosan-polyacrylic acid interpolymer complex NPs (54 nm) efficiently entrap 20% (w/w) ammonium nitrate fertilizer and exhibit pH responsive function. Gold nanoparticle (5–50 nm) was successfully green synthesized in the water-soluble chitosan (WSCS) produced from radiation-induced degradation. In addition, electron beam can also accelerate the production of AuNPs in WSCS. The polymer brush shells were grafted onto silica NPs and silver NPs (5 nm) were then constructed on the polymer brush-grafted-silica NPs (98 nm). The obtained hybrid NPs effectively inhibited the growth of building fungi, i.e., *Spergillus Niger* and *Syncephalastrum Racemosum*. All types of polymer-based nanoparticles with different functions were successfully designed and prepared using irradiation techniques.

Green Nanotechnology in Nuclear Medicine: Tumor Specific Radioactive Gold Nanoparticles for New Approaches in Cancer Therapy

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We report herein, for the first time, on the application of Mangiferin — a glucose functionalized xanthanoid found in abundance in mango peel — as a tumor targeting agent for the selective delivery of inherently therapeutic radioactive gold nanoparticles (^{198}Au) into prostate tumors in mice. Mangiferin functionalized radioactive gold nanoparticles (MGF-^{198}AuNPs) have been synthesized and fully characterized for their potential applications in tumor therapy. The highly innovative feature of this green nanotechnology focussed work is the ability of Mangiferin to serve dual roles of chemical reduction, to produce gold nanoparticles, with subsequent encapsulation to afford in vivo stability and tumor specificity. Laminin receptor specificity of Mangiferin affords site-specific accumulation of optimum therapeutic payloads of this new therapeutic agent within prostate tumor cells (PC-3) of human prostate tumor origin. Over expression of laminin receptors in human prostate tumors and the selective affinity of Mangiferin toward such receptor subtype has allowed effective treatment of prostate tumors in mice using the new MGF-^{198}AuNPs — thus demonstrating that small sized phytochemicals will play important roles in achieving tumor specificity in drug design. The dual β and the γ-emissions of ^{198}Au provides unique advantages for tumor therapy, through the β-energy while γ-rays are used for the quantitative estimation of gold within the tumors and various organs through radio scintigraphy. Detailed in vivo therapeutic efficacy studies, through the intratumoral delivery of MGF-^{198}AuNPs, revealed that over 80% of the injected dose (ID) of MGF-^{198}AuNPs was retained in prostate tumors up to 24 h. There was minimal to no leakage of MGF-^{198}AuNPs to non-target organs including liver, blood and stomach. This unprecedented retention of MGF-^{198}AuNPs within prostate tumors translated into excellent ability of this nanoceutical to reduce tumor volumes in comparison to saline control groups. By three weeks post-treatment, tumor volume of control group (saline) was significantly lower than the tumor volume of the two different groups of prostate tumor bearing mice injected with radioactive nanoparticles (1.31 ± 0.00 cm^3 for control versus 0.18 ± 0.17 cm^3 for MGF-^{198}AuNPs for group 1, and 0.22 ± 0.02 cm^3 for MGF-^{198}AuNPs for group 2). Observation of normal blood parameters, body weights and the overall systemic tolerance of MGF-^{198}AuNPs, in both the experimental and control groups, suggested new opportunities in oncology for the application of this agent for the treatment prostate and various other tumors.

State of the Art and Current Advances on Protein Cross-Linking by Irradiation: Protein Based Nanocarriers and Bioactive Nanoparticles

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The highlighted role of protein and peptide based delivery systems relies upon the possibility to develop biocompatible drug carriers featuring site specific delivery, biological affinity among unique advantages. Recently, a technique for protein nanostructuring by the use of radiation has been recently reported by our group. Advantages of the use of radiation over conventional methods are related to the possibility to achieve protein cross-linking and sterilization in a single step, as well as the capacity to allow the design of nanocarriers without the need of monomers or toxic cross-linkers. This work reports the use of high energy irradiation towards the design of size-controlled protein-based nanocarriers and bioactive nanoparticles, using bovine serum albumin (BSA) and papain as model protein and protease, respectively, including the state of the art and current advances of the technology. The technique implies on protein desolvation/solvation techniques followed by cross-linking by EB radiation or γ-irradiation alone, although nanoparticles were also achieved in absence of the cosolvents. Size-controlled BSA nanocarriers were manufactured up to 80 nm and papain bioactive nanoparticles up to 12 nm, as determined by dynamic light scattering. Nanocarrier morphology was evaluated by and negative staining transmission electron microscopy. Protein cross-linking and changes in aromatic the amino acids were evaluated by fluorescence measurements. Biocompatibility experiments were also performed by means of cytotoxicity and cytokines production. The potential of the systems for the delivery of radiopharmaceuticals or chemotherapeutic agents were also assayed, using technetium or Paclitaxel respectively. In conclusion, the technique allowed the production of biocompatible and bioactive protein nanoparticles suitable for the administration of radiopharmaceuticals and chemotherapeutic agents.

Radiation-Chemical Synthesis of Nanocomposite Adsorbents Based on Polypropylene Fibres for Selective Removal of Heavy Metals and Radionuclides

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Polypropylene (PP) fibres are widely used in sorption processes. The range of their possible applications can be extended by modification with the use of radiation-induced graft polymerization method. This method allows grafting of nano-microchains of a vinyl monomer with a desired functional group onto the inert surface of PP base, ensuring control over the length and density of the grafted chains. The resulted material consists of two parts: the polymeric base and the chemically bound chains with functional groups (ion-exchange or chelating), and so it can be used as polymer adsorbent. In the past decades, fibrous polymer adsorbents have been considered as potential alternative to granular ion exchange resins because of their high adsorption parameters. Numerous adsorbents on the base of PP fibres have been synthesized, but only a few of them could be adjusted for selective removal of pollutants from water effluents because of limited variety of available functional groups. In recent years, hybrid adsorbents (polymer/inorganic nanoparticles) have been developed as a new class of adsorption materials. They were fabricated mostly by the in situ formation of inorganic nanoparticles or by incorporation of preliminary formed inorganic nanoparticles into voids of macroporous ion exchange resins. Although polymer fibres are very attractive support in preparing hybrid adsorbents, there are only a few publications on this theme. The considered research was focussed on the fabrication of novel hybrid adsorbents based on the polypropylene fibres coated with inorganic nanoparticles for selective removal of heavy metals and radionuclides. The hybrid adsorbents were synthesized through a two-stage experiment: radiation-induced graft polymerization of a vinyl monomer with functional group (ion-exchange or chelating) onto the PP fibres' surface, followed by the in situ formation of inorganic nanoparticles within the grafted chains. For selective removal of radionuclides from contaminated waters (natural or industrial origin) 4 types of hybrid adsorbents based on grafted polypropylene fibres have been synthesized: PP fibres coated with ferrihydrite (iron hydroxide) nanoparticles; PP fibres coated with manganese hydroxide; PP fibres coated with K-Ni and K-Cu hexacyanoferrate; PP fibres coated with hydroxyapatite nanoparticles. FT-IR-ATR, and X-ray diffraction techniques confirmed the formation of inorganic nanoparticles on the PP fibres surface. SEM study revealed that nanoparticles form a homogeneous layer of nanosized aggregates which are regular in shape and pack closely forming a compact texture on the fibre surface. Synthesized composite fibres were found to be stable in aggressive solutions for long times. The targeted radionuclide adsorption on the composite fibres was studied as a function of contact time, pH, initial ion concentration and the presence of competitive ions. The synthesized adsorbents demonstrated fast adsorption kinetics, high adsorption capacity and high selectivity. The proposed strategy of the nanocomposite fibre synthesis opens ample opportunities for the fabrication of adsorbents, catalysts, biochemical and chemical sensors on the base of commercially available polymer fibres, fabrics, resins and membranes.

A13

Preparation of Polyurethane Acrylate/ Organically Modified Montmorillonite Nanocomposites by Electron Beam Radiation Curing

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The electron beam radiation curing of polyurethane acrylate (PUA)/montmorillonite (MMT) modified by octadecylamine (ODA-MMT) nanocomposites was investigated in this article. The nanocomposites were obtained and characterized by different techniques. The produced nanocomposites, showed remarkable improvement in their mechanical and morphological properties, compared to the pristine PUA. The XRD results revealed that the ODA-MMT silicate interlayer spacing increased up to 3.9 nm, indicating the intercalation structure. Whereas, the pristine MMT microcomposite showed agglomeration. The FTIR results confirmed the intercalation of the PUA chains in the silicate layers, nevertheless, the chemical structure of the PUA was not influenced by the presence of the silicate layers in the matrix. The mechanical properties of the nanocomposites showed incredible increasing in the modulus value, from 8.53 ± 0.40 to 132.43 ± 6.60 MPa by the dispersion of 5 wt% ODA-MMT in the PUA matrix, as well as the tensile and the dynamic mechanical properties were also improved. The radiation dose and the amount of the tri-functional monomer (TMPTA) in the formula were affected significantly the cross-linking affect the cross-linking density of the cured PUA nanocomposites.

A14: Technical Cooperation Success Stories

Recent Radiation Research and Technology Development in Croatia

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The Ruđer Bošković Institute is Croatia's leading scientific institute. The Radiation Chemistry and Dosimetry Laboratory (RCDL) has remained until the present day the only unit in the country pursuing both basic and applied scientific research in the fields of radiation chemistry, dosimetry and radiation processing. Physico-chemical effects of irradiation, being function of absorbed dose, are used for the quantitation of absorbed energy, i.e., dosimetry. Two families of liquid chemical dosimetry systems have been developed by the RCDL. The low-dose system is nowadays one of the best characterized chemical dosimetry systems in the range of therapy and accident doses. The high-dose system, based on the ethanol-chlorobenzene (ECB), has been accepted as a joint ISO/ASTM 51538 standard.

Research in applied radiation chemistry and radiation microbiology, analyses of epidemiologic and economic data, our presence on national and international bodies generating and maintaining corresponding regulations, permanent improvements of our irradiation facilities and other activities all have helped introduce into Croatia the necessary scientific, technical, legal, economic and other prerequisites for technology transfer in the yield of radiation processing. At present, RCDL has the only facility of its kind in Croatia and the region. The main equipment is a batch type panoramic γ-irradiator (95 kCi ^{60}Co) which has been designed by the RCDL staff, and its periodical upgrading has been regularly assisted by the IAEA. Although only an experimental facility at the beginning, it was designed with the future role of a multipurpose pilot scale irradiation facility in mind, capable to contain more than 100 kCi of ^{60}Co. The irradiator is suitable for a variety of applications, from medium dose range used in radiobiology to high doses used in radiation processing and radiation chemistry. The capacity of the irradiator chamber is 4–6 m^3 of material per batch. There is no conveyor to transport goods into and out of irradiation chamber giving maximum flexibility with respect to the dimensions and weight of the objects. Performing commercial scale irradiation for sterilization, pasteurization, decontamination and disinfestation of various materials such as medical supplies, pharmaceuticals, foods, cosmetics and toiletries, packaging, etc., provided the necessary understanding of practical aspects of irradiation processes and dosimetric control methods. In recent years the interest for irradiation protection and conservation treatment of cultural artefacts has been strongly increased and successfully carried out in Croatia and region.

In this lecture a review of scientific research and development of the RCDL over the past five years will be presented, with special attention given to the recent upgrading of the facility. This upgrading has enabled the RCDL to offer the exchange of knowledge and experience in many areas of scientific research as well as to offer more extensive and diverse applications of radiation technology.

The support of the IAEA in ensuring timely supplies ^{60}Co over the years, especially through the recent Technical Co-operation Project CRO/1/006 (2014-2015) is gratefully acknowledged.

Multipurpose γ-Irradiator and Mobile Unit with an Electron Beam Accelerator Developed in Brazil

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Radiation processing technology for industrial and environmental applications has been developed and used worldwide in the fields of water treatment, advanced materials, nanotechnology, medicine, tissue engineering, disinfestations and disinfection of books and documents, processes and industrial production and natural resources, among others. The Radiation Technology Centre (RTC) of the Nuclear Energy Research Institute (IPEN), of CNEN, Brazil, developed a small size continuous run and multipurpose industrial γ-irradiator with a revolutionary design and national technology to be used as a demonstration facility for manufacturers and contract service companies that need economical and logistical in-house irradiation system alternatives. It will be useful for supporting the local scientific community for product and process development using γ-radiation, assisting the traditional and potential users on process validation, and for training and qualification of operators and radioprotection officers. The technology developed for this facility consists of a continuous tote box transport system comprising a single concrete vault, where the automated transport system of products in and out of the irradiator utilizes a revolving door integrated with the shielding, avoiding the traditional maze configuration. Covering 76 m^2 of floor area, the irradiator design is product overlap sources with a maximum ^{60}Co capacity of 37 PBq (tote boxes, Category IV, wet storage). The performed qualification programme of this multipurpose irradiator was based on AAMI/ISO 11137 standard. The irradiator currently holds 7.4 PBq (200 kCi) of ^{60}Co. For irradiator dose optimization, the source distribution was done using the Cadgamma software. The poly-methylmetacrylate (PMMA) dosimeter system was used for irradiator dose mapping. The economic analysis and performance, concerning to the dose uniformity and ^{60}Co utilization efficiency were calculated and compared with other commercial γ irradiators available in the market.

The RTC is involved in establishing a mobile electron beam accelerator unit to treat industrial effluents for reuse purposes. The mobile unit will be equipped with an electron beam accelerator (0.7 MeV, 20 kW) with safety requirements (BSS, IAEA and CNEN Safety Standards), and can be used for effluent treatment from petroleum production, for petroleum desulfurization, and, in addition, for degradation of toxic organic compounds in wastewater for reuse. This project is supported by the IAEA (TC Project BRA1035, 2016–2018) and by the Brazilian Financial of Studies and Project (FINEP). To enlarge the national capacity to treat industrial effluents using electron beam accelerators, the mobile unit treating effluents on site from 1 m^3/h up to 1000 m^3/day, will provide an effective facility between a laboratory-scale plant to a large-scale plant, with the objective to demonstrate its efficacy and to transfer the technology. Studies have taken place in various productive sectors in the country and in other foreign laboratories to prove that radiation treatment offers technological and economic benefits over conventional techniques for treating recalcitrant pollutants.

Radiation Processing in the Philippines: Developments and Prospects

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Radiation processing is the treatment by radiation to get the desired effects in the products. It offers various advantages in the field of sterilization of medical products, food irradiation and a treatment of a variety of products, which have direct relevance to industrial productivity and healthcare.

Various R&D activities in the Philippines have been undertaken since 1965 by the Philippine Atomic Energy Commission/Philippine Nuclear Research Institute (PAEC/PNRI), the academic and other government research institutions utilizing the γ-irradiation facility of PNRI and the recently established electron beam (EB) irradiation facility. These are demonstration facilities to assess the techno-commercial viability of the processes such as decontamination of spices, herbal products and cosmetic raw materials, food irradiation and radiation sterilization of medical devices. The new areas being explored include the use of EB-grafted non-woven fabrics as metal adsorbents and the use of modified carrageenan as plant growth promoter. These studies strongly indicate that radiation processing has a strong potential for technology transfer to Philippine industries.

This paper presents an overview of current developments in research activities and commercial applications of radiation processing in the Philippines, the different radiation processing facilities, the ongoing upgrading of the γ-irradiation facility to meet the demands of the industry and the technology transfer activities currently being undertaken.

A14

Radiation Processing in Ghana: Achievements, Prospects and Challenges

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The Ghana Atomic Energy Commission (GAEC) commenced research and development activities in the area of radiation processing in 1970 with a laboratory scale irradiator through the assistance of the IAEA. The programme was facilitated by training of the relevant scientific and technical expertise at the national level. In 1994, a semi-commercial irradiator (Gamma Irradiation Facility, GIF) was installed by the Government of Ghana with the assistance of the IAEA. The GIF was further upgraded in 2010 with funds from the Export Development and Agricultural Investment Fund (EDAIF) to enable full-scale commercial operation. The Ghana Standards Authority has developed two standards to regulate radiation processing in the country. Currently the GIF provides irradiation services to the agricultural, medical and export sectors of the economy notwithstanding further emerging prospects in the agro-processing sector. The School of Nuclear and Allied Sciences has developed a postgraduate programme in radiation processing to ensure a sustainable requisite human resource base. Realistic mechanisms for public-private partnerships need to be identified and implemented to assist with transfer of the technology of radiation processing in the country. Continued support of the government, regional collaboration, and strategic cooperation with the IAEA will be vital in the successful commercialization of radiation processing technology.

Radiation Processing in Cuba: Past, Present and Perspective

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In the present paper is shown the evolution of the radiation processing in Cuba and the development reached until today and the perspectives, as well as, the technical characteristics of our radiation facilities, the results obtained with the application of this technology in several branches of the science, like medicine, biology and agriculture, as much at research scale as pilot projects. It will cover the most significant aspects related with the sterilization of medical-pharmaceutical material, food irradiation, of biological products, modification of materials, detection of irradiated foods, quality control management, dosimetric systems employed in the process control and the regulatory aspects of radiation processing in our country.

Drafting and Preparation of Proposals of Irradiation Plants: Mexico Experience

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The drafting, integration and evaluation of infrastructure projects face huge challenges. Each project has a relevance and a unique nature, although, they are developed in conditions and environments more or less similar. This paper describes different progress that were accomplished in drafting, integrating and evaluating various projects focussed to specify, design, build and commissioning industrial irradiation plants based on electron beam in Mexican territory.

Having as a background the experience that ININ has gained since 1980, when its Gamma Industrial Irradiation plant was commissioned and 1983, when its commercial operation started, the key elements to consider related to the installation of new irradiation plants based on electron beam are:

1. The market demand that justifies the need to have the facility.
2. Other additional key drivers that strength the arguments to install a new facility.
3. The different kinds of regulations, the legal framework, types of technologies and the particular requirements of industries wherein the supply of irradiation services will be focussed like medical disposables and food products.
4. The technical details to fulfil the specification of irradiation service that the facility will offer to the customers: desired effects on materials, uniformity and range of doses, guarantee, quality control and complementary services like microbiological analysis or dose mapping, risk management among users and services by the supplier.

As a result given considerations, it may be possible to have a solid foundation to draft, integrate and evaluate a new project. The next step should be the cost-benefit analysis taking into account aspects related with market study, the legal framework and a sensitivity analysis. Costs of the project should be treated with the sufficient detail according with the level of development of the Project.

From what was mentioned above, any organization has the possibility to define the technical characteristics of the main equipment, basically, the EB accelerator required: energy, EB or EB and X-rays, power, type of technology (Linac, RF), among others.

The experience shows that if at the very beginning exists uncertainty about the financial resources for the project, it is very convenient to have alternatives available since the very early stages to face changes on the scope and on the specific requirements of diverse budget sources, these issues could assure the success of the project.

A15: Emerging Radiation Technologies

Economics of Radiation Processing Technology: Posers and Prospects

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Radiation processing of materials for a variety of applications has been well-established, and is also continuing to evolve further. The cost of radiation treatment, that is, say, dollar per kGy per kg, is dependent on several factors of the radiation facility and operations, and almost always irrespective of the nature of material being treated. Consequently, materials of higher value like medical disposables, most spices, etc., have been more favourable for radiation treatment from the point of view of economics. Furthermore, certain minimum overhead cost is invariably present in all cases, and thus low-dose requirement for certain commodity may not necessarily mean lower cost for radiation treatment. The absorbed radiation dose required is known to vary (Gy to kGy) over a few orders of magnitude, and for a single radiation facility to cater to the entire range is a known challenge. There are technology options but they come with added complexities. The scope for year-round availability of the same material, or a group of materials, requiring radiation processing is another key issue to be addressed. Yet another dimension of technology has been the availability of a choice between γ-radiation plant and electron accelerator (EB machine) facility, each with its own strengths and issues. The ease and ruggedness of operation of ^{60}Co based plants and their modest infrastructural needs are appreciable and proven records are available. However, the availability and transportation of sources for replenishment, and mostly fixed-dose delivery feature of the γ-facility pose certain limitations. EB systems, especially of variable energy and power, would prove advantageous, while the ease and ruggedness of their routine functioning over sustained, long-periods has very limited record, leave alone the need for assured availability of high-quality power supply (issue in many countries). Mostly two major areas of use are contemplated by the stakeholders, namely, sterilization or hygienization of products on one hand, and tackling and treating pollutants, on the other hand. Safe and often prolonged preservation is the need in the former case and for cost consideration. The risk and cost to society and environment by not-treating the harmful pollutants in managing them are the drivers in the latter case. Placing a simple dollar figure here may not be necessarily feasible or easy. Naturally, for policy makers and end-user stakeholders, the above scenario presents an equivocal picture, of an attractive technology available for value-addition, but with techno-economic challenges. The author has had experience in dealing with stakeholder experts from IAEA Member States, and earlier in India with different industries seeking to use radiation processing. Invariably, objective, frank analysis of every specific case has been necessary and useful to better understand and/or explain the various aspects and factors to be addressed. It is imperative for technology experts to speak in single unequivocal language to the national policy makers and end-user stakeholders, so that the considerable merits of radiation processing are well harnessed to meet every specific national need and priority.

Radiation Modification of Carboxymethylated Chitosan: From Basics to Applications

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The mainstream of radiation modifications of polysaccharides was limited to reduction of molecular weight due to main-chain degradation in order to facilitate further processing or induce specific biological activities. On the other hand, graft polymerization of functional monomers initiated through radicals crated by ionizing radiation on polysaccharide chains, or as effect of glycosidic bonds cleavage, was also extensively explored. The possibility of cross-linking of polysaccharides by radiation initiation was demonstrated, firstly for water-soluble cellulose derivatives, yet high degree of substitution (DS) of cellulose with side chains and high concentration in aqueous solution were found to be advantageous to obtain significant yield of gel fraction. In the present investigation, the behaviour of carboxymethylchitosan under ionizing radiation was explored and exemplary application proposed.

Carboxymethylchitosan (CMCS) of the deacetylation degree (DDA) 93.8%, DS 96% was obtained from Kraeber & Co., GmbH (Germany). Medical grade chitosan (CS) obtained from Heppe Medical Chitosan GmbH (Germany), with DS 90% was also used. Solutions of CMCS and CS were irradiated by electron beam (EB) with and without a cross-linking agent of poly(ethylene glycol) diacrylate (PEGDA, Sigma-Aldrich). Obtained gels were evaluated by standard sol-gel analysis.

Results of this study indicated that ionizing radiation is a convenient tool to synthesize hydrogels based on CMCS either with or without PEGDA when irradiated in highly concentrated solutions, whereas CS, its parent polysaccharide, as expected, is prone to form gels only in the presence of the cross-linking agent. The method engaging PEGDA allows formation of macroscopic gels even from a CMCS and CS solutions of low concentration resulting in gels of gel fraction as high as 80%, which is distinct from the known technique of polysaccharide cross-linking in the paste-like state: irradiation of CMCS 20% concentration results in gel fraction less than 50%. The CMCS gels were found not to cause cytotoxicity (as tested by LDH assay) and demonstrated antimicrobial activity, especially towards gram-negative bacteria.

If the dose applied for gel formation is 25 kGy or more, it may be sterilized simultaneously during its synthesis. This was explored (CMCS aqueous solution) in manufacturing of internal hydrogel scaffold for nerve regeneration guides. Regular nerve guidance tubes of polylactide and polycarbonate, elaborated in our laboratory, were filled with CMCS mixture with water (paste like-state or physical gel, based on conditions determined in this study) and irradiated with EB. After in situ synthesis of the gel inside the tube, the product is ready for immediate use, because applied technology combines gel formation and sterilization into a single process.

Remediation of Petroleum Impacted Soils with Electron Beam Irradiation

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Pollution of soil by heavy hydrocarbons (HH, C12–C40) is a major global environmental issue. Heavy hydrocarbons pose a significant remediation challenge because they are recalcitrant and relatively immobile in soils, and hence will persist in the environment for a long time. Electron beam has the potential to both crack and polymerize hydrocarbons at lower temperatures than similar energetic methods for HH remediation such as thermal desorption and pyrolysis. Electron beam remediation must be proven fast, efficient, and economical at large scales. To this end, the present research has several objectives: show reduction in mass of heavy hydrocarbons in soil for proof of concept; assess impact of testing parameters (such as radiation dose); and design an experimental setup to evaluate soil treatment, both in a batch configuration and in a continuous configuration.

Samples with initial HH contamination ranging from 2% to 10% (w/w) were irradiated with an 18 kW, 10 MeV RF LINAC in various configurations. Configurations including stationary and moving soil containers were developed to irradiate samples ranging in size from 100 g to 3 kg. Various doses were tested from 50 kGy to 2000 kGy to assess the energy cost and effectiveness of various levels of remediation. Beam penetration profiles and HH reduction profiles in the soils were measured. Similar soil samples were also thermally desorbed and pyrolyzed to compare energy input to irradiation at similar maximum temperature ($\sim 420^{\circ}$C) and to characterize chemical reduction mechanisms during irradiation. Treated and untreated samples were characterized using colourimetry and gas chromatography (GC-FID) performed with hydrocarbon solutions in dichloromethane.

Tests showed effective HH mass reduction, which resulted in TPH reduction (below 0.1%, satisfying environmental regulations) in both batch and continuous treatments. Temperature programmed desorption and oxidation (TPD/TPO) showed evidence of both volatilization and char formation as the means of heavy hydrocarbon mass reduction.

Electron Beam Pretreatment of Lignocellulosic Biomass

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A15

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Cellulose is the major structural component of wood and plant fibres and is the most abundant polymer synthesized by nature. Despite this great abundance, cellulosic biomass has seen limited application outside of the paper industry. Its use as a feedstock for fuels and chemicals has been limited because of its highly crystalline structure, inaccessible morphology and limited solubility. Any economic use of lignocellulosic resources for the production of fuels will require a "pretreatment" technology to enhance the accessibility of the biomass to enzymes and/or chemical reagents. Most pretreatment techniques either are energy intensive or require the use of toxic chemicals. In this study electron beam irradiation was used as a pretreatment technique.

Samples were irradiated at IBA Industrial, Edgewood, New York, USA, using a 90 kW, 3 MeV Dynamitron. Most samples were less than 0.5 cm thick with a bulk density of $< 0.6\ \mathrm{g/cm^3}$, thus giving equal-in equal-out dose. Thick (2.5 cm) wood boards were irradiated from both sides giving a uniform dose profile. The dose was determined with cellulose triacetate films. Molecular weight was determined using a Waters Breeze size exclusion chromatography system fitted with a Waters 2414 refractive index detector, and two Polymer Laboratories Polypore columns ($330 \times 7.5\ \mathrm{mm^2}$). The relative crystallinity was determined using a Rigaku DMAX-1000 X-ray diffractometer with Ni-filtered Cu K_α radiation ($\lambda = 0.15418$ nm). All other tests were conducted in accordance with ASTM or TAPPI standards and gravimetric analysis.

As the dose was increased from 0 to 1000 kGy, the molecular weight decreased from 80 000 to 5000 Da and the relative crystallinity decreased from 0.87 to 0.45. The wood toughness and energy required for milling was decreased by about an order of magnitude. The solubility of irradiated wood in water, 0.2 N NaOH and 2.0 N NaOH increased with increasing dose with 95% of the wood soluble in 2.0 N NaOH after 1000 kGy. The hot water extraction of hemicellulose and lignin increased along with dose. The extracted lignin also showed an increase in solubility in acidic solutions. Most importantly, the rate and total sugar yields from enzymatic hydrolysis increased with increasing dose. There did not appear to be any "poisoning" of fermentation to ethanol due to the presence of furfurals. Sugars extracted from irradiated wood shows an increase in the rate of fermentation.

Electron beam irradiation of lignocellulosic biomass appears to be an excellent pretreatment technique to reduce the recalcitrance of the biomass. Electron beam treatment is less energy intensive and does not use or produce toxic chemicals than other pretreatment techniques. Electron beam treatment reduces the crystallinity and molecular weight of cellulose, increases hot water extraction of lignin and hemicellulose, and increases the rate and total sugar produced by enzymatic hydrolysis.

Radiation-Induced Admicellar Polymerization of Methyl Methacrylate on Cassava Starch

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Cassava starch (CS) is a natural polymer that is inexpensive and abundant, especially in Thailand. In addition to being cost-effective, CS is also biodegradable, compostable, non-toxic and most importantly, renewable. Consequently, blending CS with other biodegradable synthetic polyester such as poly(lactic acid) (PLA) is economically interesting, due to a high potential of cost reduction as well as biodegradability of their blends. Nevertheless, it is very difficult to blend starch with other synthetic polymers, due to their incompatibility. Several research groups reported their attempt to improve the compatibility between synthetic polymers and starch using different techniques. Among these available methods, the modification of starch surface by admicellar polymerization is rarely investigated. Admicellar polymerization offers several advantages over traditional techniques. Accomplished in aqueous solution, this environmentally friendly technique can form nanoscale polymeric thin films, with minimum chemical usage and without the use of organic solvents. Additionally, this benign technique is able to maintain basic properties of the original material. Admicellar polymerization is applied to induce surface modification to make two components of their polymeric composites more compatible. Applications of admicellar polymerization are numerous, from reinforcements of composites to value addition of functional textiles. These examples emphasize the advantages of using admicellar polymerization as an effective method to enhance compatibility between a filler and a polymer matrix, which ultimately leads to improved mechanical properties of their composites. Our recent work has proven that admicellar polymerization, induced by thermal process, can be successfully applied to coat the surface of starch with poly(methyl methacrylate) (PMMA) to render it more hydrophobic and more compatible with PLA. The objective of this research is to further expand our previous study by applying γ-radiation to induce admicellar polymerization. The third step of admicellar polymerization is traditionally induced by thermal process, with chemical initiators. However, radiation process requires no catalyst to initiate the reaction, thus resulting in contamination-free products. In this study, methyl methacrylate (MMA) is used as a monomer for the formation of ultra-thin PMMA film on the surface of CS. Surface modified CS is characterized by iodine test, flotation test, film formation analysis, Fourier transform infrared spectroscopy (FTIR) as well as thermal gravimetric analysis (TGA). The comparison is made between cassava starch modified by radiation process (RS) and thermal process (TS). Results from film formation analysis, FTIR and TGA indicate that RS shows higher percentage of PMMA film formation than TS, hence confirming that radiation processing can be applied as an alternative method for surface modification through admicellar polymerization.

Preparation and Characteristics of Reduced Graphene Oxide in Ethanol/Water Solution by γ-Ray Irradiation

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A15

Reduction of graphene oxide (GO) in ethanol/water solution in the presence of oxygen by γ-ray irradiation was studied. Suspension of GO was prepared by dispersing graphite oxide in the ethanol/water solution at a concentration of about 1 mg/mℓ under ultrasonic condition, and then irradiated by γ-rays in an absorbed dose range of 0–250 kGy. The characteristic properties of GO and reduced GO (RGO) samples were analyzed by Ultra-violet visible (UV-Vis) spectroscopy, Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), Raman spectroscopy, Transmission electron microscopy (TEM), contact angle and electrical conductivity measurements. The conductivity of the RGO was increased from 2.4×10^{-2} to 2.2 S/cm with increasing the absorbed doses from 25 to 250 kGy. Results of this study were indicated that a promising way could produce a large amount of pure graphene from GO with a simple reducing process using the γ-irradiation method.

Radiation Induced Oxidation, Cross-Linking and Grafting of Ultra-High Molecular Weight Polythylene

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Ultra-high molecular weight polyethylene (UHMWPE) has excellent chemical inertness, biocompatibility, mechanical property and wear-resistance, which is widely used in engineering and medical fields. Some drawbacks of UHMWPE can be overcome by radiation processing, such as poor compatibility, creep-resistance and yield strength. In this work, radiation oxidation and grafting were adopted to modify the surface property of UHMWPE. Radiation cross-linking and annealing were used to improve the creep-resistance, yield strength and wear resistance of UHMWPE. The results indicated that radiation oxidation and grafting could effectively change chemical groups on the surface of UHMWPE. However, radiation oxidation could not remarkably improve the surface property of UHMWPE, such as hydrophilicity, even at a dose of 300 kGy by γ-irradiation in air. Radiation grafting of acrylic acid could significantly improve the hydrophilicity of the UHMWPE powder. The UHMWPE powder with grafting yield of less than 10% presented a good dispersion in water. Radiation cross-linking and annealing improved creep-resistance and yield strength of the UHMWPE sheets. The cross-linked UHMWPE sheet with a dose of 300 kGy was without obvious deformation under a load of 0.06 MPa at 270°C in 4 h. In addition, the cross-linked UHMWPE powder as an additive, even at low content, could improve the wear resistance of pristine UHMWPE. In conclusion, the surface and mechanical properties of UHMWPE can be effectively improved by radiation processing.

B01: Advances and Trends in Radiotracer and Radiation Science and Technology I

Improved Procedures for Preparation of Argon-41 Gaseous Radiotracer from Solid Clathrate Compound

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Argon-41 can be a very good gaseous radiotracer for industrial applications if a sufficient amount of activity is produced from the reactor. The common procedures for preparing Argon-41 by irradiation of a quartz ampoule containing compressed argon gas give such low efficiency that the produced activity is not sufficient to compensate the ^{41}Ar decay during transportation to the field.

This paper introduces procedures for preparing argon in a solid clathrate compound with hydroquinol in which the concentration of argon reaches 7% by weight. The stability of the argon clathrate allows production ^{41}Ar in the reactor safely at the sufficient amount. In the field, radioactive argon gas is liberated from hydroquinol crystals by dissolving with water or alcohol solvent. The experiments tracing gas flow using ^{41}Ar and methyl-^{82}Br as reference tracer were carried out to test the procedures.

The procedures have improved the efficiency of ^{41}Ar gaseous tracer production to the level of GBq activity for industrial application.

Experimental Study of Conical Fluidized Bed Using Radioisotope Based Technique

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B01

Gas-solid conical fluidized beds are used for several applications like drying, food processing, granulation, combustion, gasification, coating of nuclear fuel particles, crystallization, catalytic cracking, sulfide ores sedimentation and particle classification, etc. The design parameter for such applications depends completely on the bed behaviour. However, research on conical fluidized beds shows that literature at in situ condition is currently lacking. So the investigation of conical gas-solid fluidized beds for in-situ conditions is required for the basic understanding of the flow pattern and bed behaviour which can be implemented for better design and process scaling of the column.

The radioisotope based technique known as radioactive particle tracking (RPT) technique and densitometry have been applied for the study of conical fluidized bed. In the RPT technique, one radioactive particle (glass bead in this case) is doped with scandium-46. This tracer particle is used as marker whose motion is tracked by using 10 NaI(Tl) scintillation detectors. The position of the tracer particle is reconstructed by using the count time series map recorded by each detector. Further post-processing, like particle position time series data, Lagrangian velocity time series, mean and rms velocities of the particle, is calculated by using the count time series map. In addition, the densitometry technique is used to measure the chordal average solid volume fraction at different axial and radial locations of the bed.

The conical column used comprises of 0.8 m conical section height and 0.05 m diameter at bottom increasing along height until 0.2 m on top. Two different particles (diameters 0.6 mm and 1 mm) having density $2500\ \mathrm{kg/m^3}$ are used. Both mono-dispersed and binary bed behaviour is studied to characterize the mixing and segregation. The bed composition has been varied as $0:100$, $25:75$, $50:50$, $75:25$ and $100:0$ to visualize the effect of composition with velocity. The total bed weight is kept constant for all experiments. In binary fluidized bed both the particle are tracked individually. Both RPT and densitometry have been conducted for three different velocities ($2\ u_{\mathrm{mf}}$, $3\ u_{\mathrm{mf}}$ and $4\ u_{\mathrm{mf}}$ of 1 mm particle). Results indicate that the solid volume fraction becomes uniform with increase in velocity, signifying better mixing with velocity increase.

Mixing and segregation studies are performed in mono-dispersed and binary fluidized bed. It is observed that the volume fraction of solid particles shows uniform distribution with increasing velocity.

Predicting Dead Pore-Volume of Pores in a Porous Media from Single Tracer Experiment

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Tracer studies are used to characterize the porous media for flow paths of different phases, pore volume and flow surface area in reactors or oil reservoirs. The stagnant or dead pore volume interacts with the tracer leading to a tailing effect in the tracer breakthrough curve. Therefore, the effluent concentration profile from a single tracer test is not sufficient to characterize the porous medium. Generally, numerical simulation of the effluent concentration profile with parameter fitting is used to determine and separate the effect of dead pore volume from other tracer behaviour in the porous medium such as dispersion or adsorption. In laboratory experiments, the tracer test is done at various flow conditions to determine the effect of dead pore volume. Numerical simulation of huge reactors and reservoirs is computationally expensive and the imposition of different flow conditions is difficult at industrial scale. The goal of this work is to develop a model for the determination of dead pore volume from a single tracer experiment for homogeneous, one-dimensional flow in porous media.

The effluent concentration profiles of the tracer from numerical experiments of tracer transport in porous media are used to arrive at the model to determine the dead pore volume and the surface area associated. Mechanistic models of tracer transport in porous media are used in the simulations.

The pore volumes injected, flow rate, axial dispersion and tracer diffusivity in the dead pore volume are found to be the governing parameters for determining the fraction of dead pore volume in the porous media using single tracer test. Conventionally, numerical simulations with parameter fitting to match the effluent tracer concentration have been used to characterize the porous medium for effective porosity and mobile porosity by modelling the tracer's flow and chemical behaviour in the sediments. The model developed here can be directly used to infer the reservoir parameters of mobile porosity from the tracer's effluent concentration profile from single tracer experiment.

Application of RPT and Densitometry for Measuring Liquid Velocity Field and Void Fraction in Convective Boiling Flows

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Convective boiling flows are found in nuclear reactors and are subject of numerous experimental and theoretical studies. The thermal hydraulics of the nuclear reactor, especially boiling water reactors (BWR), is affected by the complexities of two-phase flow around the rods driven by a vertically distributed heat flux in the rods. One of the main challenges in operating this kind of a reactor system are in the complexities of two-phase flow around the rods driven by a vertically distributed heat flux in the rods. Knowledge of the time-averaged void fraction distribution as well as the velocity profiles of the liquid phase are of great relevance in the design of these systems, for providing validation data for thermal-hydraulic CFD codes, as well as for design of nuclear safety systems.

In this contribution, measurement of the liquid phase velocity field and void fraction using RPT and densitometry, respectively, at different conditions and heater rods arrangements will be reported.

The talk will discuss the various challenges faced in making these measurements in boiling flows, and how they were overcome. Further, key findings from the hydrodynamics, which can be obtained only through the use of these radiation-based imaging techniques, will be presented.

Holdup Analysis of a Bubble Column Using an Industrial Fourth Generation Like γ-Ray Tomography

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This work has been performed using the fourth-generation-like industrial computed tomography developed at the IPEN, constituted with 70 NaI(Tl) $25.4\ \mathrm{mm} \times 50.8\ \mathrm{mm}$ (diameter $\times$ length) and a bubble column for industrial process was evaluated. The column is a Perspex glass cylindrical tube of 80 mm internal diameter, 100 mm external diameter and 1400 mm height constituted the following parts: liquid circuit (water), a gas circuit (4 ℓ/min) bubbled into a system containing two limiting holes of 4 mm and 2 mm, located at 65 mm from the centre of the column each one in opposite side. γ-ray tomography experiments were carried out, using this simulator column both empty and filled with water plus gas bubbling. In this work the scanner was set for 5 views and 14 projections each. The resulting images describe the liquid or gas phase holdup distributions for bubbles generated in a hole of 4 mm and 2 mm diameters located at 15 mm of the column wall in a opposite side, respectively. It was established that the newly developed fourth-generation-like fan-beam arrangement γ-scanner unit has a good temporal resolution acceptable given the size of the column used in this study and capable to infer the relative proportional of gas and liquid proportion in the column.

B02: Education, Training and Safety

A New Approach to Teach Beginners How to Analyze Tracing Results by a Rapid Visual Method

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When people learn how to analyze the results of residence time distribution (RTD) experiments, it is very difficult for them to immediately be able to form pertinent ideas concerning the kind of mixing only by looking at the RTD curve; the difficulty remaining in the understanding of the effects of flows in the system (in parallel and/or series, recirculation, etc.) on the global RTD curve. Everyone needs significant experience to be able to do that (from several months up to years). However, this period can be significantly reduced. To do this, we developed a new visual method to teach RTD analysis complementing the classical method (theory of residence time, transfer functions, simple systems like CSTR or plug flow reactor). We use the software DTS®. The students use it in an unusual way, to do simulations of reactors associations from the simplest to the very complex. We tested the method over several years with students preparing a master of engineering degree, and we progressively improved the different reactor configurations, to optimize teaching efficiency. Now, in only one or two hours, students testing a dozen selected configurations can gain the equivalent of several months of experience.

Education Training: INSTN Designated as an IAEA Collaborating Centre

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The National Institute for Nuclear Science and Technology (INSTN) created in 1956 by the French government has been designated as an IAEA Collaborating Centre in May 2016. This recognition allows the Agency to receive support from this Institute to implement its programmes including those from the Department of Nuclear Sciences and Applications. The competency of this collaborating centre is "Education and Training in nuclear technologies industrial and radiopharmaceutical applications". The INSTN and the Agency have defined a work plan to host specific training courses, and to develop new training courses in connection with INSTN's areas of expertise. Thus at the end of June 2017, a three weeks training course on "Training and Certification for Industrial Applications of Radiation Technologies: Radiotracers Residence Time Distribution Approach and Sealed Sources Column Scanning Technique" will be organized in Saclay, near Paris. Through column scanning equipment dedicated to training, innovative training methods, practical room for manipulating radiotracer, theoretical contributions will be delivered by experts from the Agency and practical work will be carried out by participants consisting of both fellows of the Agency but also professionals from the host country. This training will benefit from the infrastructure and logistics of the INSTN for the safe use of radionuclides used for tracing.

The INSTN as a part of the French Atomic Energy Commission (CEA), is under the joint supervision of three ministries: Ministry of National Education, Higher Education and Research, Ministry of the Economy, Industry and the Digital Sector, and Ministry of Ecology, Sustainable Development and Energy. The Institute has partnerships with various universities and higher education institutions in France and abroad but also with technical schools for academic degree from operator to PhD diploma, mostly in the nuclear domain. The Institute organizes tailor-made professional training courses in France or abroad and support continuing professional development so as to increase staff skills in a large spectrum of nuclear activities such as: nuclear engineering and applications, detection and measurement of radiations; radiation protection, chemistry and radiochemistry; Nuclear medicine, radiopharmacy, medical physics, radiotherapy and molecular imaging; new technologies for energy, economics of energies; micro and nanotechnologies.

In the field of academic and vocational training, INSTN signed an additional agreement with the IAEA in 2014 which helped to launch the Virtual Reactor Laboratory (Internet Reactor Laboratory) project, which will allow students from European universities a remote access, via the Internet, to the ISIS research reactor (nominal power of 700 kW). These students can monitor, through a video system (via Internet), the operation of the ISIS reactor by exchanging with a trainer-operator present in the control room of the installation of the CEA-Saclay. For 60 years, the INSTN is a key-player in France for education and training in nuclear domains such as industry, research and medical. Being designated a Collaborating Centre will strengthen connections that INSTN has with the IAEA.

Training and Certification in Radiotracers and Sealed Sources Industrial Applications

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The International Society of Tracers and Radiation Applications (ISTRA) has been created in 2015 with its HQ in Vienna as the federation of Tracers and Radiation Application teams in the world with about 500 members today.

IAEA activities regarding capacity building are mainly conducted within TC projects through fellowships, scientific visits and expert missions. It has been clearly seen that there is a lack of structure in these trainings. FE hosts, RTC organizer experts are doing their best providing good work but they do what and how they wish, think and can. It is also quite difficult to synchronize the event with real field work to allow practical experience for the trainees.

We have to fix these issues and for that, in collaboration with IAEA, ISTRA has developed syllabuses, e-learning modules and question banks on radiotracers applications (RTD approach, TCS 31, 38 and 49), sealed sources applications (column scanning, NBS-TCS in publication process), tracers and NCS applications in sediment transport (TCS 59).

The global objective is to create a training and certification system for practitioners, with ISTRA acting as the examination and certification body worldwide.

The system has three levels of qualification, similar to the NDT system, based on the recognized syllabuses and examination:

- Level 1: helper/assistant
- Level 2: autonomous practitioner
- Level 3: team leader

Beside the better structure of the courses and the associated examination, it is also helping the practitioners and teams in promotion of the technologies, by improving the visibility and recognition of the qualification of personnel.

Today approximately 50 practitioners have been trained, qualified and certified in Africa and Latin America and the Caribbean regions. Unfortunately, due to the lack of TC projects, nobody in Europe or the Asia-Pacific regions has yet profited.

The IAEA Methodology for Radiological Protection of the Environment, Including Human and Non-Human Biota

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In 2005 the IAEA started to work with international organizations and Member States towards enhancing international standards and guidance for the control of radiological impacts to people and the environment. Until then, protection of the environment was based on the assumption that compliance with standards for human protection would ensure that other species are not put at risk; this assumption was being challenged by the international community. IAEA standards considering a new perspective were started in 2006 with the Fundamental Safety Principles and continued with the IAEA Basic Safety Standards on Radiation Protection and the Safety of Radiation Sources. In these standards, the radiation protection objectives for non-human species were related to higher organization levels as populations, communities and ecosystems, rather than on the protection of individuals as it is the case for humans; the need to consider protection of humans and other species in an integrated manner was also recognized. The IAEA followed the 2007 recommendations of the ICRP on protection of the environment, and proposed an assessment methodology for flora and fauna similar to that applied for demonstrating compliance of doses to humans with predefined criteria. The method entails the use of a set of reference animals and plants (RAPs) that relates to various species and ecosystems. Radiation exposure levels can be estimated and compared to identified criteria below which no or only very limited adverse effects to biota are expected. The integration of the protection of humans and other species was approached by assuming the linkage of the exposure scenarios between humans and flora and fauna. This resulted in a practical methodology which can be implemented with basically the same resources as those used to demonstrate protection of humans; the effectiveness of the approach to protect flora and fauna is verifiable by environmental monitoring programmes similar to those already in place for the humans exposures pathways, considering the relevant media. The IAEA established different ways to consider protection of biota for different exposure situations. For planned exposure situations, the results of the estimation of exposures to RAPs are compared to reference levels, and this could imply the need of control of the source. For existing and emergency situations, the control of those exposures is limited or impossible and the results of the assessments should be considered as an aspect in the optimization process, together with others, like social and economic factors. The paper presents the methodology developed by the IAEA and its implementation in international legal instruments, like in the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, and in recently prepared IAEA Safety Guides.

Radiation Sciences and Applications Programme in Arab Countries

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The AAEA works since 1989 to enhance the socio-economical development in Arab countries by promoting the peaceful applications of atomic energy in many aspects of life.

The AAEA is implementing "The Arab Strategy for Peaceful use of Atomic Energy up to 2020", which focusses on: the introduction of nuclear science in educational institutions; the use of nuclear technologies to improve plant and animal production; food and radiation processing methods; the use of nuclear technology in the diagnosis and treatment of diseases; the use of nuclear techniques in water resources management; the integration of the production of radioactive isotopes among Arab countries; the use of EB accelerators in irradiation operations and processing materials; the use of ion accelerators in the field of analysis and properties improvement and strengthening and promoting of the Arab capabilities in the field of NDT.

Under the framework of the above topics, AAEA has implemented many training courses, workshops, experts meetings, expert missions, scientific visits, conferences and seminars which will be detailed in the presentation.

For the implementation of the activities, AAEA is using country infrastructure such as: research reactors (RRs) that can produce radioisotopes (Egypt–2, Algeria–2, Libya–1, Morocco–1, Syria–1, Jordan–1); ion accelerator (cyclotron) for the production of radioisotopes such as PET (Morocco, Algeria, Syria, Saudi Arabia, Egypt); ion accelerator (VDG) for material researches and analysis (Egypt, Syria, Jordan, Lebanon, Algeria); electron accelerator (LINAC) for research and industrial applications (Tunis, Egypt, Syria, Morocco, Saudi Arabia, Algeria, UAE, Kuwait); electron accelerator (LINAC) for nuclear medicine radiotherapy (all Arab countries) and γ-irradiators (γ-ray) for medical applications and others (all Arab countries).

Quality Management in Radiotracer Technology and Sealed Source Applications

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Radiotracer and sealed source applications technology for industrial processes have become important non-destructive and noninvasive tools for on-line diagnosis of process malfunctioning, optimization and predictive maintenance. The technologies have been developed and established in many countries and are used by others as a routine service activity for preventive maintenance of process columns and tanks in their local industries. The demand for the technology has been found to be steadily increasing among the countries who have developed local capacity and capability. Data interpretation from radiotracer and sealed source applications are central in strengthening the development of the technology and increasing its use in various industries.

The confidence by industry to use this technology (product) is enhanced if clients know that it has been thoroughly evaluated by an independent, competent accreditation body to provide the third party assurance that the inspection body is competent in all aspects to apply it. Accreditation is a formal means of determining the technical competence of inspection bodies to perform specific types of inspection. Accreditation provides a ready means for customers to identify and select reliable inspection services, suitable for their needs. Therefore, the need for inspection bodies applying the technology to establish quality management systems and the means of achieving this is discussed in this paper. It also provides a guide on how personnel certification by an accredited certification body can be implemented.

B03: Radiotracers for Industrial Processes Optimization and Safety I

Study by Radiotracer of a Phosphoric Acid Production Line

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The principle of the study is based on the impulse-response concept. The pulse is obtained at the studied reactor inlet by injection of the radiotracer. The study involved a phosphoric acid production line, consisting in particular of two digesters (D1 and D2) and four crystallizers (C1 to C4). Technically, the interest of the study is to establish the residence time distributions to:

- Define mean residence times in the various reactors diagnosed;
- Define the arrival times, at all studied compartments: digesters D1 and D2, crystallizers C1 to C4;
- Identify the flow pattern in each reactor (perfect mixer, piston, etc.);
- Identify potential process failures (dead volumes, shorts, etc.).

The study was conducted in two phases:

- First injection of radiotracer, at the inlet of digester D1;
- Second injection of radiotracer, at the inlet of crystallizer C1.

The radiotracer used is ^{131}I, as liquid $Na^{131}I$.

The two injections of radiotracer have established with precision the residence time distributions in the studied reactors and flow regimes prevailing there. From the response-curves, product arrival times and mean residence times were also determined.

Studying Flow Dynamics of Catalyst Powder in CCU for Troubleshooting

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γ-scanning and radiotracer applications are very effective and inexpensive tools to understand and optimize the process as well as troubleshoot the various types of problems in many chemical, petrochemical industries and refineries. These techniques are noninvasive, hence the problems can be pinpointed online which reduces the downtime, helps schedule the shutdown and maintenance of the plant equipment, thus rendering huge economic benefits.

In a leading refinery of India, the catalytic cracking unit (CCU) was malfunctioning. It was suspected by refinery engineers that the catalyst powder is being carried over to the fractionator which could have lead to erosion of the fractionator column internals resulting their rupture, consequentially creating a fire hazard. To understand the flow behaviour of catalyst powder and to ensure the mechanical integrity, catalyst accumulation and choking, both radiotracer study and γ-scanning of the CCU reactor was carried out. The reactor consists of a riser, three primary cyclones and three secondary cyclones. γ-scanning of the reactor was carried out with the help of automatic γ-scanner using 1.8 GBq of $^{60}\mathrm{Co}$ sealed source. Results showed that catalyst powder was accumulated in one of the secondary cyclones and uneven density distribution was observed in another secondary cyclone. The radiotracer study was carried out using irradiated catalyst powder as a radiotracer which contains 0.9 GBq of $^{24}\mathrm{Na}$. The radiotracer was injected in the reactor through specially fabricated injection system. Radiation measurement was done using thermally insulated and collimated NaI(Tl) scintillation detectors located at various strategic locations coupled to a multidetector data acquisition system. The data were mathematically analyzed. It was confirmed that the catalyst powder was accumulated in one of the secondary cyclones with no flow downwards. This resulted in excess powder available, to travel along with hydrocarbon towards fractionator. Since the quantity of powder released through hydrocarbon outlet of CCU was higher than the designed value, the catalyst powder was observed in various zones of the fractionator. Mathematical modelling of the radiotracer data obtained at various locations corroborated the scanning results.

The Application of CFD for Modelling Flow and Visualization in a Cement Mill and Experimental RTD Validation Using Radiotracer Technology

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B03

Cement manufacturing represents an energy-intensive process due to the large power consumption of mills which are an integral process units of the entire cement manufacturing process. Therefore, performance optimization of cement mills is key in ensuring inefficiencies. Yet, performance optimization of such mills is impossible without adequate technical information about the milling process. Experimental residence time distribution (RTD) techniques are known to provide accurate process information and are useful in the validation of computational fluid dynamic models of the particular process under study. This first part of the study presents key process parameters of a cement mill obtained using the radiotracer residence time distribution (RTD) technique at the Ghana Cement plant located in Tema in the Greater Accra region of Ghana. Some 40 mCi of liquid $^{198}AuCl_4$ agglomerated with cement powder and water was used as the radiotracer and introduced at the mill inlet. The passage of the radiotracer at the outlet was monitored by an external sodium iodide scintillation detector. Data analysis revealed the presence of dead zones or channelling within the mill as indicated by the disparity in the experimental mean residence time of 33.65 minutes and theoretical mean residence time of 58.15 minutes.

In the second part of the study, ANSYS CFD simulation software will be used to model the flow in the cement mill for visualization as a complimentary method to the radiotracer RTD technique. ANSYS DesignModeler will be used to create the geometry of the 11.4 m long mill with a diameter of 3.6 m and ANSYS meshing used to create the computational mesh. FLUENT, the fluid analysis tool of the ANSYS software, will be employed to calculate the fluid flow throughout the geometry using the computational mesh, and CFD-Post for the analysis of the results in the form of velocity profiles. Particle tracking discrete phase model (DPM) will be used for the RTD simulation by tracking virtual particles injected at the inlet of the mill and recording the time required for them to reach the outlet. The results of the CFD simulation will aid the optimization of experimental parameters of the radiotracer RTD technique for cement mill investigations.

Radiotracers for Pulp Flow Dynamics Study in Three Different Phosphoric Acid Reactors

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Radiotracers are the method of choice to diagnose the functioning of the chemical reactors providing the most important parameters of the flow hydrodynamic and homogenization. It is known that radiotracers are the most sensitive and accurate techniques for online measurements of process parameters in industrial chemical reactors. Thus three different chemical reactors for the production of phosphoric acid in Tunisian phosphate processing plant were diagnosed by applying radiotracer method. The diagnosis of these reactors hydrodynamic behaviours was requested to evaluate the necessary parameters for assessment of the current performance and for planning further action to improve their efficiency.

Tracer tests were carried out under production condition using ^{131}I (Na^{131}I in powder form). The radiotracer was dissolved in some $0.5\ \ell$ water and was injected at the entrance of the reactor inside the central unit. The injection was performed instantaneously (as Dirac pulse). Two scintillation probes ($50.8\ \mathrm{mm} \times 50.8\ \mathrm{mm}$) were placed looking at the exit pipe from reactor. Both γ-detectors were well collimated with lead shield to reduce the influence of background radiation. The measuring time was fixed $10\ \mathrm{s}$ in order to detect fast movements inside and outside the reactors, in particular to measure the flow rate of the internal recirculation inside the reactor.

The experiment allowed a determination of the experimental RTD curves, the MRT, the flow rate of internal recirculation, the coefficient of internal recirculation, the dead volume rate, and identification of the mixing model corresponding to the whole reactor system operation.

Residence Time Distribution Study of Geothermal Vapour Flow in Pipe Using Axial Dispersion Modelling

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In the present study, the residence time distribution of geothermal vapour phase flow is studied using axial dispersion model. The experiment is carried out by injection of Krypton-85 (^{85}Kr) gas isotope into 10 inch pipe diameter containing dry geothermal vapour. The pressure and the temperature of the vapour are 8 kg/cm^2 and 170°C, respectively. Three collimated radiation detectors positioned respectively at 127, 177 and 277 m from the injection point are employed to capture γ-radiation from the injected ^{85}Kr isotope. The data represents residence time distribution (RTD) of isotopes in the selected experimental section. During the experiment, the flow properties are assumed to be time invariant, therefore the flow properties are also assumed linear in character. Flow parameter calculated using first moment method shows that the flow rate of the vapour is 11 /s. Model parameter, represented by the Peclet number (P_e), predicted from the best fit of the axial dispersion model to the experimental data is 223, whereas the coefficient of molecular diffusion (μ) calculated from the Peclet number is 0.5 m^2/s. The experiment concludes that the vapour flow is dominated by convection transport and the flow pattern tends to follow plug flow due to the big value of the Peclet number.

Radiotracer Investigation of a Pulp and Paper Mill Effluent Treatment Plant

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The pulp and paper industry is highly dependent on water for most of its processes, producing a significant amount of wastewater that should be treated to environmental standards before discharge into the atmosphere. The wastewater generated primarily consist of substantial amount of organics, inorganics, nutrients, toxic and pathogenic compounds which are treated in an effluent treatment plant (ETP). The effluent treatment plant is a combination of primary, secondary, tertiary and advanced treatments and vary from industry to industry according to the process utilized. Effective performance of the ETP is crucial both for environmental and economic view points and the radiotracer technique can be effectively used to optimize its performance and detect anomalies like dead zones, bypassing, channelling and so on.

A detailed residence time distribution (RTD) analysis of the aeration tank and secondary clarifier were carried out at Shreyans Paper Ltd., Ahmedgard, was carried out using ^{131}I as radiotracer to detect possible anomalies in the system. The aeration tank and secondary clarifier had capacity of 5472 m^3 and 1017 m^3 respectively. Flow rate of effluent water at the inlet of aeration tank was 5.21 ± 0.1 m^3/min. A pulse input of ^{131}I was injected 18 m from the inlet of the aeration tank and monitored using eight scintillation detectors placed at various locations of the reactors. These detectors are attached to the data acquisition system (DAS) using wired network that facilitated collection and visualization of the online data. The recorded RTD data were used to evaluate the residence mean residence time (MRT).

The MRTs obtained from the experimental RTD data were found lower than their respective theoretical MRTs. Estimated dead volume of the secondary clarifier was found to be 30%, that indicates significant capacity of the tank is inoperative reducing its treatment efficiency.

We conclude that the radiotracer technique is a very effective tool to study complex industrial effluent treatment plant and identifying flow anomalies in the process unit.

B04: Mitigating Climate Change: Protecting Coast Line and Environment

Radiotracer Methods for Understanding Contaminant Dynamics in Aquatic Environments

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Radioactive tracers have a distinct advantage in tracing contaminant migration in natural systems and characterizing contaminant mobility and uptake into living organisms in already-contaminated environments or at trace (environmental) levels. To use the contaminant itself in its non-radioactive form, concentrations significantly higher than the normal contaminated background level are commonly required which may be undesirable from a toxicological, chemical or regulatory perspective by impacting on the very processes under study. In contrast, radioactive forms of the contaminant can often be more easily measured (often in situ or non-destructively) and imaged at trace levels (using autoradiography), and usually have the advantage of a short half-life to remove residual contaminant. As such radiotracers have a valuable role to play in contaminant dynamics studies from the lab scale to the field. In the lab, radiotracers are well established in studies of contaminant kinetics and bio-distribution in living organisms, in interactions with non-living natural environments, e.g., sorption to soils and sediment, rocks and organics matter, and in tracing contaminant flow pathways and rates.

Radioisotopes of heavy metal contaminants (e.g., Cd, As, Se, Zn, Pb, Hg), nutrients (P, C) and the shorter-lived isotopes of longer lived radioactive contaminants such as Cs and Sr are commonly used in environmental contaminant studies. Recently, there is increasing interest and benefit in using radiotracer versions of emerging environmental contaminants such as persistent organic compounds or nanoparticles.

While most radiotracer work is conducted in laboratories, this approach can be up-scaled to field environments. There are obvious scientific benefits of conducting studies in situ, where the tracer interacts with the complex natural environment rather than an artificially simplified laboratory representation. However there are few examples where this has been done. Since the first field scale uses of radiotracer in the mid-1950s, the majority of field scale radiotracer applications have been in the nexus between industry and environment sediment transport in harbours and dams, effluent dispersion from outfalls and in mining and oil extraction. Exceptions include whole ecosystem studies in the Canadian Experimental Lakes in the 1970s, heavy metals downstream of a uranium mine in Kakadu NP in Australia, and studies demonstrating the retardation of metals and nutrients in studies in Sweden. Increasingly public and regulatory concern about the potential impact and perception of radiotracing in field environments has made these methods appear largely inaccessible to the research community. However, the introduction of new biota dose modelling tools and guidelines over the past two decades has provided improved evaluation of the environmental impact of radiotracer releases to the environment and ensure and demonstrate their safe use.

Nuclear Technologies Applied to Sediment Transport in River, Estuarine and Coastal Zones to Validate CFD Codes

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Siltation in harbours is a longstanding problem which could generate important costs for the maintenance programme needed to secure nautical conditions. This paper reports different studies on sediments in France (Le Havre, Bordeaux, Saint-Michel and Fort-de-France) aiming to characterize the rheological properties of sediment, analyze sedimentation-consolidation processes and propose a numerical model for simulating sediment dumping and water injection dredging. Two non-intrusive techniques are used to measure the time evolution of the vertical profile of concentration during batch settling test. The first one is a magnetic resonant imaging (MRI) vertical prototype used on Gironde estuary. The second is an X-ray "home-made" prototype used on the Seine estuary. Both are used to observe the sedimentation and the consolidation processes of natural cohesive sediments that was sampled close to Ports. They provide both movements of the supernatant/suspension interface and the isoconcentration lines of the process. A space-time based method is proposed to close the governing equation. Two different computational fluid dynamic (CFD) codes are used to simulate observations in well controlled laboratory conditions. The one is an open source and industrial 2D code (Telemac) while the other is a research and modern 3D code (NSMP). Both are considered to reproduce sedimentation-consolidation of very fine sediments from sites of studies with an analysis of what happens when cohesive and noncohesive sediment are present. Even through the results are satisfying, there are many questions arising from these exercises. More experiments (using nuclear technologies) are therefore essential to confirm the interpretations of processes and further improve their modelling. Since the CRP F22066 is formed, there is a new hope to tackle this longstanding challenge.

Radiotracer Study to Investigate the Spatial Dispersion Pattern of Dredged Materials in Hooghly Estuary, West Bengal, India

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Maintenance of adequate draft in navigation channel for movement of ships from the sea to the port is a serious concern for port authorities. Available draft reduces over time due to silt deposition on the channel bed and one has to resort to maintenance dredging which is quite expensive. The problem of silt deposition is particularly critical for riverine ports like Kolkata and Haldia where the river and its tributaries carry large volumes of silt. The navigational channel leading to Haldia from the Hooghly estuary requires maintenance dredging throughout the year. The dredgers use the tidal window to dredge over the critical shallow area in the navigation channel and then move to the dumping grounds to dispose of the dredged materials. Effectiveness of this dredging and dumping work depends on the location of the dumping site and the dispersion pattern of the dumped sediments, since there is always a possibility of the disposed materials returning to the dredged site during tides. Hence, it becomes essential to identify the pattern and rate of dispersion of the dumped sediments, which subsequently will help in identifying proper dump site location.

With this problem in perspective, a project was undertaken to study the movement and dispersion pattern of dredged materials near the dumping site in the Hooghly estuary via a radiotracer experiment. Use of radioactive tracers offers a cost-effective method to determining transport of sediments caused by tidal currents and processes of erosion, transport, settling and deposition. Radiotracers can be used to obtain quantitative information, such as direction, velocity and thickness of sediment movement.

In this project, Scandium-46 in the form of scandium glass powder is used as the radiotracer for tracing the dredged sediments. The tracer is prepared by incorporating 1% of inactive Scandium in the glass composition, then grinding the glass to different grain size fractions to have the same grain size distribution as that of the dredged material. It is then irradiated in the reactor to produce Scandium-46. After preparation of the radiotracer, it is transported to the the dumping site in Hooghly estuary. A specially designed remote operated injection apparatus containing the radiotracer mixed with dredged sediments is lowered into the water with the help of a crane and the mixture is discharged onto the sea bed. After the injection, dispersions of the tracers were monitored using a waterproof scintillation detector mounted on a sledge which was dragged on the seabed. The concentration at different spatial locations are measured. This tracking work was performed during the next five months. Isocount contour maps are prepared from the tracking data, from which the general direction of movement of tracer is drawn and maximum longitudinal and lateral dispersion are estimated. It is observed that the overall movement of the sediments during these five months is away from the main navigation channel. A two-dimensional hydrodynamic model for the study area was also developed and the velocity distribution patterns are compared.

Technetium-99m: From Nuclear Medicine Applications to Fine Sediment Transport Studies

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Technetium $^{99m}\mathrm{Tc}$ is, nowadays, the most applied radioisotope in nuclear medicine, whose use began in the mid-1960s. Features such as emission of γ-radiation of low energy (140 keV) with very good imaging properties, half-life $\tau_{1/2} = 6.02$ h, and production via relatively long-lived generators, facilitating their supply and use in locations far from manufacturing sites, were instrumental for the widespread use of the radionuclide.

However, in the aquatic environment, heavy metals and many organic compounds are usually associated with the fine sediment phase (silt, clay, or mud). The fate of these contaminants will be associated with the dynamic behaviour of suspended or bottom sediments in polluted streams. The study of suspended sediment behaviour is central to many environmental studies. Of special interest is the study of individual discharges of contaminants associated with suspended sediments, the short-term dispersion of contaminated material dredged from harbours and reservoirs when dumped into water bodies and the behaviour of natural sediment in suspension in bays, estuaries or reservoirs. Tracking for few hours of the contaminated suspended sediments introduced into streams or in the coastal area by individual discharges could allow the quantitative in situ determination of the advection, dispersion, dilution and sedimentation rates, parameters important for the calibration and validation of hydrodynamic models that comprise both the solid and liquid phases.

Radioactive tracers, in appropriate chemical form, are used to label fine sediment by chemical sorption, and some (such as $^{198}\mathrm{Au}$ and $^{51}\mathrm{Cr}$) have been employed to study the dynamics of fine sediment in suspension. But these tracers have to be produced in nuclear reactor each time they are used and require heavy shielding due to the dense flux of high-energy γ-radiation they emit, which hampers their use in remote areas.

Given the favourable characteristics of $^{99m}\mathrm{Tc}$, the feasibility of its use for labelling mud, through the chemical reduction of the TcO_4^- eluted from Mo/Tc generators, was studied in laboratory with regard to the following aspects: 1) labelling yield as function of different factors (type and amount of reductant; effect of pH; sediment concentration; contact time; labelling stability); and 2) hydrodynamic behaviour of labelled and nonlabelled sediment, through sedimentation tests. The laboratory tests were successful and this new use of the $^{99m}\mathrm{Tc}$ allowed already interesting results obtained in various applications: Montevideo Bay (Uruguay), Pampulha Hydrographic Basin (Brazil), Orinoco River (Venezuela), environmental impact due to the fine sediment originated from bottom discharge of small hydroelectric power plant (Brazil), etc.

The work performed in some field applications used second week generators obtained, at no cost, from Nuclear Medicine laboratories. The reason is that the $^{99m}\mathrm{Tc}$ detector for environmental applications is placed into the water, in 4π geometry and for medical applications it is situated externally to the patient. So, the necessary activity concentrations for environmental use (Bq/mℓ in water) are much lower (10^{-7}) than in nuclear medicine utilization (Bq/mℓ in blood).

The Use of Nucleonic Gauge JTTX in the Port of Nantes Saint-Nazaire

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There is a continuous sedimentation in harbour basins and access channels, therefore maintenance dredging is necessary. The depth necessary for sailing includes the free space between the keel and the bed of the channel called keel-clearance. Tests on physical models indicated that free movement of ships in the harbour is possible up to silt density 1.2 g/cm^3. The layer of fluid mud (silt) where the density equals 1.2 g/cm^3 is defined as "sea bed". This layer shifts upwards with time due to deposition resulting in decrease in the "nautical depth". To keep the required nautical depth it is necessary to measure the depth periodically, usually measured using an echo sounder. The upper trace recorded by the echo sounder is taken as the bottom of the channel. It is misleading in the case of channels with muddy bottoms. In these conditions the echo sounder readings cause excessive dredging adding extra cost. This can be avoided by the measurement of sediment density at different depths. To effectively determine when and how dredging operations must be undertaken, the underwater sediment and mud layers must be monitored and analyzed. This paper presents an innovative vertical profiling technique measuring the density versus depth of the sediment layer. The instrument uses X-rays to measure the sediment density and has been developed by the French Atomic Energy Commission and ALTAIX Cie.

The information is used for two important aspects:

1. The quality control of dredging works where the data is used to determine the dry matter content of the dredged material and to know precisely the real solid matter removed during the dredging operation;
2. In combination with echo-sounding survey methods, it is used for optimizing the dredging works based on the concept of navigability depth limit. Ships can operate through loose mud layers if the physical characteristics of the mud stay below a critical limit.

Nowadays the measured physical characteristic in many ports is density. The navigability depth limit is usually corresponding to the density 1.2 g/cm^3. The proposed measurement technique allows visualization of density and enables ports to evaluate nautical depth criteria. Dredging only when the navigability depth limit is above the navigation depth allows very important savings.

The paper will present the operation of the gauge in the Port of Nantes Saint-Nazaire, France.

Water Renewal in Montevideo's Bay II: A Compartmental Fractional Model for Tritium Kinetics

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This paper describes the construction of a new compartmental fractional model for water renewal in Montevideo's Bay that improves a conventional two compartments model [1]. The validity of the fractional kinetic model and its practical applicability are discussed. The available evidence suggests that the highly polluted Montevideo bay operates as an intermittent tidal pump that injects contaminants in the nearby coastal waters, with potential effects on the beaches located east to the bay's mouth. In order to assess this effect, several field studies were done in the bay itself and in the adjacent coastal waters covering water and sediments dynamics [2]. In the framework of a field research of the dynamics and renewal of water in Montevideo Bay, 3.7×10^{12} Bq of tritiated water were evenly distributed in the north-east region of the bay, during five hours of continuous injection. The whole bay was divided in 20 concentration cells, taking into account available bathymetric data and corrections from field data obtained in situ. Tritium concentrations (activity per unit volume) and other relevant parameters (temperature, electrical conductivity, etc.) were measured in vertical profiles during three weeks, in the mid-point of each cell, first twice a day and then on a daily basis. Remnant total tritium activity was estimated from cells volumes and midpoint cells activity concentrations. The details of the measured tritium kinetics, available bathymetric data, water movements in a tidal environment measured with drogues, fluorescent tracers and current meters, as well as the results of computer fluid dynamics modelling (averaged in depth), suggests that in a first approximation the bay can be meaningfully divided in two main compartments: a North-East and a South-West compartment. The time course of the tail of the tritium remnant function suggests the use of fractional calculus to model the process of water renewal. The conventional two compartments model is generalized by the introduction of fractional derivatives (in Caputo's sense) following a procedure that does not violate mass balance [3]. Fractional order parameters are estimated from available experimental data and the measured time evolution of the tracer remnant function is explained. The wash-out kinetics from the bay of toxic chemical substances or dangerous microbial populations, introduced after a sudden contamination accident in the harbour, is described using the fractional compartment model and additional information from CFD simulations.

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The Radiotracer ^{7}Be in Studying Environmental Processes

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The objective of the study is to define the time delay between the tropopause elevation and the concentration of the radiotracer ^{7}Be in near-surface air in order to understand the aerosol transport inside the troposphere as a part of the general atmospheric cycle transfer. The relatively short-lived ^{7}Be radionuclide ($\tau_{1/2} = 53.3$ d) of cosmogenic origin occurs permanently in the atmosphere. It is formed continuously by the interactions of cosmic-ray particles with atmospheric nitrogen and oxygen. The ^{7}Be production rate depends primarily on latitude, altitude and the 11-year solar cycle and has been proved powerful tool in studying atmospheric processes.

The concentrations of ^{7}Be in the troposphere and near ground level show variations which are connected with air mass exchange between the stratosphere and the troposphere, in situation of tropopause folding events. Air coming from the upper troposphere or from stratosphere can be identified by its enhanced ^{7}Be levels.

The tropopause marks the boundary between troposphere and stratosphere. The height of tropopause is variable in space and time, because of the latitudinal and seasonal dependence of solar irradiation as well as the changes due to weather patterns. There is a well-marked "tropopause gap" or break where the tropical and polar tropopause overlap at 30°–40° latitude. The break is in the region of the subtropical jet stream and is of major importance for the transfer of air and tracers (humidity, ozone, radioactivity) between stratosphere and troposphere. The height of the tropopause varies seasonally and also daily with the weather systems.

The current study presents an analysis of ^{7}Be data at geomagnetic latitude of 40°. The presentation will show the pattern of the cross-correlation analysis of ^{7}Be surface concentration values and tropopause height, revealing that after the third day the correlation coefficient falls dramatically. The $R_{\max}$ was found in the third day (≈ 0.44). The study revealed that the concentration of ^{7}Be in surface air is expected to correspond within 3 days after the changes of the tropopause height. Moreover, measurements and calculations throughout the research were extremely beneficial in a variety of ways and led to the following findings:

- The verification of the yearly variations of the tropopause height in mid attitudes.
- The understanding of aerosol transport inside the troposphere as a part of the general atmospheric cycle transfer.
- That the persistence in the state of the atmosphere cannot be ignored.
- Temperature and tropopause height indicate the time of transport of a useful tracer radioactive nucleus through air transfer cycles and as a consequence of any other aerosol particle with similar origin inside the tropopause.
- Higher values of temperature or tropopause height result to shorter transport times.

B05: Radiotracers for Energy of the Future I

Liquid Holdup Studies in a Co-current Gas-Liquid Upflow Moving Packed Bed Reactor with Porous Catalyst Using γ-Ray Densitometry

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Upflow moving packed bed reactors are widely used in industries for hydrotreating like hydrodenitrogenation, hydrodesulfurization, hydrodemetallization, etc. In these reactors, deactivated catalyst are removed from the bottom, and fresh catalyst are added from the top, gas and liquid phase move concurrently upwards. The catalyst removal occurs only once in a week and that too in small increments. Some of the common problem associated with this reactor are maldistribution, hot spot, and reduced expected conversion. To overcome these challenges, detailed study to enhance the understanding of hydrodynamics in this reactor is still required. In this work line-average liquid holdup is determined using γ-ray densitometry (GRD) in a scaled down lab scale upflow packed bed column. γ-ray densitometry is a noninvasive radioactive technique and can be implemented to monitor the flow distribution even at industrial scale. There are no studies reported on determination of line average phase distribution for packed bed with the porous catalyst using GRD. In this study, a new methodology has been developed to determine the line average liquid holdup for a porous catalyst. Which gives the line average holdup in the void space of catalyst bed plus the line average internal porosity of catalyst. This study has been conducted on a Plexiglas column of $11''$ ID ($\varnothing = 279.4$ mm) and $30''$ height ($= 762$ mm), randomly packed with extrudate catalyst of 3 mm diameter until $24''$ height ($= 610$ mm). GRD scanning is conducted at various axial and radial locations. The line average liquid holdup is determined at superficial liquid (water) at 0.017 cm/s and varying superficial gas (air) velocity in the range of 0.6–7.7 cm/s. The results show that the liquid holdup decreased as the superficial gas velocity increased. It was also found that the liquid holdup radial distribution was not uniform. This kind of information is essential to improve the performance of the reactor.

Bed Expansion Studies in Upflow Moving Catalytic Packed/ Expanded Bed Hydrotreating Reactor Using γ-Ray Densitometry

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B05

Upflow moving catalytic packed or expanded bed reactors are widely used in industries for hydrotreating of feeds with a higher level of contaminants including heavier feeds. In these reactors, spent catalyst are replaced periodically by adding fresh catalyst at the top and removing spent catalyst from the conical bottom which supports the catalyst bed. While the catalyst moves downwards periodically, the gas and liquid phase moves upwards. The catalyst is removed in small increments once a week. The other times the reactor operates in upflow packed or expanded bed condition. The problem associated with these reactors is maldistribution, which causes hotspots, sintered carbon deposition and reduces expected conversions. It is seen that the main reason for these issues is maldistribution of phases at the local level inside the catalyst bed region. Bed expansion plays a huge role in local flow distribution of phases. In these reactors the expanded bed region gives the better radial distribution of phases, but less overall mixing intensity of phases as compared to packed bed region. Furthermore, the movement of catalyst particle in the expanded bed profoundly affects reaction kinetics in these areas. It is seen that under industrial best-operating conditions of these reactors the catalyst beds exhibit packed and expanded bed regions. Expanded bed can be seen at the top part of the bed. There are no studies done yet to demarcate the expanded and packed bed region.

In this work, quantification of bed expansion will be done on scaled down lab scale reactor by online monitoring with γ-ray densitometry (GRD) along the bed height. The time series data obtained from GRD will be analyzed to identify flow regime, and variation in flow regime trends between packed bed with expanded bed region will be used to demarcate the boundary. The analysis of time series are done on time domain (standard deviation, mean, and variance), frequency domain (power spectrum, wavelet analysis) and chaotic analysis (Kolmogorov entropy (KE)). We focus in this work on the catalyst bed section, which is a Plexiglas column of 11″ ID ($\varnothing = 279.4$ mm) and 30″ height ($= 762$ mm), filled with extrudate catalyst of 3 mm diameter until 24″ height ($= 610$ mm). The measurements were conducted at superficial liquid (water) velocity of 0.017 cm/s to 1.78 cm/s and superficial gas (air) velocity of 1.27 cm/s to 8.8 cm/s. This kind of information is essential at industrial scale, for efficient design and operation of these reactors. In this presentation, results and findings are discussed.

Radioactive Tracing of an Industrial Scale Continuous Pulp Digester

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The Indian paper industry has an approximately 2.6% share of global paper production from $\sim$ 813 paper mills. The chemical pulping process is widely used to produce paper using different types of raw material such as wood, bagasse, agro residue (wheat straw, rice straw) etc. The raw material is directly fed to a pulp digester along with white liquor to produce pulp. The pulp obtained from the digester is used to manufacture various types of paper including writing paper, printing paper, packing paper, etc. The performance of the pulp digester is very crucial for product yield, product quality, overall operating cost and waste generation. Hence, it is important to understand the flow behaviour/ hydrodynamics of the pulp digester to optimize operating variables.

The industrial scale experiments were conducted for radioactive tracing of three tube continuous pulp digester in Satia Industries (India) using radioisotopes ^{82}Br and ^{198}Au. The tube length and diameter of single tube of pulp digester is 12 m and 1.45 m respectively. Wheat straw and white liquor were fed to the digester at 157–169°C temperature and 5.39–6.45 kg/cm^2 pressure. The white liquor was fed at the rate of 360 ℓ/min and wheat straw was fed at feeder screw speed of 65 rpm. The radiotracer was injected at the inlet of the pulp digester using a high pressure pump. Four radiation detectors were used to record the radiotracer concentration at the inlet and outlet of each individual digester tubes. The recorded radioactive signals were compared and used to elucidate the residence time distribution, mean residence time (MRT) and flow behaviour of pulp digester.

Approximate 20% difference were found in MRTs of ^{198}Au and ^{82}Br. The higher value of MRTs for ^{198}Au than ^{82}Br indicating some adsorption of ^{198}Au on wheat straw. MRTS for ^{198}Au is representing MRTs of bulk flow (pulp), whereas MRTs using ^{82}Br represent MRTs of liquid phase only. The segregated, erratic and inhomogeneous flow were observed in first digester tube. The axial dispersion model with plug flow component in series were found suitable for both cases. The non-dimensional axial dispersion coefficient for third digester tube were found as 270 and 250 for ^{198}Au and ^{82}Br, respectively.

The present radiotracer technique is found well suited for tracing of the pulp digester even at high temperature and pressure to identify the malfunctioning such as back-mixing, reverse flow, bypassing and stagnation volume of pulp digester, etc. This technique can be used for locating the leakage, fouling or other abnormalities.

Evaluating the Operating Conditions of a Rectifier Column Using γ-Column Scanning

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This paper reports the γ-scanning carried out to a rectifier column in one of the refineries in the Philippines. Several scans were performed to gather information on the operating conditions of the column at different sets of operating parameters using a 10 mCi ^{60}Co source and a 2″ (50.8 mm) detector tandem. Results of each scan reveal the presence of blockages at several sections of the column. These blockages cause flooding inside the column when process settings were changed as reflected in the profiles of several scans. γ-column scanning was able to specify the presence and location of blockages and their effect to the operating condition of the column at varying process parameter settings.

B05

γ-Scanning Technique as an Efficient Investigation Tool for Diagnostics and Troubleshooting in Industry: Case Studies

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In nuclear technique applications in industry, γ-scanning is recognized as a simple but very common and useful on-line investigation technique for diagnostics and troubleshooting. Based on the principle of attenuation of γ-beam intensity according to the density of material while penetrating through the object, γ-scanning provides data or information about situation of components such as pipe, columns to optimize the performance or to identify maintenance requirement.

Among a number of applications carried out by CANTI, this paper gives the typical case studies of use of γ-scanning to detect damage, pipeline blockage and to investigate malfunctions in process columns in the petroleum refinery which provided technical evidence to engineers for repair planning.

γ-column scanning was used to determine a malfunction in the flue gas absorber tower of Dungquat Refinery. The scanning results showed a heavy foam occurred in many trays that helped the operator to adjust the operational parameters to recover normal performance which was confirmed by a followup re-scanning. In other applications of γ-column scanning, the inside situation of columns such as tray damage, flooding, deformation of tray and so on, was also detected in preparation for maintenance.

In pipelines, the γ-scanning technique was used to detect the blockage inside flare pipeline, to inspect the damage of refractory inside the withdrawing well and to detect a part of a steel valve dropped and stuck inside a steam pipeline.

In many cases, γ-scanning was the only technique capable of solving problem owing to the high penetration capability of γ-ray through the thick steel wall of components, permitting internal inspection; and implementation of the online inspection without shutting down the process.

Validation of CFD Codes Using Radiotracer RTD Analysis of Stirred Vessels

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Radiotracer residence time distribution (RTD) and computational fluid dynamics (CFD) are two methods (experimental and numerical) that can be used to study the performance of industrial process reactors. Although all the required parameters of a process vessel can be found using RTD methodology, experimental results should be used to validate CFD codes. CFD simulations not only makes the design of flow systems much easier but also better explains the system's flow structure. The aim of the investigation was to used results obtained from a radiotracer RTD analysis of stirred vessels to validate CFD codes. The flow field in the vessel was simulated using CFD multiphase and turbulence models. The simulated flow field was used generate the RTD using a Lagrangian particle tracking method. The simulated RTD curves and mean residence time were in good agreement with experimental results.

B06: Radiation Techniques for Energy of the Future

The γ-Scanner: A Tool for the Quality Control of the Process of Alcohol Distillation

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γ-scanning is a technology management tool to increase manufacturing efficiency. Modern industrial production requires strict process control, in order to meet established quality standards. The technique of γ-ray scanning allows non-destructive diagnosis, which has among its applications the study of distillation columns. The method is based on the different degree of attenuation of γ-radiation as it passes through materials of different density. Through the analysis of a vertical density profile, it is possible to identify functioning problems without stopping the industrial process under study, and without physical intrusion. This improves the operational efficiency and reduces the time for maintenance. The present paper shows the results of a study conducted applying the technique of γ-ray scanning to a distillation column of alcohol from the distillery "Hector Molina". The study revealed the presence of some small anomalies such as the presence of foam in some regions of the distillation column. The identification of these anomalies contributed to efficiency improvements of the tower, improving as a consequence the quality of the obtained alcohol, and contributing to the environmental management system that should be associated to the process of alcohol distillation

A New Method for Detecting Trace Oil Concentration by Neutron Radiography Technique

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The modern neutron imaging (NI) facility in the ETRR-2 provided precise information for detection of trace oil concentration in cultural heritage treasures. The presence of high scattered oil materials distorted the neutron radiography quantitative measurements and caused blurred images.

This work presents a new technique in precise quantitative measurement and calibration. The technique was based on the scattering correction of images. The correction was not based on the Monte Carlo (MCNP) code simulations, but rather on a real case scattering correction by a designed code. Also, the distinction of this work was showing a real free scattered image that was not performed before.

The designed code possesses an extensive set of algorithms for digital image processing. The code has arithmetic menu commands performing versatile operations between images. The installation of the excellent neutron imaging system at the research reactor in Egypt increased the reliance on appropriate software for advanced imaging processing and data analysis. The code provided up-to-date high quality images by designing formula commands supported by all standard mathematical functions. This open source code was used for detection and measurement of trace oil concentration by the neutron radiography (NR) technique.

Leaks Determinations in Reboilers from Natural Liquid Fractioning Units

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In recent years, IPEN has developed various techniques based on the application of tracers and radiation sources to solve problems operating facilities oil refining and gas.

The objective of the experiments was to identify leaks and passes in reboilers, either thermal fluid or hydrocarbon products in the reboiler of a depropanizer column, in the reboiler of a debutanizer column and, in the reboiler of a stripping column from a fractionation column naphtha-diesel. A set of determinations are reported with various radiotracers experiments in reboilers from natural liquid fractioning units, for leaks / passes that could exist in three reboilers.

The tracer technique for online detection was used, by using two radiotracer depending on the phase to be investigated: oleic acid labelled with ^{131}I as a radiotracer for the hydrocarbon phase and an aqueous solution of ^{133}I for the aqueous phase, when necessary. A data acquisition system, a portable PC, and detectors in proper positions were used. Recording values were synchronized as well as ambient background, prior to each injection of radiotracer. Radiation counts were recorded at 1 s intervals in each case.

B06

Six determinations were conducted by six injection of radiotracer incorporated, either in tubes or shell, as applicable. We achieved detection limits leakage of 0.1%, of one stream to another.

RPT for Tracking Microalgae Cell Movement in Split Photobioreactor Column

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Radioactive particle tracking (RPT), is a visualization technique utilized for multiphase flow systems. This technique has been used to track microalgae cells movement through all the segments of growth by tracking a single radioactive particle (200 μCi of ^{60}Co). This particle was coated by 2 mm polypropylene particle to mimic the motion of the liquid inside the reactor. The γ-ray intensity distributions were revealed by 30 NaI detectors placed uniformly around the reactor at specific angles and levels. The performance of the split photobioreactor requires in-depth knowledge and understanding for photosynthetic growth and for hydrodynamic parameters: the advanced non-invasive measurement technique of radioactive particle tracking (RPT) will provide that information.

This present study investigates the flow features in the 5.5″ (140 mm) inner diameter Plexiglas split photobioreactor for air-green algae (Scenedesmus) system. Moreover, it seeks to examine the impact of algae growth rate on the three-dimensional liquid velocity field and turbulent parameters (Reynolds stresses, turbulent kinetic energy, and turbulent eddy diffusivities) at different superficial gas velocities (1, 2, and 3 cm/s). The experimental results will provide benchmark data for simulation, design, scale-up, and performance calculation of the split photobioreactor. The experimental results and conclusions will present at the conference.

B06

Flow Regime Identification in a Co-Current Gas-Liquid Upflow Moving Packed Beds Reactor Using γ-Ray Densitometry

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In industries, upflow moving packed bed reactors are widely used as guard reactors for residual desulfurization units (RDS). Efficient reactor function has a huge impact regarding efficiency and product quality from the subsequent RDS units. Identification of flow regimes is one of the important aspects of design, scale up, predictive model and reactor performance. Flow regime identification in this reactor was studied using γ-ray densitometry (GRD). GRD is an important noninvasive measurement technique and flow identification can be determined by on-line monitoring. Time domain, frequency domain, and state space or chaotic methods are employed on photon count time series of GRD to determine flow regime. Time domain analysis includes determination of standard deviation, mean, and variance. Frequency domain analysis includes power spectrum and wavelet analysis. Chaotic analyses include determination of Kolmogorov entropy (KE). All analysis are done using in-house developed programmes.

GRD experiments were performed on a lab scale upflow packed bed reactor built by scaling down the industrial reactor. The lab scale reactor is a Plexiglas column of 11″ ID ($\varnothing$ = 279.4 mm) and 30″ height (= 762 mm), randomly packed with extrudate catalyst of 3 mm diameter until 24″ height (= 610 mm). Various axial and radial position are selected to conduct GRD scanning. The selected test location covers the bottom, middle and top of the packed bed. The measurements are conducted at superficial liquid (water) velocity 0.017 cm/s and superficial gas (air) velocity in the range of 0.6–7.7 cm/s. All analysis showed similar flow regime trend. When compared with flow regime map for upflow packed bed, the results indicate bubbly and pulse flow are the main regimes under this operating conditions. In this presentation, results and findings are discussed.

B06

B07: Radiotracers for Energy of the Future II

Simulation and Optimization of a Neutron Backscattering Analysis Set-Up Using MCNP5 Code

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A neutron back scattering set-up for analysis of hydrogenous sample materials has been simulated using MCNP5 neutron and photon transport code. The set-up is mainly composed of an Am-Be neutron source of 37.2 GBq and a ^{3}He neutron gas detector which are embedded in polyethylene block, the latter acting as a reflector. The modellization used in the simulation was validated comparing thermal neutron flux calculated values with measured ones using indium activation foils and ^{3}He neutron detector. Then, calculations were carried out to determine optimal dimensions of the reflector and the sample holder with the constraint that the neutron and γ-doses must be at acceptable levels. We have also studied the response of the set-up for other reflector materials such as wax and Perspex. Finally, the analysis of organic samples was simulated and the calibration curves were determined for hydrogen and (C+O/H) ratio. The simulated calibration curves were then compared with those experimentally determined

B07

RPT Study on a Vertical Impeller Mixer

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Radiotracer techniques have been widely applied in various fields of industry in order to diagnose plant processes during operation. This is possible because radioisotopes can selectively label certain process media and represent their movements. Recently, radioisotopes have been successfully used as tracers in the investigations for clarifiers and digesters in wastewater treatment plants. Quantitative information about the performance and flow patterns of digesters and clarifiers were obtained without posing any disturbance to the systems themselves. More recently, studies were conducted to show the feasibility of radiotracer techniques in investigating the particle velocity in fluidized bed reactors compared with the techniques based on optical fibre probes and borescopic particle image velocimetry [1]. It has been well described that radioisotope technologies are somewhat superior to others in terms of the limitations in the measurements caused by the signal cross-correlation and minimum measurable flow velocity and vertical angle. CFD simulations on a digester with an internal airlift loop were performed to study the influence of the geometric design on the flow pattern, location of circulation and stagnant regions, liquid velocity profiles, and volume of dead zones, and are subsequently compared with experimental data obtained by radioactive particle tracking [2]. CFD simulations must be developed for individual situations because multiphase systems have very complicated physics and are difficult to fully understand. Once the CFD predictions are validated with experimental measurement data, the predicted hydrodynamic parameters can be quantified and used in the design selection and optimization of systems [3].

A vertical impeller devised to move up and down along the axis of a cylindrical digester is believed to generate a mixing flow inside, saving the energy for operating the process since the downward movement can be accomplished with the gravitational force. However, the flow pattern and mixing characteristics as a function of the operation parameters of the vertical impeller have not been investigated. In a preliminary study, a radiotracer experiment was carried out for a pilot-scale digester equipped with a vertical impeller. Unfortunately, tomographic measurements that can reveal the flow in 2-dimensions cannot be applied due to the size of the digester. The flow was roughly guessed from the data collected from radiation probes installed inside the digester. In the present paper, as a subsequent study, a smaller lab-scale digester was built for further tomographic investigations. Radiotracers were injected into it for SPECT and RPT studies that provide local information on the flow and multidimensional visual images.

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Linear Attenuation Coefficients and Gas Holdup Distributions of Bubble Column with Vertical Internal Bundle for FT Synthesis

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Linear attenuation coefficient distribution, time-averaged cross-sectional gas holdup distribution, and their radial profiles have been measured in 6″ (152 mm) Plexiglas bubble columns with and without internals for the air-water system at a superficial gas velocity 45 cm/s by utilizing a γ-ray computed tomography (CT) technique. Several 1″ (25.4 mm) diameter Plexiglas internals cover 25% of total column cross-section have been installed in the column, similar to those using for Fischer-Tropsch (FT) synthesis.

The experimental results revealed that the reference scan significantly affects the values of the linear attenuation coefficients and consequently the gas holdup distribution images. The results show that using air (no column) as a reference scan, enhances the accuracy of linear attenuation coefficients and hence the precision of gas holdup results, while using the empty column with internals as a reference scan gives incorrect values for linear attenuation coefficients and gas holdup values. Moreover, using air (no column) as a reference scan had eliminated the error in gas holdup profiles in the wall region. Furthermore, the CT scan images exhibit symmetric gas holdup distributions for bubble columns with and without internals as studied for the superficial gas velocity. Finally, the γ-ray computed tomography technique was capable of capturing the wall thickness of a column and position of each internal when air (no column) is used as reference scan.

Numerical Simulation of Measurement by γ-Ray Scanning of Coke Deposition in Packed Bad of Distillation Column

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In distillation columns, the packed column for gas-liquid contacting are used extensively for absorption, stripping and distillation operations. A principal problem encountered in operating a packed bed is the coke disposition which is related to both process condition and structural problems. As the γ-scanning technique is adequate to define on-line troubleshooting, in the present study, we try to define by Monte Carlo numerical simulations the minimum rate of coke deposition in the packed bed that can be revealed by this technique. Such information assists engineers in troubleshooting process problems, optimizing production and minimizing plant down time.

A simple packed bed geometry was reproduced in the numerical model, with different coke deposition rates. The preliminary simulation results show that it is possible to detect coke deposition for coke occupation volume higher than 7.3% compared to the packed bed total volume. The second part of this work will be dedicated to define an optimal configuration of γ-scanning to provide accurate measurements of the coke deposition rate taking into account the coke.

Noninvasive Radiation Based Densitometry and Velocimetric Monitoring of Fluidization of Coal and Bottom Ash Mixtures

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Utilization of noninvasive radiation based techniques has become widespread in several industrial applications. Of particular importance is its deployment in systems involving two or more phases. Such systems are ubiquitously found in areas concerning from the processing of fuels and chemicals to the production of feed, food, pharmaceuticals, and specialty materials. In spite of extensive presence of multiphase systems, lack of knowledge on complex local flow structure have rendered non-availability of any single established methodology for their design. Nonetheless, two classes of radiation based measurements — tomographic and velocimetry (commonly referred to radioactive particle tracking) — have emerged as attractive strategies for providing dynamic information on phase distribution and flow pattern of phases of interest respectively.

In this work application of such measurement techniques are being reported for fluidization of coal and bottom ash mixtures. The talk will present details of this work and how radiation based noninvasive tool proves to be a great benefit in fundamental analysis, design and scale-up of coal fluidized bed gasifiers.

Experimental Study of Pebble Flow Dynamics in a PBMR Using RPT

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The pebble bed modular reactor (PBMR) is a type of 4th generation nuclear reactor. In a pebble bed reactor, nuclear fuel is in the form of spherical pebble and moves slowly inside the core of the reactor under the influence of gravity. A coolant gas moves through the voids formed in between the pebbles and removes fission heat generated from the nuclear fuel. Multiphase Reactors and Applications Laboratory (mREAL) at Missouri S&T has designed, developed, and tested a scaled down continuous pebble re-circulation experimental set-up, mimicking the flow of pebbles in a PBMR. An experimental study of pebble flow dynamics in a cold flow setup was carried out using a radioactive particle tracking (RPT) technique that used a ^{60}Co based tracer to mimic pebbles regarding shape, size, and density in a noninvasive way. The RPT technique is capable of providing a full description of the 3D flow field in highly dense and opaque reactors. Obtained results of the radioactive particle tracking technique regarding Lagrangian trajectories, residence time distributions, velocity field, etc., are a valuable benchmark data for an assessment of the contact force model used in the discrete element method (DEM) based simulations.

B08: Seeing the Invisible: Structure Imaging — Safe and Effective Industry I

Next-Generation Fast-Neutron/X-Ray Scanner for Air Cargo Interrogation

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There is a growing need for improved methods for rapidly inspecting bulk air cargo, the majority of which is currently subjected to no physical inspection or scanning. Fast-neutron/X-ray radiography provides a method to produce images that show the shape, density and composition of objects in cargo. These can be used to identify a wide range of threat materials, including organic substances such as explosives and narcotics that can be hard to resolve using conventional, X-ray–only scanning technology.

Following initial development and demonstration by CSIRO of a fast-neutron/X-ray scanner at Brisbane Airport in Australia, the technology was commercialized with the Chinese security technology firm Nuctech Company Ltd. First-generation air cargo scanners combining neutron and dual-energy X-ray imaging are operating at airports in the Middle East and China.

In this paper, we present the latest technical developments, which have focussed on reducing the footprint, cost and complexity of the technology, whilst improving image quality and performance. We have developed a completely new plastic-scintillator neutron detection system with silicon photomultiplier (SiPM) readout. The low-noise characteristics of SiPMs allow much lower energy neutron interactions to be detected than was possible using our previous photo-diode based readout, increasing detection efficiency for 14 MeV to 30%. The small form-factor and simple signal amplification and processing requirements allow detectors to be tightly packed; the complete detection system includes 1440 elements and has a five-times higher detection efficiency than the array used in the first-generation scanner.

This efficiency has allowed us to significantly decrease the size of the neutron source. The first-generation scanner used a liquid-cooled, deuterium-tritium (DT) neutron generator producing 5×10^9 n/s to image air-cargo at scan speeds of up to 6 m/s. The latest system uses an air-cooled, laboratory-scale neutron generator with an output of just 3×10^8 n/s. With advanced image processing, image quality and scan speeds can be maintained despite the reduced neutron output. The smaller generator is also considerably easier to install and maintain in airport environments. We also report on the development of novel, low-cost and compact neutron shielding, that allows a combined neutron/X-ray scanner to be deployed within a footprint similar to that of conventional X-ray–only cargo screening systems. Details of the system and its operation will be presented.

Monte Carlo Simulation and Experimental Verification of Blockages in Pipelines Using γ-Ray Computed Tomography

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Blockages and material build-up in pipelines are a most common problem in many types of process industries, particularly, in petroleum and chemical industries. Partial blockages may impair process plant operation whereas total blockages could lead to a shutdown. Thus, development of non-destructive methods for on-line blockage detection in pipelines is of a prime importance. In this paper, a study on Monte Carlo simulation using Geant4 code package and an experimental work using a newly developed portable γ-ray computed tomography (CT) system, called "GammaSpider" for detecting blockages in pipeline was conducted.

The Geant4 code package provided various features suitable for simulating the geometry and required parameters of GammaSpider, the results were compared and validated by the experimental data and finally mass attenuation map of various materials was reconstructed in 2D or 3D image. Elements to be implemented in the simulation code include a highly collimated incident beam of 662 keV γ-rays from a ^{137}Cs radioisotope source, the transmitted radiation after traversing through a cross-section of a 200 mm diameter steel pipe containing process water and a simulated partial blockage (concrete deposit) and the transmitted intensity data were recorded by a collimated sodium iodide (NaI) scintillation detector at many different translation steps (projections) and rotation angles (views). The results of the Geant4 simulation permit optimizing the experimental parameters of the γ-ray CT system. This will also provide an improvement in the resolution of the reconstructed tomographic images. Results from the Geant4 simulation can be used in planning a test for the routine use of the GammaSpider system.

Associated Image Processing Algorithm in Dual-Projection Systems

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Methods like single-projection detecting and CT detecting are widely used in radiation scanning systems, however, these methods have shortages such as an inability to differentiate materials and low efficiency so that methods with high accuracy and efficiency are required.

In this paper, we introduce a dual-projection radiation detection technique. Two groups of radioactive sources and detectors are fixed to obtain gray-scale images of target objects from two orientations. Algorithms are developed to combine these images and calculate the shape, position, attenuation coefficient and density of target objects rapidly and accurately. Ideally, target objects are assumed as convex polygons of single material. The gray-scale curves follow the ray attenuation theorem which contains physical property information such as attenuation coefficient and density. Inflections on the curve show when vertexes on target objects are scanned. To recover the target object geometry from gray-scale images, algorithms are developed with functions as follows:

1. Locating the position of each inflection on the curves and calculating their coordinates in real space coordinate where the vertexes are.
2. Combining these calculated vertexes to form polygons and remove those that do not meet the mentioned assumptions.
3. The selected polygons are re-projected by emulation. The calculated polygon whose gray-scale curves are closest to the ones of target object is chosen as the result of recovering. And its position, shape and density can also be calculated.

Matlab simulations were performed, verifying the feasibility of the algorithms. Given 10 mm detectors and an arbitrary pentagon target object, the result shows that the relative error of calculated absorption coefficient is 0.33%.

Realistic experiments with ideal target were performed. Standard aluminium blocks with sections of quadrilateral and pentagon are used as the target. The detectors are 7 mm in size and the radioactive source is ^{60}Co. The relative error of calculated density is within 3–5%. The difference between two experiment results of absorption coefficient is 4×10^{-3} which shows the high reproducibility of this system. Further experiments using non-ideal objects were made. A bucket of water was put in a container as the target. By moving the container continuously, a series of gray-scale curves, representing different sections of all things in it, are obtained and processed to recover the shape and position. The results show that the relative error of calculated density is 10.4% after eliminating the impact of background noise.

Details of the method and its application will be presented.

Comparison of Image Reconstructions for γ-Transmission Computed Tomography System by Using MATLAB and i-Gorbit Software

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With wide industrial application, computerized tomography (CT) is a rapidly developing technique that is especially useful for imaging and measuring multicomponent and multiphase processes. The most important contribution of CT is to greatly improve abilities to distinguish regions with different γ-ray transmittance and to separate over-lying structures. The CT system of single source and detector γ-transmission tomography GORBIT, designed by CANTI, Viet Nam, was used to analyze different density materials. Hardware of the GORBIT CT system consists of two servo motors, data logger, computer, a radiation source and a radiation detector. The measurements in GORBIT system were carried out at the CT Laboratory in the Department of Atomic Energy, Yangon. This tomography system operates with a γ-ray source of ^{60}Co at 1.85 GBq (50 mCi) and a NaI(Tl) scintillation detector.

Measured γ-transmission data were used to reconstruct the cross-sectional images of research samples. These images were reconstructed from the measured data via different image reconstruction algorithms. Analytical methods of back projection (BP), the filtered back projection method (FBP) and iterative algorithms of algebraic reconstruction method (ART) and estimation maximizations (EM) methods were used in i-GORBIT image reconstruction software. Another image reconstruction programme GCTS was created by using MATLAB package. In this image reconstruction, different algorithms of back projection (BP) and filtered back projection (FBP) were used. In FBP method, different filters of Ram-lack filter, Sheep-Logan, Hamming, Hann and Cosine filter can be chosen and different interpolation methods can be applied to improve the image quality. The results of different image reconstruction programmes were compared and analyzed for the sample materials. In this research work we will present some results obtained by using tomographic techniques to analyze various samples to check the distribution of various density materials. These samples are made by using different properties of materials with high and low density materials of lead, iron, six-hole bricks, polymer slab contained in a polymer pipe vessel. These samples are also used to verify the outcome from the CT analysis with different image reconstructions programmes i-GORBIT and MATLAB.

B08

Gorbit – The Flexible γ-Computed Tomography System for Pipeline Inspection

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γ-computed tomography is a non-intrusive technique, capable of providing density-based images of structure or phase distribution inside industrial components without shutting down or disturbing normal operation. However, the field applications pose many challenges to a tomography system related to mobility, compatibility to mount on the components, weight and cost of system, etc. Enter GORBIT, a flexible γ-computed tomography system designed and fabricated for pipeline inspection. The first version of GORBIT was based on the parallel configuration that allows inspection of pipelines of OD up to 600 mm at any angle, easy installation and mounting on the pipe and automatic scanning. The image resolution can be achieved 16×16, 32×32, 64×64, 128×128 and 254×254 pixels. The image reconstruction software was also developed based on filter back projection (FBP) and algebraic reconstruction technique (ART) algorithms. The GORBIT system has been deployed to inspect pipelines in the petroleum industry for detection of corrosion, deformation and blockage. GORBIT was also used for in-house experiments to validate the CFD simulation results of fractional phase flows.

The new version of GORBIT was recently developed based on the modified 3rd generation using fan beam that reduced significant operation time while maintaining the resolution of the image.

B09: Radiotracer for Managing Natural Resources

Development of Radiometric Methods for Optimization of Phosphate Transport Process by "Slurry Pipe"

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Moroccan reserves of phosphates are the largest in the world, estimated to be more than 85 billion m^3. The drainage of the phosphate rock from the mine site to the chemical sites, which is currently done by train, requires dry phosphate to lower the humidity in order to carry it cheaply. However, the chemical processing of raw phosphates, to get the final products (phosphoric acid, fertilizers, etc.) requires large amounts of water to be reintroduced. For the transport of phosphate, it has been decided to build a pipeline between Khouribga mines to the JorfLasfar chemical units, to help converge the problems of transport cost reduction and rationalization of water and energy consumption.

Determination of physical parameters, such as concentration, viscosity, flow rate, etc., of the material inside the pipe becomes a key issue for handling and maintaining the whole system. The current study aims to develop radiotracer methodologies and specific nucleonic control systems to obtain such information. The first phase of the study consists in carrying out of a series of field experiments, targeting flow measurement of pulp phosphates transported by gravity, by using radiotracers (^{131}I) in various flow conditions.

B09

Determination of Mineral Behaviour in Ball Mills at Chilean Copper Minning Using Radioactive Tracers

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Minera Los Pelambres (MLP) is located in the IV Region of Chile, with a mine located at 3100 m a.s.l and a concentrator located at 1600 m a.s.l. MLP started its operation in the year 2000 and by 2015 it was one of the 10 largest producers of copper concentrate in the world, achieving 405 300 tons of copper and 9000 tons of molybdenum concentrates in 2013. MLP has established within its goals to improve the process efficiency and to increase the concentrate production. For these reasons, all the process stages are being evaluated, including the comminution circuits (crushing and grinding), which are the most intensive in terms of energy consumption.

The MLP grinding circuit consists of three parallel SAG mill lines, each one formed by a semi-autogenous mill (SAG) and two parallel ball mills. The first two SAG mill lines have ball mills of 10 500 HP, and the third has one ball mills of 10 500 HP and another of 20 700 HP. The ball mills operate in a closed-circuit (direct circuit) with a hydro cyclone battery, which allows adequate particles for the flotation process to be obtained. In this paper the fluid dynamic characterization of ball mills by means of the residence time distribution (RTD) is presented. The RTD were obtained at industrial scale by using direct measurements of radioactive tracers in the input and output streams of the ball mills.

Dried mineral samples from the hydro cyclone underflow were used as a solid tracer. This material was irradiated by neutron activation in the La Reina Nuclear Center, Chilean Nuclear Energy Commission. The RTD determination was obtained by measuring the solid tracer in the input and output streams of the ball mills, employing scintillation detectors for real-time measurements. The tracer activities were of 15 mCi of ^{24}Na in each injection, which contained between 15 and 30 g of solid. A pneumatic system was designed for the tracer injections, which allows the tracer injection to be carried out remotely.

The measurements demonstrated that a significant percentage of tracer recirculation to the input stream exists. Therefore, the use of parametric deconvolution methods for the RTD determination were required. The model of N perfectly mixed reactors in series was employed for the RTD descriptions, where N ranged from 2.1 to 3.9 with effective mean residence times between 1.9 and 9.5 minutes. The RTD estimation by the use of radioactive tracers is a powerful tool to characterize the mixing regime in large industrial machines from the mining processes and other productive industries.

Radiotracer Methods for Ore and Flotation Tailings Leaching

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Copper mining and ore processing is one of the most stable and profitable branches of the Polish economy and its fastest growing industry. However, the technologies used lead to high losses of valuable and so-called deficit metals (rare earths, uranium and copper) in solid wastes streams. The development and implementation of hydrometallurgical technologies is a feasible solution for efficient higher element recovery and decreased toxicity of the wastes storage on the environment. Radiotracer methods are the suitable tool for process investigation since most of the elements involved may be activated and their radioactive isotopes easily detected. The separation efficiency, process kinetics and flow dynamics of hydrometallurgical systems can be therefore qualitatively and quantitatively evaluated.

The objective of the project is the elaboration of a new efficient method to recover copper and critical metals from the various raw materials using radiotracers for process optimization. A key stage of the metal recovery process is a leaching process. The raw material was crushed and decarbonized using oxidation techniques and characterized. Initial concentrations of copper and other elements were determined by ICP-MS, ASS and chromatography methods. The leaching process is carried out in a periodic chemical reactor. For process optimization, a radiotracer techniques based on nuclear activation analysis has been used. The samples of the material were activated by a neutron flux at the MARIA Reactor and mixed with leached materials. The radiotracers (activated ^{64}Cu) were used to determine leaching efficiency instead of common analytical methods. The results were validated using ICP-MS and ASS analyses. Obtained metal solution will be separated at mixer settlers and ion exchangers also optimized by radiotracers techniques.

B09

As raw material we used copper ore and flotation tailings. As we expected, the samples contain several metals (Cu, V, Zn, Co, Ag, Ni, Mo, Fe, Pb, Mn, U, REE, etc.). The copper concentration was at 4% in the ore and less than 1% in the tailings waste. Sulfuric acid was selected as the optimal leaching medium for future experiments. The material was ground and sieved to extract individual fractions. The optimal granulation was selected: 0.25–0.5 mm. At the leaching step the material was treated with sulfuric acid at various concentrations (2–16 M). We also calculated activation parameters for developing activation procedure. The samples were activated and used at leaching experiment for RTD test.

Radiotracer methods seems to be a suitable tool for leaching process investigation since most of the elements involved may be activated and their radioactive isotopes easily detected. The separation efficiency, process kinetics or flow dynamics of hydrometallurgical systems can be therefore qualitatively and quantitatively evaluated. Radiotracer methods were validated using common analytical procedures and can be used instead of them for controlling and optimization of the process.

This work is part of the studies for the IAEA Coordinated Research Projects: "Radiometric Methods Applied in Hydrometallurgical Processes Development and Optimization" and "Radiometric and Radiotracer Techniques in Hydrometallurgical Processes for Deficit Elements Recovery" co-financed by the Polish Ministry of Science and Higher Education.

Radiotracer Investigation in an Industrial-Scale Fluid Catalytic Cracking Unit

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Fluid catalytic cracking (FCC) is one of the main processes used for processing crude oil in refineries. The cracking process efficiency depends upon process parameters such as residence time, residence time distribution, radial distribution and axial mixing of catalyst and gas phases in various sub-units such as riser, disengager, stripper and regenerator of the FCCU. Radiotracer techniques are widely used for measuring process parameters in industrial process systems. The measured parameters are often used for troubleshooting, performance evaluation, design improvements, and process visualization, optimization and intensification. This paper describes a series of radiotracer experiments carried out in an industrial-scale FCCU in India to measurement the flow parameters of catalyst and gas phase in various sub-systems of the FCCU. The objective was to measure the process parameters to evaluate performance of the FCCU and process intensification.

A series of radiotracer experiments was carried out in four sub-units of the FCCU for tracing catalyst and gas phases. Lanthanum-140 (^{140}La) as catalyst itself and krypton-79 (^{79}Kr) gas were used as radiotracers for tracing catalyst and gas phase cracked, respectively. The amount of activity used for tracing catalyst and gas phase in different sub-systems ranged around 0.5–2 GBq and 4–8 GBq, respectively. The radiotracer was instantaneously injected at the inlet of each sub-system and monitored at different strategically selected locations using scintillation detectors.

The data recorded in different radiotracer tests were treated and analyzed. From the treated curves mean residence time, velocity and slip factor were obtained. In order to investigate radial mixing of the phases across the cross-sections of the different sub-systems, multiple detectors mounted at each axial location were plotted and analyzed. In case of a good radial distribution, all the detectors mounted at an axial position will provide identical responses provided the wall and insulation thicknesses at the monitoring conditions were identical. However, different intensities of the monitored curves will indicate poor radial distribution of the phases. To investigate axial mixing, and axial dispersion model was used and values of model parameters, i.e., Peclet number (Pe) were obtained. The parameters were successfully measured and flow anomalies were identified. Homogeneous radial distribution of the two phases was observed in the riser section of the FCCU, whereas in other sub-systems, the radial distribution of the phases was poor. The velocity of gas and solid phase were measured to be 9.9 and 6.4 m/s, respectively. The slip factor was estimated to be 1.5, which was as per design criteria for efficient cracking reactions in the riser section. The flow of gas phase in the riser was observed to be as plug flow, however, moderate degree of axial backmixing was observed in case of catalyst flow. The results obtained helped to plan the necessary modifications in the FCCU, scale up the capacity and optimize the performance of the system.

Developing a Commercial Facility for Rapid Assay of Gold and other Elements in Mineral Ores Using γ-Activation Analysis

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The global mining industry relies on elemental analysis throughout their value chain. The development of near real-time analysis techniques such as on-stream and hand-held X-ray fluorescence allows assay data to be used for process control and optimization. Unfortunately, current methods have insufficient sensitivity to measure metals such as gold, which are mined at concentrations of a few parts-per-million (ppm) or less. Gold is currently measured commercially using the process of fire-assay, a laborious, time-consuming, manually intensive and hazardous process. Extensive sample preparation requirements mean that analysis turn-around times are typically at least 24 hours, precluding the use of the results for control purposes.

We have been developing γ-activation analysis (GAA) as an alternative approach. GAA mimics the more conventional neutron activation analysis (NAA), using a high-intensity radiation source to activate target elements in samples, and then measuring characteristic γ-rays emitted from activated radioisotopes. Unlike the nuclear reactor commonly required for NAA however, GAA uses a high-energy X-ray beam produced using an electron accelerator.

GAA is particularly well-suited to the analysis of gold via excitation of the 409 keV, 7.73 s half-life meta-state of ^{197}Au. The short half-life of the meta-state, and the fact that it can be excited using X-ray with energies below the activation thresholds of major rock-forming elements, make the method particularly rapid and sensitive. Notwithstanding these potential benefits, the GAA method has found only very limited commercial application, with only one industrial facility operating worldwide to our knowledge.

In this paper we report developments in several areas:

- Our work to better understand the physics of GAA and significantly improve sensitivity and accuracy. We demonstrate how a novel correction method allows accuracies of better than 1–3% to be achieved.
- Optimization of a practical system for round-the-clock commercial operations, including X-ray source design, shielding, detectors, and automated sample handling.
- Safety and regulatory approval. We discuss the development and use of advanced Monte Carlo software tools for shielding design and evaluation of residual activity.
- A profitable facility model and effective industry engagement strategy. We detail experiences setting up our first commercial GAA facility and our strategy for engaging with industry partners and customers to build acceptance of a new analysis method.
- Planning for a containerized GAA facility, suitable for rapid deployment on mining and mineral processing sites to facilitate provision of near real-time analysis data.

The new facility is currently in the advanced planning stage and is scheduled to start operations in mid-2017.

A Tracer Application in Detecting Damage to Oil Industry Piping

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Damage to the internal surfaces of piping systems of process industries is caused by continuous exposition to mechanical and chemical processes throughout their life span. This paper reports on a preliminary evaluation as to whether radiotracer techniques can be used in the detection of the two most frequent deterioration processes in an oil production and refining, viz., corrosion and scaling. Usually conventional non-destructive tests, all of which suffer from some limitation, are used in inspecting the impaired material and equipment. In turn, radiotracers are can be inserted into the flow and afford easy detection and measurement. The question: Is the method is sensitive enough? Residence time distribution models that are widely used in fluid flow studies may disclose the conditions inside the investigated system.

In this paper both the competence of the tracer technique in identifying which process — corrosion or scale formation — is acting, and of evaluating how much it is interfering with the flow. The tests were performed in pieces of the API 5L-B structural steel, commonly used in oil refineries. Three test specimens were used: one was flawless (CP-A), in a second one (CP-B) an ad hoc groove had been carved around its inside surface aiming at simulating a corrosion singularity, and in the third one (CP-C) an encircling metallic bulge was welded to its internal surface to simulate a scaling anomaly. Activated manganese sulfate monohydrate ($^{56}MnSO_4 \bullet H_2O$) in aqueous solution was used as the radioactive tracer. The manganese salt has been irradiated in the CDTN TRIGA reactor facilities. A fluorescent tracer (Rhodamine-WT) has also been tested for comparative purposes. The tests were performed under different flowrate conditions: 0.10, 0.40, and 0.90 m^3/h. The DTSPRO software has been used to analyze the flow residence time distribution curves and the ANSYS CFX 15 fluid dynamics software was used to define the flow in the flow obtained inside test specimens. The results achieved with both radioactive and fluorescent tracers indicated that the presence of the discontinuities in the specimens caused a perturbation in the flow that could be detected by the tracer technique. No deviations relative to a free flow were found in the CP-A probe, whereas some localized recirculation was detected in the CP-B probe, and stagnation or dead zones were noticed in the CP-C probe. It has been considered that the tracer technique has a potential use in discerning the presence of discontinuities such as corrosion and scale formation in pipes.

B10: Radiotracers for New Materials Development

Quality Control of Neutron-Absorber Materials for the Nuclear Fuel Cycle: Principle of the JEN_3 Neutron Backscattering Gauge

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It is projected that by 2030 there will be other nuclear reactors in addition to 437 reactors already operating commercially today in the world. A quarter to the third of the spent fuel rods from these reactors must be removed from a reactor every 12 to 24 months and stored between one and two years in the spent fuel pools. This delay allows the decrease of their radioactivity and thus their cooling, in order to facilitate transportation to the reprocessing plant. During that pool storage period, prevention of critically is ensured by the borated stainless steel plates, used as coated of the spent fuel pools. In general, this material plays a major role in the nuclear fuel reprocessing industry as a neutron-absorber material.

Several metallurgy techniques have been developed for manufacturing the borated stainless steel plates. To ensure a functional of radiation protecting and criticality, this material must meet strict specifications regarding the boron content and uniform distribution of the boron in the stainless steel plate. CEA (French Atomic Energy Commission) has designed several gauges to provide proof through non-destructive inspection that the finished products fully satisfy their intended objectives.

The main geometries have been considered:

- Backscattering geometry, when the criticality shield must reduce the reflection of neutrons.
- Transmission geometry, when the shield must reduce the interaction of exchanging neutrons.

B10

In this paper, we present the JEN-3 Backscattering neutron gauge. This gauge contains a neutron radio-isotopic sealed source whose activity depends in the final control and the site constraints. The neutron measurement is affected by randomness of the neutron emission and their interactions with the matter so, the uniform distribution of the boron will be checked by statistical criteria of acceptability.

The industrial prototypes are already installed and their performances have been validated in two manufactures of borated stainless steel plates (the first one in Austria and the second one in the US).

Radionuclide Technique in Mechanical Engineering: A Powerful Measuring Method for Tribological Tasks — Installations at and Services of ZAG Zyklotron AG

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The radionuclide technique in mechanical engineering RTM is a powerful and sensitive method to measure online the wear rates of running engines or tribometers in the range of nm/h. The three parts of this technique will be explained: 1) The process of radioactive labelling at a cyclotron; 2) The two possible measurement procedures; and 3) The measurement equipment. The installations for machine part activations at the cyclotrons of ZAG Zyklotron AG are shown. Based on measurement examples, the possible sensitivity of this method is demonstrated. Special developed activations and the status of implantations of radioactive ions are discussed.

B10

Replacing the Isotopic Radiation Sources in Thickness Measurement on X-Ray

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Currently, there is a tendency in industry if refusing isotopic radiation sources in favour of X-ray machines. This is due to several factors, chief among them radiation safety and maintenance problems, movement and disposal of γ-ray sources.

Compared to the γ-ray source devices have a number of disadvantages. The spectral energy distribution and therefore change in the spectrum as the radiation passes through the controlled material. Instability of radiation compared with γ-sources. All this complicates the use of X-ray sources for the thickness measurement of materials with different chemical compositions.

We offer solutions that reduce the measurement error when using X-ray radiation sources below 0.2% of the measured value.

Development of Thin Layer Activation for Wear Measurement

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Since the early 80s, when a cyclotron was installed in our laboratory, both fundamental research and application areas have been established. In the first years of operation, a relatively large amount of radioactive isotopes was produced for medical purposes. Parallel with the medical isotope production, a number of other isotopes were elaborated for industrial and agricultural purposes, intended for use as radioactive tracers. During the cooperation of national and foreign companies and research institutions the idea of using the radioactive tracers for wear, corrosion and erosion measurements emerged. Appropriate irradiation facilities were elaborated for activation of different parts of different forms and sizes as well as simple pieces of equipment (grinding machine, Microtom, etching desk, etc.) were installed to monitor the wear of the activated parts. During the cooperation, real machine parts were activated and investigated in tribometers or test benches. By broadening the range of the materials and samples to be investigated it turned out that the nuclear data, especially the cross-section and yield data for nuclear reactions necessary to estimate the produced activities are poor in some cases, that's why we launched a nuclear data measurement and compilation programme to establish a database for these reactions in cooperation with the IAEA. The materials, which cannot be activated directly were labelled using the secondary recoil activation. The international transport regulations and cooperation partners without licence for using radioactive materials in their premises motivated us to elaborate the thin layer activation (TLA) method by using activities under the free handling limit (FHL).

The irradiations/activations are performed on a dedicated beam line of our cyclotron laboratory mainly with proton or deuteron activation. The bombarding energy is set to a value so that the activity distribution of the main radioisotope produced is constant up to a given depth of the surface (homogeneous activation). If it is not possible the distribution is set to linear. Single or multiple spots, larger areas are activated into a depth required by the particular task. The depth can be adjusted by altering the irradiation angle. A particular task may require the presence of different radioisotopes in the same sample or in two samples with friction contact. In this case a non-interfering pair of isotopes are chosen. The first measurements are performed by using high resolution γ-spectrometers in order to assess all isotopes and their activities, the real wear (corrosion or erosion) measurement can be performed by high efficiency detectors (e.g., scintillation crystal) with discrimination to a given radiation of the chosen isotope.

During more than 20 years experience in thin layer activation we could successfully use both the high activity method and the FHL activations to solve real wear measurement tasks, as well as developed the production of a series of radioisotopes applicable for wear measurements. Our results also extend to the nuclear data measurements, where much more radioisotopes are measured and discussed from the point of view of TLA.

Industrial Applications of the IEA-R1 Research Reactor in Brazil

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The IEA-R1 is an open pool type research reactor located at the Nuclear and Energy Research Institute (IPEN-CNEN/SP) site and achieved its first criticality on September 16, 1957. IEA-R1 is the largest research reactor in operation in Brazil, with a core composed of 24 fuel elements with 20% enriched uranium silicide, 4 control rods (Ag+In+Cd) and many irradiation positions supplying thermal neutron fluxes ranging from 10^{12} to 10^{14} n/cm^{2}s. Currently, IEA-R1 is operating at 4.5 MW on an 8 hours per day and 4 days per week cycle.

The IEA-R1 reactor is a multipurpose facility used for basic and applied research in nuclear and for the production of radioisotopes for industry and nuclear medicine. For industry, IEA-R1 produces radiotracers and sealed radioactive sources (^{60}Co and ^{192}Ir) for industrial γ-radiography, as well as doped silicon by neutron transmutation.

For radiotracer production, IEA-R1 has been working with a compact local staff (3 persons) and is assisted by the Radiation Technology Centre at IPEN-CNEN/SP, in which there are installed hot cells for high activity handling. Most of the radiotracers produced at IEA-R1 are irradiated in a quartz bulb inside an aluminium vessel; the only exception is for ^{41}Ar production, where a special device that doesn't require a hot cell is used. These are the radiotracers produced at IEA-R1 and their applications in industry and environment:

- ^{203}Hg: determination of the mercury mass immobilized in electrolytic cells from soda and chlorine producing industries (46.6 days and 0.28 MeV).
- ^{131}I and ^{82}Br: flow rate measurement and residence time distribution (RTD) studies in rivers, lakes and wastewater treatment plants (8.04 days and 36 h, 0.36 MeV and 0.55 MeV, respectively).
- ^{192}Ir: environmental studies, in the form of a premixed sand (glass powder plus activated iridium), to study drag sediment in river (73.8 days and 0.32 MeV).
- ^{198}Au: representative study, in real conditions, of the impact of great civil works for the construction of important artificial harbour, airport and hydroelectric reservoir, by labelling sand to be removed from the bottom with emulsion of gold (2.7 days and 0.41 MeV).
- ^{41}Ar and ^{79}Kr: study the gas phase of fluidized cracking catalytic plants (110 min and 35 h, 1.29 MeV and 0.51 MeV, respectively).
- ^{140}La: study the solid phase (catalysts) of fluidized cracking catalytic plants in petroleum refineries (40 h, 1.16 MeV).

For doped silicon production, a device that affords the best axial and radial uniformity of the neutron dose is used. These doping uniformities as well as the doping accuracy are determined using resistivity values, showing an excellent doping quality.

A recent improvement was the development of an irradiation system to produce gaseous radioisotopes (^{41}Ar and ^{79}Kr), delivering the activated gases directly into the shield bottle without handling and dose exposition for operators, instead of via small quantities (batches), through quartz ampoules containing these noble gases.

B11: Seeing the Invisible: Structure Imaging — Safe and Effective Industry II

Investigation of Two-Phase Flow Behaviour Across a 90 Degree Horizontal Bend: CFD Simulation and γ-Computer Tomography Validation

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Investigation of two-phase (gas-liquid) flows is of vital importance due to their numerous applications in process industry. In the era of high speed and high capacity computers, such process engineering investigations are carried out using computational fluid dynamics (CFD) simulations. However, there is always a need to validate the fascinating CFD simulation results with experimental technique. γ-computer tomography (CT) provides a means to validate CFD results. In this technique, the transmission property of γ-rays is used to exploit density distribution of materials in the process under investigation. This procedure is carried out by obtaining several radiographic projections of the process followed by image reconstruction using various image reconstruction algorithms.

Two-phase flow regimes in straight pipes are well established and reported in literature but little has been focussed to define these flow regimes across bends. This paper presents an investigation of two-phase (air-water) flow behaviour across a 90 degree horizontal bend for a range of superficial velocities of phases using CFD and γ-CT techniques. Simulation of the system is carried out using the software FLUENT 6.3.26 while computational grid was generated using the preprocessor GAMBIT 2.4.6. Euler-Euler multiphase model is used while turbulence is incorporated using the standard k-epsilon model. Validation of simulation results is carried out using the first generation γ-CT system GORBIT. The 90 degree horizontal bend is scanned at various cross-sections for this purpose. Stratified flow patterns with major portion of void at the upper section of bend have been observed on the inlet and outlet of bend on the studied operating parameters. However, the void has been noticed to move towards the inner curvature of bend at the central location.

New Developments on the Automatic γ-Column Scanner

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Gamma transmission scanning of distillation columns is one of the most frequently used radioisotope techniques in industry. Recently, a new version of an automatic γ-column scanner was developed by cooperation between KAERI and GammaTech Inc., to facilitate high quality γ-scanning services to local industry. The scanner controls the movements of the source and the detector, records radiation counts and shows graphically the result of scanning on the screen. Instead of using multiple lines (guide cables, holding cable, signal cable and ruler) for the source and the detector in manual column scanning system, only one line is used in each side by employing tensioning tools and wire signal cable in the automatic system. Remarkable improvement in both hardware and software were made in the new version. The new system features shockless movement of a source and a detector for their precise control which is pivotal for acquiring measurements with high confidence. Software and associated hardware of the system was built with the products that have a worldwide reputation as standard tools in engineering fields to make the maintenance as well as further improvement more convenient. The improvements in the tensioner system, the encoder and its calibration method, radiation detection system and γ-energy spectrum, control box, software programme and its operation methods are introduced. The procedures for installation and operation of the scanner are presented.

B11

Radiotracer Applications in Industry and Environment

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Radiotracer techniques are widely used for troubleshooting, measurement of hydrodynamic parameters, flow visualization and evaluation of design of process equipment in industry and environment because of their many advantages over conventional tracers. The main advantages of radiotracers are their physico-chemical compatibility, high detection sensitivity, ability of in situ detection, availability of a wide range of radiotracers for different phases, non-degradability in harsh industrial environment and limited memory effects. In a radiotracer application, the radioactive material in a suitable physo-chemical form, similar to that of the process material, is instantaneously injected into the system at the inlet and its passage is monitored at the outlet or along the system at strategically selected locations using collimated radiation detectors. The monitored tracer concentration data is plotted as a function of time and interpreted to obtain qualitative as well as quantitative information about process parameters, hydrodynamic behaviour of the system and occurrence of malfunctions, if any. The commonly carried out applications of radiotracers in industry and environment across the world include:

- Leak detection in buried pipeline and heat exchangers;
- Mixing/blending studies;
- Flow rate measurements;
- Studies on residence time distribution in process vessels;
- Sediment transport investigations in port;
- Effluent dispersion studies in water bodies;
- Wear rate measurements;
- Radioactive particle tracking technique for flow characterization;
- Radiotracer applications in oil field investigations.

These applications across the world are either carried out by private companies or atomic energy establishments of the different countries. The end-user industries have been enormously benefited from these applications. In recent years, some new developments have also taken place in tracer techniques. During the presentation, a few case studies recently conducted in India and emerging trends in radiotracer applications in industry and environment will be discussed.

Tomographic Methods for Multiphase Flow Measurement

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Measurement of multiphase flow of gas, oil and water is not at all trivial and in spite of considerable achievements over the past two decades, important challenges remain. These are related to reducing measurement uncertainties arising from variations in the flow regime and the fluid properties, improving long term stability and developing new means for calibration, adjustment and verification of the multiphase flow meters.

Tomographic imaging is a powerful tool to unravel the dynamics of the gas liquid distribution in multiphase pipe flow and is regularly applied to provide reference data in the development of multiphase flow meters and for experimental validation and development of flow models. A high-speed γ-ray tomograph developed at the University of Bergen has been developed for this purpose. The image capture rate in the example shown is 100 frames/second, however, the system is capable of identifying the gas-liquid distribution at rates up to 1000 frames/second.

The high-speed imaging systems are designed for use in laboratories and at test facilities and are not suitable for in situ or permanent installations. For this purpose simpler systems with fewer projections are applied. These are referred to as tomographic measurements, tomometry or agile.

An example of a γ-ray system using one source and multiple beams, will be presented. This concept can be applied as a stand-alone meter or to provide accurate measurements of the gas volume fraction for a multiphase flow meter. The pipe flow is split into temporal segments of which the gas volume fraction is measured. One ^{241}Am source with principal emission at 59.5 keV is used because this relatively low energy enables efficient collimation and thereby shaping of the beams, as well as compact detectors. One detector is placed diametrically opposite the source whereas the second and eventually the third are positioned to the sides so that these beams are close to the pipe wall. The principle is then straight forward to compare the measured intensities of these detectors and through that identify the instantaneous cross sectional gas-liquid distribution, i.e., the instantaneous flow pattern. By counting the intensity in short time slots ($<$ 100 ms), rapid variations are revealed.

In conclusion the sensitivity to temporal flow regime variations multiple beams are considerably reduced by this multiple beam principle and is now implemented in commercial meters.

Determination of Interfaces in Packed Columns by Using Sealed Sources

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Process involved is the application of nuclear gauges to evaluate bed interfaces in packed columns, which are used in different industries, petrochemicals, etc. In this case, different types of packing have been used within a PVC column in order to analyze the γ-radiation attenuation response that different materials, of different density, present when a radioactive source whose beam passes through them is used. Thus, the results obtained by the detector from the attenuation of radiation gives information about the distribution and height of the packing material within the column.

The present study performed in the laboratory consisted of the determination of phases within a column packed with material of different density, to which a γ-profiling was done by means of a source-detector system, in order to establish the interfaces of the packing distributed within the mentioned column. A ^{137}Cs source (10 μCi) was used, with a scintillation detector mobilized by a stepper motor ($v = 6.6$ m/s) and the packing consisted of several types: sand and gravel, fine gravel, clay, coarse gravel, fine sand, air and water. This experiment was carried out with two types of measurement: 2 measurements/s and 5 measurements/s and it was demonstrated that that this technique used to estimate packing heights and interfaces is very efficient and that with a profile made with more measurements per second, best results with lower percentages of variation are obtained.

B11

A γ-Ray Computed Tomography for Investigating the Wood Structure

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The γ-ray computed tomography (CT) technique represents an effective solution for the control of the internal of the objects and provides, after measure and appropriate treatment of the data, a mapping of the inside of an object.

The idea is to control and to characterize the status of several trees of the forest of Mamoura. We will begin by measuring thickness of the bark and trying to identify the rings of growth.

B12: Radiation Techniques for Industrial Processes Optimization and Safety II

Radiotracer Residence-Time Distribution Method in Diagnosing Industrial Processing Units: Case Studies

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Radiotracers are unique in troubleshooting and diagnosing industrial processing units in harsh and opaque field conditions; the success of radiotracers is primarily due to their certain advantages such as online detection without shutting down or disturbing the process.

The paper gives examples showing how the information obtained by radiotracer experiments is used to analyze the operation of industrial processing units, to eliminate troubles and to optimize the performance of processes.

Radiotracer residence time distribution (RTD) measurements have been applied to investigate the pulp flow characteristics in the superphosphate production chamber using the radiotracer ^{51}Cr impregnated in the solid phase of the pulp in the mixing chamber; the mathematical model constructed on the basis of the experimental RTD showed an unsatisfactory functioning of the reactor; ways were proposed to correct this shortcoming, both in the existing chamber and in that which was being designed for a new plant.

Characterization by radiotracer RTD of flow dynamics in laboratory and pilot-plant molecular sieves columns dehydrating organic liquids is another case study. Experiments with ^{113m}In radiotracer in 0.01 M aqueous solutions of EDTA have been carried out to investigate the fluid flow dynamics in columns of three different diameters filled with molecular sieve spherical particles. The dependence of the fitting of experimental with theoretical RTDs upon the column diameter-to-particle diameter ratio was found and rather bad fitting for ratios smaller than 10 were observed. The influence of these phenomena on the adsorption process was investigated.

B12

Investigation of the Multiple Side Injections on Hydrodynamics of the Gas-Solids Fluidized Bed Using Radiotracer Based Techniques

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Fluidized bed reactors are the core of the chemical industries. The contact between fluid and solid phase plays an important role in the overall yield and performance. The liquid injection of the reactants has tremendous application in the various industries such as polypropylene production, catalytic cracking, coating and drying, etc. These processes occur in the fluidized bed reactors in which precursors are added to the reactor in atomized form through side injections. The jetting phenomena affects the system locally as well as globally and may change the solid recirculation profile in the reactors. These recirculation profiles contribute to the solid mixing and hence the quality of fluidization. This works focusses on the effect of the multiple injections on the solid distribution and velocity field via radiotracer based techniques.

The experiments are carried out at three different air inlet velocities, which correspond to 1.5, 2 and 3 Umf. For each air inlet velocity, experiments are performed with secondary gas injection through single and two side nozzles (placed at the same and different planes) operated at three different nozzle flow rates (80, 100, 120 LPM). Glass beads of 660 μm size and density 2500 kg/m^3 are used in all the experiments. The solid distribution and solid velocity profiles are estimated using the γ-ray densitometry and radioactive particle tracking (RPT) techniques, respectively. Densitometry provides line averaged attenuation measurement for each radial location. The term "densitometry" refers to measurement of the density of a material by determining the degree to which that material attenuates radiation of a given energy. By using the Beer-Lambert law, the phase holdup can be calculated along the chord length in which the attenuation in the radiation is measured. In RPT motion of a single radioactive particle, which has same size, shape and density as of the other particles, is tracked by using NaI(Tl) scintillation detectors. In current experiments ^{46}Sc embedded in glass beads is used as a tracer particle.

Densitometry and RPT experiments are performed for different nozzle configurations and flow rates. The time average radial solid distribution profile is estimated at different axial planes. The bed is operated at 3 Umf at different nozzle injection velocities. Results indicate that compared to without nozzle case with nozzle injection cases show higher fraction of solids similarly, The other experimental finding will be addressed in full paper.

It was observed that most of the injected gas flow near the injection wall even at the higher flow rate and resulting in the low solid fraction at the wall in the case of single nozzle injection. The multiple nozzle injection (their location and configurations) have significant impact and depending upon injection velocity the second nozzle may increase or decrease these effects.

Radiotracer and Sealed Source Technologies for Measurements in Industry

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The field of radiation technology came into being right at the discovery of radioactivity in 1896 by Henri Becquerel. In the coming years, several useful applications of radiation influenced the development of various radiation detector and analysis systems so that qualitative observations can be converted to precise measurements of energy, intensity and location of radiation. Some of these major applications include medical applications, industrial applications, high energy physics and nuclear security. Various means of development of artificial radionuclides and their transformation to useful radiotracers were explored keeping in view of these applications. Portable radionuclide/radiotracer generator systems were established for on-site production of radionuclides which have proved very successful in medical and industrial applications. The objective of this presentation is to give an overview of the applications that are driving radiation technology research for making useful measurements. Keeping in view of the substance involved in subject research field and my special field of research, the talk is focussed on radiation technology for measurements in industrial applications. The principle and applications of radioisotopes for making measurements and troubleshooting in industry will be discussed. The development of various nucleonic control systems for on-line measurements in industry will be presented. Thin Layer Activation technique for wear measurements in industrial systems will become under discussion. In addition to this, radiotracer applications for industrial process optimization will also be covered. Modern day approach for diagnosing complex industrial systems (multiphase flow systems) using radiotracers in combination with computational fluid dynamics (CFD) technique will also be elaborated during the presentation.

B12

Radioisotope Techniques for Detection of Coking in Liquid Flow through a Solid Phase in a Lab-Scale Distillation Column's

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The petrochemical industry is one of the most important sectors of radioisotope technology applications. The distillation columns are considered as one of the most critical components in oil refineries. In packed bed distillation columns, the coking phenomenon is likely to occur inside the packing (solid) through which a liquid is flowing.

The aim of the proposed work is to try to address the coking phenomenon as a challenging issue in petrochemical industry by combining or integrating sealed radioactive source techniques and radiotracer techniques. The results correspond respectively to tests using two radioisotopes with γ-scanning technique and radiotracers. In the first approach, the structural characteristics of a laboratory constructed distillation column have been investigated by using the γ-scanning technique which consists in using a $^{60}\mathrm{Co}$ as a γ-ray sealed source associated with a NaI(Tl) detector. The second approach by radiotracers consists of an injection of an appropriate quantity of a specific radiotracer ($^{99m}\mathrm{Tc}$) at the inlet of the process and studying its presence in the column.

Results shows that the radiotracer method may be a good approach for detecting the presence of coke in case of liquid flow through solid packing in distillation columns. Further, data will be useful in numerical modelling and validation by CFD simulations.

Measurement of Residence Time Distribution of Wastewater in a Constructed Wetland System Using Radiotracer Technique

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Constructed wetlands (CW) are human engineered systems that utilize natural process for treatment of wastewater. They have been highly applicable in developing countries, due to their characteristics like utilization of natural processes, simple construction, operation and maintenance, process stability, and cost effectiveness. The design of constructed wetland requires multidisciplinary inputs involving biological and ecological sciences, aquatic chemistry, engineering hydrology and flow hydrodynamics. The CW are heterogeneous in nature. Thus, they are prone to show deviation in the designed flow pattern and residence time for the treatment of wastewater. Thus, the aim of the present study is to measure mean residence time (MRT) and flow patterns of CWs using radiotracer technique.

The wetland is 13.0 m long, 3.0 m wide and 0.7 m deep. The geometric volume of the system is 27.3 m^3. The system walls and bottom were lined to prevent leakage. The wetland has slope of 1% at the bottom and an average porosity of 52%. About 100 MBq of ^{99m}Tc ($\tau_{1/2} = 6.6$ h, $E(\gamma) = 139$ keV) as sodium pertechnatate used in each run. The radiotracer concentration monitored at different planes across the width and outlet using NaI(Tl) scintillation detectors were connected to a computer controlled data acquisition system was set to record tracer concentration at an interval of once per minute at outlet and across the bed of the system.

The RTD data was treated and analyzed using a RTD analysis software. The data treatment includes background subtraction, tail correction, radioactive decay correction, zero shifting, smoothing and normalization. The data was used to calculate MRT, system dead volume and hydraulic efficiency of the plant. A four-parameter model i.e., tank in series exchanging with dead volume model prefixed with plug flow component was used to simulate the RTD data.

Radiotracer experiments were successfully conducted in an artificially constructed wetland system and mean residence times and dead volumes were determined at different operating conditions. No bypassing/short-circuiting was observed in the CW. The proposed four-parameter model was found suitable to describe hydrodynamics of wastewater in the wetland. The hydrodynamic parameters were indicating that CW works efficiently at bed height of 0.6 m, wastewater flow rate of 2.3 m^3/s and two point distributor geometry. However, the results of the study also indicate that on increasing the number of injection points, the efficiency of the CW will increase.

Radiotracer Investigation of the Effect of Impeller Type on Mixing in Industrial Process Simulator

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Radiotracer technology has been applied in the industry for the investigation of process performance, online monitoring of conditions of process plants, troubleshooting and diagnosing anomalies including mixing conditions in continuous stirred tank reactors.

In this study, radiotracer methodology was used to carry out investigation on a laboratory water flow rig which serves as simulator of industrial processes. The aims of the investigation were to assess: i) the effect of impeller type on mixing, and ii) the fluid dynamics of the water in the vessels since both the vessels and the impellers were redesigned and reconstructed. Four similar vessels in series circuit with different impeller configurations were investigated. Tank 1 has 1 axial impeller, tank 2 has 2 axial impellers, tank 3 has 2 radial impellers and tank 4 has no impeller. The data was collected by introducing 8 mCi liquid ^{99m}Tc at the inlet stream of the vessels and the γ-signal was collected with thallium activated NaI detector placed at the outlet of the vessels. Residence time distribution (RTD) curves for the outlet tracer concentration were generated from which the mean residence time (MRT) and variance were calculated by the method of moments. The extent of material mixing in the vessels was inferred from the variances and the fluid dynamics was obtained by modelling.

The extent of mixing was highest in tank 3 followed by tank 1, and tank 4 gave the poorest mixing. The outlet response curves were fitted with mathematical models using DTS pro and RTD Software. The best fit for tanks 2, 3 and 4 was perfect mixers in series with exchange (PMSE) model while perfect mixers in series with recycle (PMSR) model best described the fluid dynamics of the material in tank 1.

B13: Radiotracer for Managing of Natural Resources, Energy and Processes

Investigation of Heavy Metal Release at a Municipal Solid Waste Incineration Facility: An Excellent Example for the Unique Potential of Intrinsic Radiotracer Application to the Investigation of Industrial Processes in Chemical Engineering

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Radiotracers are widespread in use for the investigation of material transport processes in industry and environment. Often they are used for the measurement of the residence time distribution in continuously operating chemical engineering facilities and reactors. Mostly intrinsic or physical tracers are used for these purposes.

In case of phase transformation processes are in the focus of interest physical or extrinsic tracers are not the labelling material of choice. Intrinsic or chemical tracers are required in that case. At example of the heavy metal release investigation at a municipal solid waste incineration facility the unique potential of intrinsic radiotracers will be demonstrated in the given paper.

The goal of the investigation at the municipal solid waste incineration facility reported in this paper was the behaviour study of different heavy metal species at various incineration conditions. With the help of short lived radioisotopes of copper (^{64}Cu) and zinc (^{69m}Zn) could be shown at which position of the incinerator and in which amount the heavy metal under investigation was released.

The experimental results of this investigation were an essential contribution for better understanding the processes inside the incinerator and to optimize the processing conditions.

Radiotracer Investigation in an Aeration Tank of a Waste Water Treatment Plant

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A radiotracer experiment was conducted in an aeration tank of a waste water treatment plant in a chemical plant in Malaysia. ^{131}I [$\tau_{1/2} = 8$ days, energy: 360 keV (80%), 640 keV (9%)] as sodium iodide was selected to be used as a radiotracer. About 12.5 GBq (200 mCi) of radiotracer was used. The radiotracer was diluted in a volume of about 30 ℓ and injected into the splitter pit at a constant rate for a period of about 10 minutes using a specially fabricated injection arrangement. This ensures good mixing of the tracer with the inlet stream of wastewater and almost equal division of radiotracer into two individual tanks (tank A and tank B). The period of injection is negligibly small as compared to expected mean residence time of the wastewater in the tank and hence the tracer injection can be considered as an impulse or instantaneous injection.

The radiotracer was monitored at different strategically selected locations using 11 waterproof scintillation detectors ($2'' \times 2''$, or 50.4 mm by 50.4 mm). All the detectors were connected to a common 12-channel computer-controlled data acquisition system programmed to monitor tracer concentration data at an equal time intervals. During the acquisition, the data was saved at regular intervals. The continuous on-line monitoring of tracer was conducted for a period of 26 days.

Results revealed that no malfunctioning such as bypassing or short-circuiting of the flow was observed in the tank. The mean residence time in the tank was estimated to be about 6 days, which matches with the theoretical mean residence time (hydraulic retention time). The residence time in the membrane was negligible as compared to the residence time in the tank. No considerable dead volume was found in the tanks. This indicated that the entire volume of the aeration tank was used for the treatment of the wastewater. A model with a tank connected to a dispersed plug flow component in series with a recycle flow was found suitable to describe the flow of wastewater. The results of the model simulation showed that the aeration tanks behave as an ideal mixer. However, the membrane behaved as a plug flow reactor. The result of simulation indicated that the recycle flow rate is about 1.4 times the inlet flow. The results of the investigation will help the plant engineer to evaluate the performance of the aeration tank.

B13

Data Fusion Approach for Improving the Reliability of Radiographic Testing and other Complementary NDT Techniques

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Non-negligible uncertainty and imprecision in defect detection and defect sizing exist when only using one single non-destructive testing (NDT) technique. To increase the reliability and reduce the uncertainty of defect detection and defect sizing, the complementarity and redundancy of radiographic and ultrasonic testing data is exploited. The reliable concept to improve the detection and characterization of defects is by combining the data sets of these NDT techniques. This goal is achieved by employing mathematical data fusion techniques [1, 2]. These are techniques allowing for simultaneously taking into account heterogeneous data coming from different sources in order to get an optimal estimation and evaluation of defects under investigation. The present study focusses on the development of a data fusion approach based on the evidence theory (Dempster-Shafer theory) [3, 4] in order to merge a large number of data sets, in a suitable manner, and obtain more reliable results of localization and characterization of defects inside a component. The proposed method is validated by a real ultrasonic and radiographic NDT data of different industrial components.

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Neutron Backscatter Technique as an Alternative Method for Quality Assurance and Standardization of Petroleum Products

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Crude cost is one of the most important parameters in the operation of an oil company. The choice of crude is very vital in that it determines the profit margins of oil companies, hence the selection of an optimum crude for processing requires careful consideration. Neutron backscatter technique is a non-destructive method used for industrial investigation, including determination of hydrogen content of crude and its finished product. This method has a wide scope of application and is faster in comparison with the chemical methods employed by the petroleum industries which are destructive, product specific and often requires several hours of heating samples at temperatures up to 750°C to obtain results.

Neutron backscatter technique was used in this work to determine the total hydrogen contents of petroleum samples from Tema Oil Refinery (TOR) and crude oil samples from the Jubilee oil field in Ghana and Bonny light and Forcados oil fields in Nigeria. Excess neutron counts were measured and reflection parameters determined as a function of hydrogen content of the samples. Liquid hydrocarbons of known hydrogen and carbon contents were used as standards to draw calibration curves against which the total hydrogen contents of the samples were determined.

The total hydrogen contents were found to be in the range of 7.21–15.06 (hw%) for vertical geometry and 7.20–14.94 (hw%) for horizontal geometry respectively. The results agreed well with other results obtained using different methodologies. The results shows a high hydrogen content in both Nigeria's Bonny light and Ghana's Jubilee crude oil samples however, in Nigeria's Forcados crude oil sample there was a low hydrogen content. This confirms that neutron backscatter technique is able to distinguish between light sweet crude and heavy sour crude.

Identification of the Internal Condition of Crude Oil Distillation Unit Using γ-Column Scanning Technique in Myanmar

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The γ-column scanning technique was utilized to identify of mechanical problems such as missing, collapsed or buckled trays in trayed column of Crude Oil Distillation Unit C at the No. (1) Refinery (Thanlyin), Yangon, Myanmar. It has 52 trays, diameter is 2 m and height is 43.55 m. Scanning type of work is Blank Scan and this unit has been shutdown since 2010 due to some processing problem. The refinery wanted to know internal condition of a column before operation. The scanning work was performed using a 50 mCi ^{60}Co γ-source, NaI(Tl) scintillation detector, manipulation system (winchers) and ColScanCK1 Data Acquisition (DAQ) system with NibraS software to investigate condition of all trays.

By reference to the mechanical drawing of the tower, the point at elevation of 7350 mm was assigned as starting point of the scan and it was denoted as 0 mm. Three scan lines were selected; one for single pass trays and two for double pass trays within the left and right down comer areas of the Distillation Unit. The Radiation source was placed at 44°, 59° and 107° and detector was placed at 224°, 291° and 224°, respectively.

It was challenging to scan because the space between insulator and ladder is very narrow, in some places detector and source were passed the ladder with considering of radiation safety aspect. Although size of tray #1 to 8 are very small and wall of column is very thick in these place, we could determine tray #1 to #8 were in their positions. From identification, all scan profiles interpreted that tray #1 to #52 were normal and in their positions.

B13

B14: Radiation for Cultural Heritage Characterization

A Survey of the Possibilities of Various Radiographic Techniques for the Non Destructive Examination of Cultural Heritage Artefacts

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How, where and when artefacts were manufactured, how they were exchanged, when, where and how techniques appeared, prospered or disappeared, what has been their evolution and/or degradation during time, are topics of increasing interest. How can we better understand art objects and cultural heritage artefacts and keep them available, in best condition, for future generations is a very significant challenge. Due to the broad diversity of materials, and as the artefacts have various, often complex and undetermined compositions, as their elaboration processes are often unknown or at least uncertain, it is generally necessary to combine various examination, characterization and analysis methods, to get pertinent information and thus to give a rational basis for their restoration and conservation. Furthermore, because of the unique or rare nature of cultural heritage artefacts, as a general rule, the techniques which can be used must be either well tested and proven non-destructive and noncontact methods without any sampling, or tests with strictly authorized small size sampling Radiography has long been applied to medical diagnosis and to non-destructive examination of industrial objects. In the area of cultural heritage, it has proven to be invaluable for the examination and the study of works of art.

In a first part, a brief survey will be given of the basic physics principles of the different possible variants of the radiographic techniques. They include: conventional X-ray radiography, γ-radiography, radiography using accelerator, radioscopy, β-radiography or secondary electron radiography, electron emission radiography, neutron radiography, autoradiography and computer assisted tomography. Many major types of artefact collections are concerned by radiographic examination: easel paintings (X-ray, electron emission, autoradiography), ceramics (X-ray), stone, metal and wooden statues (X-ray and γ-ray, tomography), paper and drawings (α particles and secondary electrons), archaeological objects (various techniques), musical instruments (X-ray and tomography).

The second part will provide examples of applications of these different techniques on various types of artefacts, focussing on issues related to the study of historical fabrication techniques, the diagnosis of eventual previous restoration and of the object's condition.

If this palette of techniques, eventually associated with complementary NDT techniques, is used by a competent and skilled technician, and if there is a real dialogue between himself and the curator, or the conservator-restorer, or the art historian, or the historian of techniques, or the archaeologist, it can provide many pertinent elements, contributing to a deeper knowledge of the artefact and insure a conservation process as pertinent as possible.

Application of Ionizing radiation in Studying Akaba and Masai Art Objects Made from Glass

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Glass is known to deteriorate under environmental conditions and therefore it is of major concern to conservationist, cultural heritage fans and museum institutions. However, glass art products are common wares, made and sold by artists in the low-income groups of different Kenyan communities. They are therefore an economic asset and income provider for many poor households. For the authorities to make a decision on how to help the involved artists and resellers, to add value to their products and capture a wider market, especially from tourist and business visitors, a better understanding of product structure, morphology and elemental content was seen to be necessary. Ionizing radiation instrumentation are good tools for this kind of study and therefore XRF and radiography facilities at the Institute of Nuclear Science and Technology were used to analyze randomly purchased objects from street hawkers and market resellers. The spectra and radiographs will be analyzed and the resultant data used to assess the source of deterioration and give informed recommendations to policy makers and stakeholders in the business.

Radiographic Investigation of Archaeological Objects

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Radiography is a versatile technique with many applications to archaeological and art historical artefacts. It can be used to assess the condition of objects before conservation or restoration treatment, to gain information of materials used and methods of construction, and to reveal the secrets of the embalmer's art, hidden within mummified remains. The techniques can be applied to materials as diverse as papers, fabric, wood, ceramic and metal, as well as to human and other animal remains. Radiographic examination basing on film imaging or digital imaging techniques may provide images of objects concealed within a mass of corrosion and may even reveal a previously unknown painting, hidden beneath a later work. All of this can be carried out non-destructively, making radiography an invaluable tool for the study of cultural materials.

Radiographic investigations of the archaeological objects at Çekmece Nuclear Research and Training Centre were carried out since 2004 in collaboration with Archaeology Museum of Istanbul and Directorate of Istanbul Central Laboratory for Restoration and Conservation. This work describes radiographic investigations of the archaeological objects in order to support museums, laboratories and archaeology specialists for the restoration, conservation and replica processes, as well as inventory purposes. Film based, flat panel and imaging plate radiographic techniques were used in the examinations. Some of the investigated objects in this study are anchors of 13th Century of Byzantine Empire taken out from a wracked excavation, chains used in the Golden Horn during the period of Byzantine Empire, head of the Snaky Statue from Roman Period being situated in Sultan Ahmed Square in Istanbul, metal objects from Bathonea excavation in Istanbul, etc.

Findings obtained from the examined objects were assessed together with archaeology specialists in order to make comment about their history and production methods and to decide for the restoration and conservation processes.

The use of radiographic examination for the preservation of cultural heritage became a very important tool that allows scientists and archaeologists to accurately identify and conserve items that would have been lost or damaged in the past. The results obtained from this study were very beneficial for the Istanbul Archaeology Museum and Conservation and restoration Laboratory for determining the internal structure and surface condition of the objects before treatment for restoration, conservation, replica works and a lot of other processes.

Using X-Rays to Detect Hidden Images (Old Masters) on Priming Canvases

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Improving the radiation technology: enhancing the stability of the sources, the possibility of fine adjustment of the anode voltage, emission control range and high sensitivity and stability of detectors allow the use of this equipment for the detection of latent images on canvases (paintings).

Experience in the use and methods of application of this equipment to solve the problem of detection of illegal movement of works of art. The presentation will discuss emerging issues and their solutions.

Some Applications of X-Rays in the Service of the Archaeological Site of Volubilis

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The studies done during this work are part of the collaboration agreement between the Ministry of Culture and CNESTEN. Investigative studies, diagnosis and characterization of a cultural archaeological heritage, carried out before any repairs or restoration and conservation. The studies are to implement two approaches combined namely industrial radiography X and PMI (positive material identification) for quantitative and qualitative evaluation of a variety of archaeological items on the site of Volubilis. These two complementary methods allowed us firstly to evaluate the condition of structures for possible restorations, mobilizations and characterize in situ controlled materials without sampling.

Secrets and Mysteries of our Past Revealed by Neutron and X-Ray Radiography/Tomography

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Heritage is our legacy from the past, what we live with today and what we pass on to future generations. Our cultural and natural heritages are both irreplaceable sources of life and inspiration. Places as unique and diverse as also the wilds of East Africa's Serengeti, Cradle of Humankind in South Africa, the Pyramids of Egypt, the Great Barrier Reef in Australia and the Baroque cathedrals of Latin America make up our world's heritage. What makes the concept of World Heritage exceptional is its universal application. World Heritage sites belong to all the peoples of the world, irrespective of the territory on which they are located.

It is a universal need to reveal those important and in most cases hidden features of findings such as artefacts or fossils in a noninvasive manner in order to preserve, sometimes only artefact ever found, in the most a responsible manner for future generations to also study with possible new developed analytic techniques.

Currently, neutron and X-ray based analytical techniques play an important role in both applied research and practical applications. Today, various experimental setups of neutron techniques can be used effectively for imaging purposes. Moreover, recent developments of X-ray methods, which are used primarily for medical applications, like diagnostics or treatment (e.g., X-ray based computer tomography, tomotherapy, image guided radiotherapy, etc.), use advanced imaging principles. However, both neutron and X-ray imaging techniques do not offer directly analysis of elemental composition of studied entities. One important application of neutron and X-ray radiation based imaging techniques is the non-invasive study on objects from cultural heritage importance, where these probes reveal valuable hidden information in a non-destructive and noninvasive manner.

The aim of this presentation is to highlight the non-destructive analysis of cultural artefacts using the capabilities of neutrons and X-ray's as penetrating probes. Several case studies will be discussed about neutron and X-ray radiography and tomography investigations of cultural artefacts being practiced at various research institutions worldwide.

The Radiography in the Service of the Preservation of the Moroccan Historical Heritage

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Moroccan historical heritage is extremely rich and varied. The history more than millennium of Morocco bequeathed us objects of the heritage going of the prehistoric and antique Art to the Amazighe and Arab-Islamic art by way of Greco-Roman period. Numerous objects of the Moroccan heritage suffer from a doubtful state of preservation, even critical in certain cases.

It is consequently indispensable to develop and to apply techniques of examination, characterization and analysis of the oeuvres of art of the Moroccan cultural heritage, constituent materials of these works, to know the mechanisms of their elaboration, their evolution and/or degradation and establish recommendations with the aim of their restoration and of their preservation. For that purpose, we privilege the non-destructive methods, without contact (when possible), without sampling. Among these methods, some make use of X-rays and the γ-rays. These methods, the only ones or associated with other techniques are applied to very diverse works and materials of all kinds, any origin and any age.

The application of X-ray radiography in numerous pieces of the Archaeological Museum of Rabat, in particular the statue of Ptolémée (marble), a Roman ceremonial helmet (bronze), a pyxidium with relief (bone) so allowed:

- To estimate the area and the extent of the damages undergone by these objects;
- To contribute to a better knowledge of the techniques of manufacturing by the artists having realized these works as well as the previous restorations made on the studied pieces;
- The assistance-advice for the benefit of the curators and the restorers for the establishment of specific methodologies of restoration to every type of object.

The radiography also allows the contribution to the establishment of detailed identification sheets of valuable museum pieces, particularly those being often the object of loans between museums.

B15: Advances and Trends in Radiotracer and Radiation Science and Technology II

Nuclear-Based Monitoring of Industrial Mass Flow I: The Potential Use of Small Transportable Neutron Generators

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Radiotracers for industrial monitoring are produced mainly by two main methods: 1) Activation in research nuclear reactors (RNR) or at charged particle accelerators, and 2) by radiotracer generators (RG). Both methods face challenges:

1. The production by activation is often difficult from both administrative and technical reasons. Administrative reasons imply that the production of specific radionuclide has to be known and authorized at the irradiation facilities. Technical reasons imply that irradiation facilities are often non-existing in many countries. Where irradiation facilities do exist, there are limitations due to periodical shut downs. Finally, transportation time between irradiation facilities and industrial site limits again the use of short half-life radiotracers.
2. The number of commercially available radiotracer generators for industrial use is rather limited for the moment. Other options for nuclear-based monitoring of industrial mass flow that appear may therefore be interesting to pursue.

One such option is the application of recently developed small-sized neutron generators. Two types of neutron generators are available using deuterium-deuterium (DD) reaction (neutrons at 2.45 MeV) and deuterium-tritium (DT) reaction (neutrons at 14.1 MeV). Commercial DT generators may produce neutron outputs of $>10^{11}$ n/s. Unlike isotopic neutron sources, the neutron generators contain no radioactivity (except the inventory of tritium in the DT neutron generator) making them inherently safe (no external radiation) when turned off.

This presentation will review the current status of such neutron generators and discussed possible applications for use in industrial in situ or even on-line monitoring processes. The various approaches include on-site production of radiotracer by off-line irradiation of suitable target, on-line and in situ generation pulses of short-lived radiotracers from macroelements in the flow, direct continuous activation of matrix elements in the flow, activation of injected pulse of a stable chemical compound, PGNAA of injected non-radioactive tracer pulse, neutron transmission measurement after pulse injection of a strong neutron absorber and others. The broad industrial use of such techniques is at present in its infancy, and a considerable R&D work remains to be done to ensure the robustness of the different approaches.

Nuclear-Based Monitoring of Industrial Mass Flow II: The Potential Use of Small Transportable Neutron Generators

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Radiotracers have been widely used throughout industry to optimize processes, solve problems, improve product quality, save energy and reduce pollution. Stricter regulatory regimes lately demand, however, that the radioactive labels are as short-lived as practically possible in order to reduce radiation load to personnel involved. This requirement introduces some challenges. Short half-lives limit the permissible transportation time from radionuclide production facilities like nuclear reactors or particle accelerators. Thus, the use of tracer technology in process monitoring on remote industrial sites is hampered. One remedy to cope with this problem is to develop and apply radiotracer generators based on radionuclide generators. These are again based on suitable and specific mother-daughter nuclear genetic relationships with a long-lived mother and a short-lived daughter.

This presentation describes various types of generator principles from column-based equipment where the mother nuclide is fixed on a solid support and the daughter is eluted in an external liquid, systems where the mother radionuclide is exclusively dissolved in one of two immiscible liquids and where daughter separation takes place in a liquid-liquid extraction process, to systems where the mother is a gas and the daughter a solid (or the other way around) and where the separation process includes a cryogenic step. The presentation also describes which generators are commercially available today for industrial monitoring, and which type of development work is needed to extend the selection of desirable generators.

B15

Residence Time Distribution Measurements in Industrial Scale Reactors with Recycle Using Radiotracer Technique

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All process industries go through a series of routine steps to produce economically viable products. The raw materials are initially made to go through a number of physical treatment blocks to be converted into the form which is conducive for the chemical reactions. They are then introduced to the reactors where chemical reactions occur and the products are formed. Lastly, the products are separated, purified, etc., and the desired commercial grade products are obtained. Reactors, in this whole process, play the most important part in any process industry and better reactor efficiency results in better product quality. The ideal reactors are: batch reactor, continuous stirred tank reactor and plug flow reactor. Recirculation reactors are a type of continuous stirred tank reactors where the mixing of the reactants is done by the turbulence created by the recirculation stream. These are employed where the installation of agitators in the reaction vessel is not desirable like bio-reactors, nuclear reactors, etc. The mixing process of such reactors can be optimized by residence time distribution studies. It helps in determining the non-ideality of the reactors for instance, dead zones, channelling or short-circuiting and the extent to which it deviates from ideality. Once known, the information can be used to increase the reactor efficiency by tweaking the reactor geometry and an accurate model can be derived to describe the working of the reactor. In process industries, usually single pass conversions are low and the reactants are recycled back to the rector to achieve high overall conversion. Developing models from residence time distribution data obtained from recycle reactor are relatively complex and literature references are also scarce as the input to the system (recycle) changes to a random input.

Residence time distribution studies are performed by injecting a suitable radiotracer in the ethyl acetate reactor as a pulse, measuring the output signal and plotting the residence time distribution of the reactor. Bromine, ^{82}Br as ammonium bromide, with a half-life of 36 h and good compatibility with the contents inside the reactor yet unreactive, was chosen as radiotracer. It was introduced online as a pulse input into the feed line of a recirculation reactor producing ethyl acetate via a reversible equilibrium-limited esterification reaction. The reactor had recycle streams coming from two different distillation columns containing unreacted reactants.

After the output concentration of radiotracer was plotted against the time, preliminary observation of the residence time distribution curves showed the presence of internal recirculation, which was obvious as the reactor worked on the principle of internal recirculation for proper mixing of contents.

Neutron-γ Discrimination Using Non-Negative Matrix Factorization Blind Sources Separation Algorithms

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In this study, we apply blind sources separation methods (BSS) based on non-negative matrix factorization techniques (NMF) to extract independent components from signals recorded at the output of fission chamber detectors. Since these modern signal processing methods require no hypothesis on the way that the signal and the noise are mixed, encouraged us to apply these methods to reach n–γ discrimination in a soft way. For that reason, we use Geant4 as nuclear simulator, to model the neutron detection system installed inside the TRIGA MARK II Reactor (Nuclear Facility of the Moroccan National Center for Nuclear Energy, Sciences and Techniques). The fission chamber is used in a research nuclear and a flux-mapping experiment is performed. We use the simulated fission chamber's output signals as time series mixtures that will be analyzed through non-negative and blind sources separation algorithms. The computation of performance index of each blind separation method will allow us to select the most efficient NMF algorithm that permit to achieve the best n–γ discrimination. In addition, the computation of the auto and cross-correlation functions, the power spectral densities and time-frequency decomposition of the resulting independent components will provide a better characterization of these nuclear signals with very high precision.

Contrabands Detection with a Low Energy Electron Linac Driven Photoneutron Source

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A low energy electron linac driven photoneutron source, which can provide both X-rays and photoneutrons simultaneously in the same system, is realized to interrogate contrabands concealed in luggage or cargoes. X-rays produced by the 7 MeV electrons that bombard the tungsten target are used to penetrate the inspected material and form the 2D mass thickness image. Photoneutrons, which are the by product of X-rays, can be used to penetrate the inspected materials to form the neutron image. The fusion of the X-ray image and photoneutron image is helpful for the separation of organic materials, light metals, medium-weight metals and heavy metals. The (γ,fission) induced β-delayed neutrons in the heavy metal indicates the possible existence of the special nuclear material. Photoneutrons within the eV energy range can then be used to penetrate the heavy metal in order to identify its isotopic concentration, if it is suspected as the special nuclear material. The thermalized neutron can also induce the prompt γ-rays in the inspected material, the detection of which provides the fingerprint information of special nuclides, which in turn helps the detection of explosives or drugs. This system can be held in a truck, and hence is a mobile system that can provide in situ contrabands detection abilities.

B15

Combining CT Scan and Particle Imaging Techniques: Developing New Applications to Sediment Transport

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Physical models were built to study sediment transport in coastal and fluvial environments. X-ray computed tomography (CT) technology has useful applications in geosciences providing density and porosity of non-homogeneous materials. The medical CT scanner is interesting because of its large opening, allowing a field of view up to 65 cm for the reconstructed image. Dynamic systems could also be studied with the CT scan by doing temporally resolved measurements. This project uses optical imaging techniques to characterize the effect of different flow types (i.e., uniform flow and waves) on sediment transport.

A movable sand-bed model was built in the Multidisciplinary Laboratory of CT Scan for Non-Medical Use at the INRS (Québec, Canada). A rectangular flume ($0.30 \times 0.30 \times 7.0$ m^3) made with 25 mm thick transparent acrylic material was inserted into a medical X-ray CT scanner (Siemens, Somatom Definition AS+ 128). The CT scanner moves on 2.6 m rails along the flume. For preliminary tests, the water depth in the flume is 0.14 m. The sand bed is composed of quartz (SiO_2), Ottawa sand, with grain median diameter (d50) of 217 μm and uniform density. The bed height is 5 cm. In addition, as the examination table is static and the gantry moves along the object, the use of large fixed physical models is possible. Steady flow can be created using a water pump joining the two water tanks placed at each extremity of the flume. A honeycomb diffuser reduces the turbulence at the water inlet. A wavemaker can also be installed at one extremity to generate waves. A wave absorber made of angular pebbles is placed at the other extremity. A particle image velocimetry (PIV) measurement system is mounted on the CT scanner allowing time-synchronized and co-located measurements. The camera is protected from the X-ray by a lead sheet.

The method consists of coupling a medical CT scanner and a particle image velocimetry (PIV) system. The two datasets are combined to provide an image with density values as well as velocity vectors, and the the PIV system can be successfully synchronized with the CT scanner. With this settings, fundamental information can be gained to understand the physics of particle-fluid dynamics and improve the modelling of the underlying processes. This experimental apparatus allows for the parametrization of shear velocity and sediment density at the boundary layer, which is an essential but otherwise difficult to determine parameter of sediment transport.

B16: Technical Cooperation Success Stories: Country Reports

The Participation of the Technological National Centre in the Technical Cooperation Programme Activities

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The National Technological Centre (CTN) with headquarter in Luanda, is a public institution tutored by the Ministry of Science and Technology, focussing on applied scientific research. This paper aims to inform the success of the participation of CTN in the cooperative activities between Angola and the IAEA through the Technical Cooperation Programme. The purpose of the cooperation is to help the country to build, strengthen and maintain human and institutional capacities for the safe, peaceful and secure use of nuclear technology in support of national development, and activity that the CTN has pursued since 2006.

To achieve the proposed goals, three main phases have been set up in the projects implementation: outward specialists visits (from other latitudes), human resources empowerment and training (member mobility in the projects) and laboratory equipment acquisition (creation of laboratory-based infrastructure). With this program, the CTN was able to set up laboratories for non-destructive testing and radioisotope tracing. Around 20 project members were trained in renowned centres in different regions. Through these laboratories, the CTN has accrued the capacity of radioisotope tracers application in oil industrial as well as the use of non-destructive techniques to improve quality of industrial goods and service. In terms of contributions to socio-economic development in the country, in the process of empowerment and training of science, technologies and innovation system's actors in Angola, the CTN through this laboratories trained 21 trainees in non-destructive test, level I, in penetrant testing, magnetic particle testing, ultrasonic testing and radiography testing, 9 are working now in local companies, and another group of 5 trainees are training on radiotracer techniques in CTN.

Future prospects are to empower human recourses in various techniques to use the maximum potential of machines existing in the Centre to solve practical problems and address basic human needs. The cooperation concept always ends up in a win-win. From experience, the CTN thinks that feedback is not significant enough in term of sponsorship assessment but this does mean it will never be noticeable. It cannot appear at this initial time, it will surely.

Progress, Problems and Prospects of Radioisotope Technology in Nigeria

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Nigeria as a member state of the IAEA has benefited immensely in the field of radioisotope technology through the agency's support in manpower development, deployment of relevant equipment and other relevant support towards the Centre's desire to setup an Industrial Isotope Technology (IIT) laboratory at the CERT, Ahmadu Bello University (ABU), Zaria. The Center has organized many training courses in this regard, among these is the National Seminar organized in collaboration with the Kaduna Refinery and Petrochemical Company Limited (KRPC) hosted by CERT and supported by the IAEA. This national conference was held on 12th to 16th August, 2013 which saw a large number of participant mainly from the oil and gas industries in attendance. Nigeria with its position as one of the top nine oil exporters worldwide, with five functional refineries, eleven licences issued for construction of new refineries, a host of other process related industries and thousands of kilometers of pipelines transporting crude and refined petroleum products that crosscut the country, is believe to be an ideal terrain for radioisotope technology application. This paper highlights the progress, evaluates the problems and prospects of this technology in Nigeria.

B16

Industrial Application of Radioisotopes in Zimbabwean Industries: A Report on RTD Experiments in Cement Industry, Radon Monitoring in Coal and Fly Ash of a Small Thermal Power Plant and NDT Activities

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Major activities carried out Zimbabwe with support from the IAEA towards industrial applications of radioisotopes are presented. Radiotracer ^{198}Au was used to determine the residence time distribution (RTD) of limestone and clay in the production of clinker at PPC Colleen Bawn factory near Gwanda with the objective of determining hold-up and grinding efficiencies of a ball mill operating in a closed circuit regime. Three experiments were conducted using ^{198}Au and highly sensitive NaI(Tl) detectors for radiation measurement. In two experiments, 50 mCi of ^{198}Au was used to tag limestone and clay which were fed into the ball mill at 85 tonnes/h and 90 tonnes/h, respectively. In the other experiment 100 mCi of the tracer was used to tag limestone with a feedrate of 90 tonnes/h. The estimated efficiency of the separator of nearly 90% showed that the performance of the separator is satisfactory. It was concluded that the grinding process of raw materials inside the mill was not optimal.

In order to determine the amount of γ-radiation released to the environment by coal-fired thermal power generation and environmental γ-radiation levels we have monitored radon concentrations in a coal powered thermal power station (ZPC Bulawayo). Results obtained suggest that there were no high radon concentrations in the coal nor in the fly ash produced by the power plant. Four IAEA Fellows in NDT are currently doing their fieldwork before certification. NDT field work activities using radiography, ultrasound and liquid penetrate techniques were carried out and details of the field work carried out are presented.

Computed Tomography for Characterizing Industrial Materials

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Computed tomography (CT) is a noninvasive technique that can provide two-dimensional cross-section image and information on the internal structure of an object including abnormalities and their dimensions using spatial measurements across it. CT has been long used and is well established in the medical and NDT applications but because of emerging technologies and through research and development, it is now carried out for industrial applications. CT is a powerful tool of quality control and has shown a wide range of industrial applications in mechanical, plastic and chemical and ceramics industry. The benefits that the technology offers to industries make γ-ray CT an interest for research and development endeavours.

This paper reports the capability of a first generation γ-ray CT system is characterizing different material in terms of the density distribution along the cross section of each sample. Measurements were taken from samples of wood, industrial steel piper and polyethylene products using a single-source, single-detector system and images were recreated using an image reconstruction software. Reconstructed images show relatively good representations of the actual samples that provide a qualitative density distribution along the object cross section. With further refinement and optimization of measurement parameters and review of reconstruction algorithms, the technique could be a useful tool for inspection and troubleshooting in a variety of industries.

Measurements of Radiotracer Residence Time Distribution Using a Flow Rig in Kenya

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The Kenya Bureau of Standards (KEBS) in partnership with IAEA has set up a radiotracer data analysis measurements facility using a flow rig under Project RAF/0/004:"Cleaner and Safer Management of Industrial". The purpose of the facility is to promote the radiotracer residence time distribution (RTD) method extensively to industries, in order to optimize processes, solve industrial problems, improve product quality, save energy and reduce pollution. The radiotracer methodology includes the accurate measurement of the RTD and its utilization for troubleshooting and diagnosis. The process involve injecting a compatible radiotracer into an appropriate inlet upstream of the flow rig vessel and monitoring its passage through, therefore allowing fluid RTD to be measured. Sensitive radiation detectors, are placed at strategic elevations and locations on the flow rig. The scintillation detectors are used because they are relatively small and easy to mount at each position. Each scintillation detector is connected by a cable to a central data logging device that records radiotracer concentration versus time information. The data acquisition system ensures collection, treatment and visualization of the data. When the radiotracer passes each detector a response is registered and recorded. Before the investigation, each detector is assessed and its response normalized so that each detector responds identically to a given unit of radiotracer. The flow rig consists of a tank with four stirrers, a pump flowing the water inside the rig, two flow meters for measuring flow rates in two different branches, several two and three way valves for regulating the flow direction and regime, two injection points, pipes and ion exchange resin column for trapping the radiotracer after a test. The radiotracer used is $^{99m}\mathrm{Tc}$ with relatively low activity for each test. From the results, different flow patterns are then simulated using the flow rig. The investigations performed are dead volume measurement, by-pass measurement, determination RTD measurements that include parallel flow measurements, re-circulation experiment, pump mixing and flow rate. The important features and benefits of radiotracers above conventional methods is that measurements can be made while a plant is on-line, with no disruption to operating processes.

PA1: Posters PA1: Irradiation Facilities and their Applications

New Trends in Radiation Dosimeters

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A radiation dosimeter is a device that measures exposure to ionizing radiation. It has two main uses: for human radiation protection and for dose measurement in both medical and industrial processes. The personal ionizing-radiation dosimeter is of fundamental importance in the disciplines of radiation dosimetry and radiation health physics and is primarily used to estimate the radiation dose deposited in an individual wearing the device. Workers exposed to radiation, such as radiographers, nuclear power plant workers, doctors using radiotherapy, those in laboratories using radionuclides, and HAZMAT teams (personnel specially trained to handle dangerous goods, which include materials that are radioactive, flammable, explosive, corrosive, oxidizing, asphyxiating, biohazardous, toxic, pathogenic, or allergenic) are required to wear dosimeters so a record of occupational exposure can be made. Such devices are known as "legal dosimeters" if they have been approved for use in recording personnel dose for regulatory purposes. Dosimeters can be worn to obtain a whole body dose and there are also specialist types that can be worn on the fingers or clipped to headgear, to measure the localized body irradiation for specific activities. The aim of this study is to identify and highlight the new technology in the types of radiation dosimeters.

The study comprises a personal selection of recent reports from radiology journals and the results of Medline searches which highlight new trendS in radiation dosimeters. Radiation dosimeters and dosimetry systems come in many shapes and forms, and rely on numerous physical effects for storage and readout of the dosimetric signal. The four most commonly used radiation dosimeters are: ionization chambers; radiographic films; thermoluminescent dosimeter systems (TLDs); silicon diode dosimetry systems (Diodes). However, there are a variety of electronic personal dosimeters, extremity dosimeters, and comprehensive dosimetry management systems to monitor the exposure to ionizing radiation at any work environment. It can get an effective dose monitoring when and where we need it. Electronic dosimeters protect the wearer from the harmful effects of radiation by tracking changes in exposure and keeping an ongoing record of the user's dose over time. Combined with access control systems, it is possible to limit total exposure to radiation and control access to radiological areas. Dosimetry readers ensure accurate radiation exposure monitoring. Manual and automated systems for whole body, extremity, neutron, and environmental monitoring are easy to operate, service, and maintain. Extremity dosimeter is a disc dosimeter designed for nuclear power or nuclear medicine personnel that have a high risk of exposure to ionizing radiation, particularly on their hands, due to their work in close proximity to radiation materials and radiation producing equipment.

Setting up of New Radiation Facilities in Alexandria, Egypt

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The γ-Irradiation Facility (400 kCi) from Isotope Hungry is the only unit in Alexandria capable of sterilizing medical and agricultural products as well as industrial irradiation research and applications. The activity of this ^{60}Co facility could be increased to (2 MCi) in order to meet the market demand for irradiated food and healthcare products. Such an upgrade seems to be sufficient for the wide demand of medical companies especially those who are going to increase their export capacity of irradiated medical products.

In Situ and Non-Destructive Detection of Oleoresin in Standing Agarwood Trees Using Portable γ-Ray Tomography Imaging System

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Agarwood is known for its fragrant resinous wood. It is a rare and precious oleoresin on the planet, prized for its rich and wonderful fragrance and healing properties. Because of its high economic value, agarwood has been subject to intensive exploitation in South East Asia's natural forest for hundreds of years. Consequently, agarwood-producing tree species have become extremely rare. The extinction threat to agarwoods is becoming more worrisome because their harvest is often done by trial and error; specifically, by cutting standing trees without any reliable means to detect and confirm the presence of oleoresin. This practice is not only inefficient and technically and economically ineffective, but it also contradicts sustainable forest management principles.

To decrease random harvesting, technological innovation is needed to detect the presence of oleoresin within the trees. Technology based on the measurement of γ-ray attenuation to assess internal trunk or wood characteristics has been developed. The attenuation of γ-rays is highly correlated to the atomic number and density of materials. The principle of this technology is based on measuring and recording the transmitted intensity of γ-rays that pass through the tree trunk. The transmitted γ-ray intensities will differ depending on the density of the wood. Since the presence of oleoresin in agarwood changes the density of trunk wood, this technology can theoretically detect agarwood within a tree.

A portable clamp-on γ-ray tomography system, called GammaSpider, was designed and manufactured by scientists and technologists at the Centre for Computed Tomography and Industrial Imaging in the Malaysian Nuclear Agency. This paper presents the results of tomographic imaging of several standing agarwood trees of different ages. In addition, the effectiveness of inoculation process to produce oleoresin was also evaluated. Computed tomography (CT) images of the samples were obtained at 1.25 mm resolution. Besides a clear distinction between oleoresin, void and wood fibre, some bright white areas occurred in the reconstruction images caused by a denser medium component in the wood, apparently oleoresin deposits that attenuated the radiation. This technique demonstrates a potential application of γ-ray computed tomography in the detection of oleoresin in standing agarwood trees. The development of GammaSpider was carried out in an attempt to provide an alternative non-destructive means to the conventional cutting methods for the detection of oleoresin in standing agarwood trees. The system has produced quality images with excellent contrast, which shows clear and correct representation oleoresin, void and wood fibre. From the CT images, the positions and extent of oleoresin could be precisely quantified. The scanner has been successfully used for non-invasive detection of oleoresin in agarwood trees in a number of field tests in plantations in Malaysia. The successful utilization of this innovative has been recognized both nationally and internationally, as GammaSpider has won a number of awards. The method offers great advantages for in situ inspection of agarwood tress as compared to the conventional methods. Work is continuing on improvements to meet the demands of faster scanning.

Facilitating Sustainable Education in Nuclear Science and Technology

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Many e-learning tools are currently available for using in education, however, the environment for nuclear education is changing. Teaching methods and techniques have evolved as have enrollment trends in science and engineering studies. E-learning is regarded as the most modern and cost effective means to supplement traditional face-to-face education, and the way forward to provide more opportunities to access valuable information and knowledge regardless of time and place.

In this paper, we review the new learning methodology, potential challenges of e-learning, the author e-learning tools and the different e-learning tools such as educational platforms and web-based meetings. We also comment on the most important aims of each tool and define the advantages and the disadvantages.

An educational platform is effective in e-learning development but does not provide social networks. However, the web-based meeting is an innovative collaboration solution providing an exceptional experience with the simplicity of a web browser, easily and naturally.

The overall objective is to contribute to improving the sustainability and quality of nuclear education process and recommended best practices to improve efficiency and effectiveness

Pilot-Scale Study of the Radiation-Induced Silica Removal from Underground Brackish Water in Saudi Arabia

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Brackish underground water desalination is the second main water supply, after seawater desalination, used in the Kingdom of Saudi Arabia. Most of the inland cities and villages rely entirely on this supply mode for their domestic industrial and agricultural purposes. High silica concentrations are found in these waters and can cause an excessive and recalcitrant deposit on the membrane, fouling the reverse osmosis (RO) units. This membrane fouling is a worldwide problematic issue in the cost-effective operations in water desalination plants.

In this work, we investigated the effectiveness of γ-radiation induced removal of silica in water sample from the Salbukh water treatment plant (near Riyadh, Saudi Arabia). A ^{60}Co source was used to γ-irradiate the acidic pH solution containing silica mixed with metal iron powder and saturated with pure oxygen gas before irradiation. The radiolytically produced hydroxyl radicals $OH^{\bullet}$ oxidize the iron metal into ferric ions which co-precipitate with the silica resulting in the removal of the latter.

The influence of several reaction parameters, i.e, iron powder dosage, radiation dose, initial pH and equilibrium pH effects were investigated. The removal increased with the irradiation dose and reached a plateau at 350–400 Gy. For a percentage removal as high as 75% obtained in this work, the optimal conditions of the main reaction parameters studied here, were as follows:

- optimum initial pH is 2–3;
- the removal increased with increasing pH up to the pK_a of the silicic acid.
- Fe0 dosage: 8 g/l.

This preliminary study showed that this environmentally friendly γ-radiation process is effective in silica removal from underground water. This process could be implemented in arid regions in Saudi Arabia, where population has a limited access to fresh water.

PA1

Radiation Activities at ENEA Calliope γ-Facility

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Since the eighties, the Calliope γ-irradiation facility (Casaccia R.C., Rome, Italy) was deeply involved in many research activities, in the framework of international projects and collaborations with industries and research institutions, focussed on the investigation of γ-irradiation effects on chemical and physical properties of different materials. The Calliope Facility, located in the ENEA-Casaccia Research Centre, is a pool-type irradiator equipped with a ^{60}Co cylindrical γ source array (mean energy of 1.25 MeV) in a high volume ($7.0 \times 6.0 \times 3.9$ m^3) shielded cell. The plant is equipped with dosimetric services and a monitoring system for logging the irradiation time, allowing accurate calculation of the absorbed dose in materials. Available dosimetric systems include Fricke, Red-Perspex, alanine-ESR and TLD. Different irradiation dose rates, from zero to a maximum of some kGy around the rack longitudinal axis, are available by placing the sample in specific position within the irradiation cell. The irradiation tests can be performed in air or inert atmosphere, or under vacuum.

Several research and qualification activities, in compliance with international standard specifications, were carried out at the Calliope facility. Irradiation and dosimetric certifications are issued by the Calliope facility after each irradiation test. Qualification tests are mainly performed on electronic components and devices for application in hostile environments (nuclear plants and aerospace) and on concrete matrices for nuclear waste disposal and storage. The Calliope facility is indicated by the Italian Space Agency ASI as ASI Supported Irradiation Facility (ASIF), recommended by the European Space Agency ESA.

Synthetic and natural polymeric materials used in many fields (e.g., nuclear and space application, medical devices, food packaging, cultural heritage) are studied in term of γ-induced processes (cross-linking and degradation). The behaviour is evaluated in different atmospheric conditions (air, vacuum or inert gases), paying particular attention on the irreversible modification occurring during or after the end of γ irradiation.

At the Calliope laboratory, research for cultural heritage material conservation and preservation (books, images) centre on biological deteriogen eradication by γ radiation and the assessment of recovery procedures. Other biological studies relate to agriculture and the environmental, such as biological pest control via γ irradiation (sterile insect technique: SIT) and agricultural product treatment.

Activities concerning polymers and biological applications on cultural heritage are carried out in the framework of IAEA Coordinated Research Project F23032 (Research Agreement No.18922/RO, 2015–2019). The Calliope laboratory has several instruments for the evaluation of scintillating material performance by optical (UV-VIS and FTIR spectrophotometer, luminescence measurements), spectroscopic (ESR spectrometer) and light yield measurements in term of number of photoelectrons emitted per unit of absorbed energy. Great expertise has been achieved on radiation detectors, optical components and scintillators (optical fibres, crystals and glasses) applied in High Energy Physics experiments, such as CMS ECAL experiment at LHC CERN and Belle II experiment at SuperKEKB (Japan).

Detoxification of High Toxicity Substances by Radiation Transformation Technique

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Developing a new pharmaceutical substance takes a large amount of time, money and effort over the full process. Usually, translation of a promising molecule into an approved drug takes more than 10 years. Therefore, there is pressure advance techniques to reduce the time and cost. We have attempted to develop radiation fusion technology for transforming toxic substances such as abandoned drugs and naturally occurring polyphenols, known to be toxic, in order to reduce their toxicities. About 200 substances were exposed to γ-irradiation, resulting in 18 compounds generated with low toxicity compared to their mother compounds. For instance, rotenone, isolated from roots of derris plant, was reported as an anticancer agent. However, recent studies have demonstrated that rotenone has the potential to induce several adverse effects such as a neurodegenerative disease. Radiolytic transformation of the rotenone with γ-irradiation created new products, named rotenoisin A and rotenoisin B, monitored by HPLC and purified by column chromatography. It was found that rotenoisin A and B were potent anticancer candidates (similar to the parent rotenone) for breast and hepatic cancer cells, respectively, without toxic effect to normal cells even at high concentrations when compared to rotenone. These results suggest that the radiolytic transformation of high toxicity compounds by γ-irradiation may be a good strategy for modifying the structure and decreasing the toxicity of the parent compound. More systematic structural modifications together with γ-irradiation will be performed in the future to further clarify these interesting findings in order to develop even more promising anticancer candidates.

Evaluation of Radiation Shield Integrity of DD Neutron Generator Facilities by Monte Carlo and Experimental Methods

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A new deuterium-deuterium (DD) neutron generator has been installed for a wide range of applications. The generator is an excellent fast, epithermal and thermal neutron source for laboratories and industrial applications that require neutrons but with safe operation, small footprint, low cost and small regulatory burden. The generator has three major components: a radio frequency induction ion source, a secondary electron shroud, and a diode accelerator structure and target. Monoenergetic neutrons (2.5 MeV) are produced with a maximum yield of 10^{10} n/s using 25–50 mA of deuterium ion beam current and 125 kV acceleration voltage.

Detailed knowledge of the radiation dose rates around the neutron generator are essential for ensuring radiological protection of the personnel involved with the operation. This work describes the Monte Carlo and experimental studies carried out in the Neutron Generator facility of the National Center of Nuclear Sciences and Technologies (CNSTN). Verification and validation of the shielding adequacy was carried out by measuring the neutron and γ-dose-rates at various locations inside and outside the neutron generator hall during the operational conditions and comparing the results with theoretical simulations. A successful operation of this generator will provide a convenient neutron source for basic and applied research at CNSTN.

Fungal Decontamination of Historical Oil Painting by Using γ-Ray

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Preserving historic heritage is the duty of a nation that cares about its history. Canvas based paintings are mainly subject to fungal infestation under improper conservation conditions. The aim of this study was the evaluation of optimal γ-ray dose for fungal decontamination of a XIXth century historical oil painting (3.03×1.60 m^2) stored in the Melal museum of Sa'dabad Palace. Sampling was done from 31 points of the discoloured points via wet sterile swab, then surface cultured on SDA medium. Fungi growth was determined after 8–12 days incubation at 29°C. Classification was based on overall morphological properties. The colours used were identified with infrared spectroscopy (mid and far regions). Canvas type was identified by flame testing the fibre: type of burning, burning behaviour when away from the flame, burning smell and ash type.

Fungi resistance to irradiation was investigated on strips made of similar canvas painted with the same colours. Light-thermal ageing of strips were done in a QUV/Spray device powered with fluorescent lamp with the emission maximum of 0.71 W/m^2 for UVB 313 nm, at 60°C for 100 h, 4 h in 100% relative humidity at 50°C. Aged strips were inoculated with spore suspensions and exposed to 0.2–2 kGy of γ-rays from ^{60}Co in GC220, dose rate of 2.08 Gy/s calibrated with Fricke dosimeters. Surviving spores were cultured and counted after 5 days. D10 was determined by graphing survival populations after a series of radiation doses. Irradiated strips with 5–25 kGy were subjected to sterility test. The minimum dose in which fungal growth is detected after 14 days of incubation in maximum two tests out of 20 was the sterilization dose.

Sampling indicated that Penicillium and Aspergillus were common fungi of the front and the back and between canvas and the frame. Infrared spectroscopy revealed that burnt umber brown and vagone green earth were common colours used in the painting. Checking the fibre showed that linen was the board type. The mean D10 value of Penicillium crysogenum ATCC12690 and Aspergillus niger CBS 104.57 on aged coloured linen strips was 0.9–1 kGy. There were differences between D10 values on culture medium (0.41 and 0.34 kGy for Penicillium and Aspergillus respectively) and canvas stips (0.9–1 and 0.9 kGy for Penicillium and Aspergillus, respectively) and no significant differences on aged and unaged strips. Aged strips showed better capacity for spore recovery (1.7%) compared to unaged (0.15%). This may be due to nutrition production during the ageing process. Sterility test indicated that a minimal dose of 5 kGy was sufficient for sterilization of strips with 2.7×10^6 colony forming units (cfu) of each fungus. The colour measurement of aged and irradiated samples will be studied later. In conclusion and according to fungal contamination of the painting, the dose of 5 kGy is suitable for decontamination.

PA1

The Study of γ-Ray Efficiency in Converting Tehran Municipal Sewage Sludge into a Sanitary Fertilizer

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The reuse of urban sewage water and sludge in agriculture leads to the transfer of some pollutants into the food chain which is hazardous to public health. Sewage sludge samples are from Shahid-Mahallati wastewater treatment plant in North-East of Tehran-Iran. The heavy metals (As, Mo and Zn analyzed by graphite furnace atomic absorption spectrometry (GF-AAS), Hg by a hybrid system, and flame atomic absorption used for Pb, Cd, Cu, Cr and Ni), pathogens (fecal coliforms, Salmonella, Ascaris ova) and shelf life of irradiated sludge samples according to heterotrophic mesophilic bacteria and their resistance to radiation were investigated in this paper before and after 10, 25 and 50 kGy γ-irradiation from ^{60}Co over a period of three months. However, sewage sludge is a rich source of organic matter and nutrients but agricultural utilization of this material is limited by excessive quantities of heavy metals. In this paper the results obtained showed these elements were below the maximum permitted levels of EPA standard and comply with Environmental Pollution Agency standards.

The pathogen counts reduced to the permitted level after exposure to 10 kGy. This dose had the efficiency of reducing 6 log numbers of heterotrophic mesophilic bacteria (as irradiation indicator) but exposure to 50 kGy inhibited the regrowth of the bacteria for 80 days of study. Bacterial resistance (D10) was between 0.02–3.09 kGy. About 0.074% of studied bacteria had D10 of 2 kGy or more. The obtained result showed that 10 kGy of γ-rays destroyed Salmonella. The number of fecal coliforms (dominant bacteria in human faeces) in this study were in acceptable limit before irradiation and γ-rays cause a significant reduction in their numbers (ttest, $\rho = 0.05$). Among the helminths of sludge, Ascaris has the most resistant eggs to physical and chemical treatment, in this research the number of fertile Ascaris eggs in the sewage sludge (385/4 g), were more than EPA requirements before irradiation but 10 kGy γ-rays caused a reduction to an acceptable limit (< 1 egg/4 g) so that there were no fertile eggs in irradiated studied samples. The odor of samples reduced by increasing dose to the point that 50 kGy irradiated samples had no odor.

According to the measurements, irradiation by 10 kGy converted the studied sludge from class B (studied municipal sewage sludge) to class A biosolids which means that it can be applied to agricultural lands, public contact sites and home gardens. If the sludge is not used immediately after the treatment, the storage time should be regarded. Vector attraction reduction processes must be conducted before use. The capability of the mentioned γ-ray dose in converting municipal sewage sludge into a sanitary fertilizer depends on the microbial contamination level, especially on the numbers of viable Ascaris eggs.

The Application of Radiochemical and Isotopic Studies to Inform on the Impact of Acidic Effluent Discharges from the Caldas Uranium Mine into Neighboring Surface Waters

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Located in the Poços de Caldas Plateau, in the southeast of Brazil, the Caldas Uranium Mine is being decommissioned. The uranium ore consists of uranium oxides, sulfide and zirconium minerals, fluorite, rare earth phases and molybdenum-bearing minerals. The main environmental problem in the site is the generation of acid mine drainage (AMD) due to the presence of sulfide minerals in the ore and in the host rocks. Acidic effluents flow from a tailings dam, from the open pit and from waste rock piles. The study evaluates the influence of these effluents on the surrounding surface water courses. Twelve sampling stations were established in order to carry out the investigation. Two of them were located inside two effluent retention ponds: the tailings pond that collects the effluents percolating from the major waste rock pile at the site, and the settling pond immediately downstream from the tailings dam. The remaining stations were located downstream and upstream of the mine. Sampling was performed in the rainy and dry seasons in 2010 and 2011. Electrical conductivity and pH were measured in situ; uranium and sulfate concentrations were determined by ICP-MS and by liquid chromatography, respectively. Radiochemical procedures were used to measure the ^{226}Ra, ^{228}Ra and ^{210}Pb activity concentrations. The lighter ^{18}O and ^{2}H isotopes were determined by isotope ratio mass spectrometry. ^{238}U was estimated to be 12.3 Bq/mg of uranium mass. Samples from the ponds exhibited high median values of SO_4^{2-} (1301 mg/ℓ), electric conductivity (1788 μS/cm), ^{238}U ($\approx 10^9$ Bq/ℓ), ^{226}Ra (0.49 Bq/ℓ), ^{228}Ra (0.47 Bq/ℓ), ^{210}Pb (0.70 Bq/ℓ), and low pH (3.6). The effluents from the tailings dam pond presented a more enriched isotopic composition (δ^{18}O$= -2.6$‰ and δ^2H$= -18$‰) than the other sampling stations, while the opposite was noticed in the pond collecting the waste pile effluent (δ^{18}O$= -7.1$‰ and δ^2H$= -44$‰). The results also indicated that acidic effluents from the ponds were entering the surrounding downstream watercourses, causing a significant increase in the acidity, electric conductivity, sulfate concentration, and ^{238}U, ^{226}Ra and ^{228}Ra activity concentrations. The variation of δ^{18}O and δ^2H values along the watercourses suggests that: waste pile effluent discharges caused a depletion of ^{2}H and ^{18}O in the waters downstream; tailings dam effluents have enriched the stable isotope composition of the waters downstream. These results can be relevant to the stakeholders and to the authorities responsible for the site remediation. The authors will continue to carry out studies on the site, emphasizing the identification of acidic effluent underground leakage points. In future work, tracers, radiotracers and isotopes will be used, contributing to the dissemination of these techniques as important tools for solving environmental problems, with focus on those arising from the mining industry.

Application of Electron Beam for Preservation Biodeteriorated Cultural Heritage Paper-Based Objects

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Paper provides the ideal nutrient base for mold fungi, thus, biodeterioration is the most common source of degradation of paper-based materials in museums and libraries. Application of electron beam irradiation in the field of cultural heritage preservation is a very promising alternative to the commonly used ethylene oxide treatment, which is toxic to humans and the environment. Moreover, electron beam irradiation can be effectively applied for decontamination of biodeteriorated archives as well as for preventive conservation of large volumes of books in short time. However, to gain public acceptance for radiation methods in large-scale applications, many analytical techniques must be used in order to determine possible changes of mechanical, chemical and physical properties of treated objects. Complex study of material properties before and after radiation decontamination should ensure degradation monitoring and process validation.

In this work, the influence of electron beam irradiation for microbiological decontamination of paper-based objects was evaluated. Connections between electron beam irradiation doses and a change of some chemical, optical and thermal properties of different kinds of paper were established. Electron beam radiation inactivation patterns of different microorganisms present in different paper materials were studied as well. The samples were exposed to electron beam irradiation using a 10 MeV–10 kW linear electron accelerator "Elektronika" and dosimetric analysis necessary for the proper realization of the process was performed with application of Riso B3 thin-film dosimeters as well as graphite calorimeters.

A wide range of doses, from 0.4 kGy up to 25 kGy, were studied in order to determine safe and simultaneously effective dose for different papers decontamination via electron beam. Changes in all sample properties were determined according to the relevant ISO and TAPPI standards. Microbiological investigation confirmed that a dose of 5 kGy completely eliminate all studied kinds of bacteria (gram-positive and gram-negative) as well as fungi in Whatman CHR 1 paper, newsprint paper and office paper. Optical parameters for all studied papers are stable for materials irradiated with doses not higher than 5 kGy, however, colour coordinates are still changing with time after irradiation and the effect is being evaluated. Investigation of optical parameters of the paper after irradiation confirmed that coordinate $b*$ is the optical parameter the most sensitive to electron beam irradiation, what means that paper samples irradiated with high doses became more yellowish. The control samples and the irradiated samples show similar thermal stability in air on heating. Taking into account even high levels of microbiological contamination (in the order of 10^5 cfu/cm^2) of paper-based objects electron beam irradiation with doses of 5 kGy ensures elimination of harmful microorganisms and simultaneously prevents paper materials degradation.

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Using of Radiation Sterilization

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There are two general types of radiation used for sterilization, ionizing radiation and non-ionizing radiation. Ionizing radiation is the use of short wavelength, high-intensity radiation to destroy microorganisms. This radiation can come in the form of γ or X-rays that react with DNA resulting in a damaged cell. Non-ionizing radiation uses longer wavelength and lower energy. As a result, non-ionizing radiation loses the ability to penetrate substances, and can only be used for surfaces sterilizing. For enforcement of the Law on State Supervision of Public Health and the Law on the safe deployment of nuclear and radiological activities in Moldova, we developed the scientific technology on ionizing radiation of products of different origin on the base of International Standard ISO 11137 with adaptation at the country needs and specific. This scientific elaboration specifies requirements for validation, process control and routine monitoring in the radiation sterilization and will be implemented under the IAEA coordination.

It is stipulated that the following sources of ionizing radiation can be used: γ radiation from radionuclides ^{60}Co or ^{137}Cs; X-rays generated by machines operated from a nominal energy (maximum photons energy) less than or equal to 5 MeV; electrons produced by machines operated from a nominal energy (maximum energy of electrons) less than or equal to 10 MeV. High energy rays damage the DNA of living organisms and make them unable to grow or reproduce. The elaboration stipulated that the mean total dose of absorbed radiation (kGy) (maximum) for the treatment of dried herbs, spices and vegetable products consist up to 10 kGy. EB and γ sterilization are planned to be used for medical devices. From experience of other countries is known that both methods are equally effective, but EB is more powerful and hence the exposure time of the device is lower.

During irradiation, certain parameters of the irradiating unit (according to legal metrology standards) must be controlled and continuously recorded. For installations using radionuclides, the parameters include product transmission speed or time spent in the radiation zone and indications confirming correct position of source. For accelerator facilities, the parameters include product transport speed and energy level, electron current and the width of barrier installation. Before starting the irradiation for a certain category of food minimum/maximum dose level can be determined by performing dose measurements throughout the product volume. These validation measurements must be carried out in sufficient numbers (e.g., 3–5 times) to account for variations in density or geometry. The dose reference position will be quantitatively correlated with minimum/maximum dose. The reference position is to be situated in a convenient place, where dose variations are reduced. If fluid unpackaged products are irradiated, minimum and maximum dose cannot be determined. In this case, it is preferable to conduct surveys to determine the dose extremes.

Relevant Safety Aspects for Radioactive Tracers in Industrial Process

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The use of radiotracers plays an important role to provide methods to optimize industrial process and improve product quality. An increase in the use of radiotracer investigations has been observed in Brazil, however, as there is no specific standard for the licencing of these facilities, generic radiation protection regulations have been used, but these are not comprehensive nor technically suitable for this purpose. Regulatory inspections carried out in radiotracer facilities have reported failures to follow best practices for radiological safety, mainly in radioactive waste management and in the control of workplaces during radiotracer injections. In this work, an assessment of radiation protection aspects of radioactive tracers, not covered by generic regulations, is presented, with the aim of contributing to the future development of specific safety regulations in Brazil. The study is based on an assessment of the licencing process of facilities using radioactive tracers in Brazil, as well as the experience of regulatory inspections carried out at facilities using radiotracers and a review of international standards, in order to point out relevant radiation safety aspects in the establishment of regulatory standards for working practices, procedures and protective measures before, during and after injections of radioactive tracers.

Among the relevant key aspects and actions for radiological protection in radiotracer investigations, we can point out: 1) Detailed radiological protection procedures, including storage,should be elaborated for operations before, during and after injection, taking into account: i) The different radiotracer injection strategies; ii) The available monitoring and decontamination equipment; iii) The complete injection apparatus should be checked for proper functioning including pressure tests before tracer injection. iv) A water injection through the injection apparatus and connected equipment should be performed for an extended period to clean out any contamination traces before disconnecting injection apparatus. 2) The facility should have a Radiation Safety Officer (RSO) certified by the Regulatory Authority, specifically for radiotracer applications. The RSO should not be subordinate to operational groups. 3) Personal alarm monitors should be mandatory for each radiotracer worker; for non-uniform exposures, it may be necessary to wear additional, e.g., hand, dosimeters. 4) Survey tests should be performed in order to ensure successful decontamination in all areas that have been contaminated by radioactive material. Equipments that cannot be decontaminated at the jobsite should be properly packaged and sent to the field station for further cleaning or storage. Additionally, calculations should also be made on the impacts of any possible discharge into the environment, identifying the exposure pathways in order to ensure agreement with authorized limits of national regulations.

The lack of a specific regulatory standard for radioactive tracer operation licencing in Brazil weakens the nuclear regulatory body in its aim of regulating and licencing the activity. In this study recommendations are presented concerning relevant aspects of radiation protection for radiotracer applications, discussing specific features that should be part of the future regulations, with the purpose of ensuring safety during radiotracer investigations.

Radiation Induced Environmental Remediation of Toxic Cr(VI) Heavy Metal in Aerated Neutral Solution under Simulated Industrial Effluent

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Chromium(VI) heavy metal is a major water contaminant in most industrial effluents, due to its carcinogenicity and its impact on ecosystems, while Chromium(III) is non-toxic and is an important element for human metabolism. Cr(VI) can be reduced to Cr(III) by the superoxide $O_2^-\bullet$ free radical radiolytically produced in aerated solution at neutral pH in the presence of formate.

The degradation of Cr(VI) was investigated by steady-state γ-irradiation using a ^{60}Co source and by pulse radiolysis using a van de Graaff accelerator in aerated solution at neutral pH, which is close to natural conditions in most wastewaters.

The degradation of Cr(VI) increased linearly with the absorbed dose and was significantly enhanced by the added formate but not by the radiolytically produced hydrogen peroxide at this pH. The rate constant for this reduction was found to be 1.28×10^8 M^{-1}s^{-1} and the absorption spectrum of Cr(V) transient species was obtained. A partial recovery of Cr(VI) is observed over a period of ~ 5 ms following a second order kinetics with a rate constant 8.0×10^6 M^{-1}s^{-1}.

These outcomes suggest that γ-irradiation of Cr(VI)-contaminated wastewaters and industrial effluents in presence of formate can be simple, effective and economical means for the remediation of this major contaminant.

Intergrating Management Systems to Good Irradiation Practices within a Framework of Social Responsibility

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For more than 50 years, commercial radiation processing has been used for healthcare products, food and other applications with a main goal in common, which is adding value to products, achievable only if predetermined specifications are met. Technology, process control, standards, quality management systems and personnel training, are some of the many branches which constitute good irradiation practices which should lead to safe and quality products. The introduction of Management Systems for Facilities and Activities (IAEA's GS-R-3), which through the integration of safety, health, environmental, security, quality and economic elements in a single structure, establishes requirements to be met in order to ensure the protection of people and the environment, enables irradiation facilities to work with unified objectives. The further incorporation of social responsibility principles into the overall management activities helps to increase credibility to society, and motivate and promote commitment of workers, an essential factor to develop safety and a good irradiation practice culture, by understanding actions generate impact on products, environment, organization, employees, community and other stakeholders.

The implementation of social responsibility at CNEA's irradiation facility (PISI) was originally set out with three main objectives: its integration to safety, health, environment, quality and good irradiation practices management systems; relationship consolidation with community and stakeholders; and as an instrument to deploy potentials in different areas by increasing its human capital. This process was divided into three phases. The research phase consisted in selection of the ISO 26000 standard; the identification of overall applicable regulatory framework, including international treaties and further evaluation of our degree of compliance; and formulation of an implementation plan. The training and awareness activities consisted of a thorough study of principles and core subjects defined in the standard. The planning of the application phase was based on the need to prioritize the increase of human capital as it is the main actor in PISI's activities, which included training the senior management team to strengthen governance as well as activities to improve communications, relationships, teamwork, staff motivation and exercise of individual and group self-evaluation, and promoting participation in continuous improvement of processes. Other activities included worker's biopsychosocial health care, the identification of stakeholders and expectations, and so on.

Relevant results were the elaboration of a shared vision statement and values between members of PISI; strengthening of governance performance; increase of commitment; development of self-evaluation and communication tools; stakeholder's map.

Although societial impact is still not measurable, the implementation of social responsibility in a public domain irradiation facility is possible and replicable. Principles and core subjects are closely related and directly or indirectly contemplated in integrated safety, health, environment management, quality and good irradiation practices, and contribute to increasing cultures and consolidation of relationship with stakeholders.

ESR Dosimetric Properties of Sodium Glutamate

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Monosodium glutamate powder and rods (3×10 mm) were studied to be a radiation sensitive material for ESR dosimetry. Samples were irradiated with ^{60}Co γ-rays. The developed signal after irradiation increases with the increase of the monosodium glutamate in the rods. The prepared powder can be used in the dose range from 10–90 kGy, whereas the rods are useful in the range from 10–120 kGy. The obtained number of free radicals per 100 ev (G value) was found to be 0.201 ± 0.01. The g factor is 2.0113 ± 0.0001. The rods have the advantage of negligible humidity effects during irradiation. The pre- and postirradiation stability was found to be satisfactory.

PA1

Ionizing Radiation as a New Technique for Treating Sewage Wastewater and Sludge in Arid Regions

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The production of sewage water and sludge is continuously increasing as a result of population growth and industrial expansion. Utilization of sewage water and sludge without proper treatment can induce environmental pollution and human health problems. Treated sewage water could be considered as a water resource and treated sludge could be used as organic fertilizer and soil conditioner. This is particularly true in arid region, where water scarcity is a major problem for agriculture and the lack of organic matter and nutrients is the main feature of sandy soil. The reuse of treated sewage water and sludge can solve these problems.

Sewage water and sludge contain several contaminants, e.g., pathogenic organisms, toxic organic pollutants and heavy metals, high nitrate and high BOD & COD. The convention methods of sewage water treatment (primary, secondary, tertiary) are not efficient in removing such contaminants. Sewage water and sludge were exposed to γ-radiation from ^{60}Co sources and electron beam from accelerators. Analysis of pathogenic organisms, heavy metals and toxic organic pollutants, before and after irradiation, was performed according to The Standard Methods for the Examination of Water and Wastewater.

Results indicated that ionizing radiation is an effective method in treating sewage water and sludge. The potential effect of radiation includes pathogen disinfection, organic pollutants degradation and soluble heavy metals reduction. The best radiation dose for pathogens disinfection was 1 kGy and 6 kGy for sewage water and sludge, respectively. A reduction in soluble heavy metals was observed in sewage water and sludge as a result of radiation treatment. Degradation of toxic organic pollutants (PAH) in moist sludge reached 79% at 6 kGy γ-radiation dose. Irradiated sludge applied to sandy soil has increased crop yield, improved soil fertility (organic matter and nutrients), improved soil physical and chemical characteristics.

In conclusion, radiation treatment is recommended as an innovative and reliable method to improve sewage water and sludge characteristics.

EPR Characterization of a Medical Grade Polyethylene for High Dose Dosimetry

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The quality control of radiation processing of polymers and composites by electron beam (0.1–10 MeV), γ- and X-rays (0.6–7.5 MeV) can often be achieved by full knowledge of the irradiation parameters and by periodic product analysis. In such cases where the product itself is used for the quantitative control of process efficiency other radiation dosimeters are not necessary. The main changes induced by irradiation on the polymer structure are the creation of free radicals and the modification of the electronic configuration of these materials. The electronic paramagnetic resonance of the ionizing radiation induced free radicals in polyethylene has been extensively investigated by many authors. However, to the best of our knowledge, there is no data in the available literature regarding EPR dosimetric properties of the polyethylene.

In this work we are interested in the free radicals induced by γ and electron beam irradiation in polyethylene in order to investigate its use as high-dose dosimeter.

The polyethylene samples were obtained from commercial medical-grade polyethylene sheets of 28 μm thick which were cut into pieces of 30×4 mm^2 for EPR measurements. The PE samples were subjected to different irradiation doses in air and in nitrogen at room temperature by ^{60}Co) γ-rays (5–118 kGy) and 2.2 MeV electrons beam (25–1000 kGy). The EPR measurements were recorded at room temperature by means of an X-band Bruker EMX machine with a microwave frequency of about 9.5 GHz.

The EPR spectrum obtained immediately after irradiation consists of six lines with a small asymmetric component, the six-line spectrum is attributed to alkyl radicals (AR) and the unbalanced line spectrum is attributed to the peroxide radical (PR). The effect of increasing the dose of PE films was studied in the range 5–50 kGy. The intensity of the EPR spectra increases with increasing dose. The dose response curve of AR follows a linear model, while the evolution of the PR curve follows a first-order kinetics model. We observed a strong decrease of ARs during the first three days after irradiation followed by a slow decrease until their total disappearance after 9 days. The PR concentration increased significantly after irradiation to stabilize after 31 days. The PRs thus formed are interesting for dosimetry because they exist alone without overlapping with other radicals and are stable. However, the very long stabilization time is a disadvantage. We found that the PR is completely separable after annealing for 20 minutes at 100°C. The repeatability of measurements for the two radicals has been proven. The variation coefficients were found to be less than 1%.

Treatment of Organic Pollutants Based on PCB in the River Sediment by Electron Beam

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Polychlorinated biphenyls (PCBs) belong among the most persistent and bioaccumulative substances. Long-term production of PCBs in the 20th century has resulted in excessive concentrations of this organic pollutant in the environment with about 200 000 inhabitants in eastern Slovakia. Different techniques for removing PCBs from sediments were evaluated, but none of them has met three requirements of the local district authority: a) the PCB degradation facility should be mobile and easily relocatable to other contaminated sites; b) Techniques for PCB destruction should have negligible secondary waste generation, with minimum catalysts, without PCB burning, and be easily automated; c) non-prohibitive capital and operating costs.

The goals of the present work are to justify the method for electron beam degradation of PCB (EBDPCB) in sediments, which so far has not yet been used industrially. To fulfil the requirements of the local district authority the following methods were chosen: a) A relocatable electron accelerator for in site EB processing in environment with shielding corresponding to electron accelerator parameters and dimensions is considered; b) The toxic equivalency factor was used to determine the toxic equivalent which determined the clean up and remediation levels for the PCB mixture; c) Investment and operating costs depend on the effectiveness of radiochemical reaction, design and technical parameters of the electron irradiator.

The EBDPCB method demonstrated that ionizing radiation produced by high-energy electron beams is remarkably effective in transforming PCBs into less problematic species with minimum catalysts. To increase the efficiency of radiochemical reaction of the EBDPCB, chemical pretreatment of sediments by using various combinations of isopropanol, K_2CO_3 and $CuSO_4$, have been tested. EBDPCB efficiency increased by using an electron energy of 3.6 MeV compared to 5 MeV. In comparison to other types, the accelerator based on DC transformer 50/60 Hz has an advantage in its reliability (availability), high average beam power (productivity), electrical and beam utilization efficiency (operation cost), beam energy for EBDPCB, transportable shielding and price (capital cost). Design of transportable DC transformer type 50/60 Hz electron accelerator for EBDPCB has been calculated by the Monte Carlo code MCNPX for electron beam irradiators of 2.5 MeV/100 kW and 3.5 MeV/100 kW.

The main source of PCB contamination in eastern Slovakia are sediments in Channel Strážske. Among several methods for environment remediation, the method of radiation degradation of PCBs in sediments by electron beam is the most appropriate for application at Channel Strážske. The radiation degradation method for PCBs is environmentally friendly and the irradiation facility with electron accelerator can be transported directly to the site of PCB contamination. Treated sediments are recyclable as building gravel sand.

A New Fluorescence Detection Method with Plastic Scintillators Using a Conventional LSC-Organic Waste Less Method

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For tracer experiments in life science field, many types of compound are labelled with β-emitters. The β-emitters are generally measured using a liquid scintillation counter (LSC) because of their low energies. An LSC is a superior machine with high counting efficiency; however, there are two main demerits. Organic liquid wastes are generated after measurement because the sample is dissolved in liquid organic scintillator, and a spectra quenching arises, erasing the identities of the kind of nuclides in a sample. We developed a new fluorescence detection method with plastic scintillators, an alternative material to liquid scintillator, using a conventional LSC without generation of organic liquid waste.

Two kinds of plastic scintillator (PS) were prepared; a sheet type (BC-400; Saint Gobain USA) and a pellet type (EJ-200; G-tech Japan). The sheet was 0.5 mm in thickness and was cut 55 mm in length (max. 75 mm) and 20 mm in width (max. 30 mm) for a 100 mℓ Teflon vial of inner diameter 33 mm (Sanplatec Co. Japan) used for nonvolatile compounds. The pellet was a 3 mm cylindrical shape and approximately 90 g of pellets were put in the Teflon vial, which were used for volatile compounds. The LSC used was LSC LB-7 (Hitachi, Ltd. Japan). Radioactive materials used (Moravek Biochemicals Inc. USA) were ^{3}H-methionine, ^{14}C-arginine and ^{35}S-methionine as nonvolatile compounds and tritiated water and ^{14}C-acetic acid sodium salt as volatile compounds. Additionally, the surface of the PS-sheet was treated with dielectric barrier discharge plasma or fluorine gas treatment for tritium compounds measurement, because the surface was changed hydrophilicity and the contact area with the sample solution was extremely widened. Quantitative analysis and detection limits for using both sheets and pellets were studied.

The counting efficiency using the PS-sheets was same as that of liquid scintillator use, when the surface of PS-sheets were treated with plasma for tritium measurement. Though the PS-pellets showed higher counting efficiency compared with that of liquid scintillator when the sample solution was less than 500 $\mu\ell$, the counting efficiency was decreased depending on the sample solution increased. However, the detection limit became low with large sample solution.

Quantitative and qualitative analysis of β-emitters were possible using plastic scintillators without generating of liquid organic waste. The PS-pellets and sheets could be used repeatedly after rinsing under hot running water. These PS-methods are low load and eco-friendly.

Optimal Design of ^{60}Co Single Source Radiation Facility with Monte Carlo Method

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A reference radiation field is necessary for the calibration of radiation dose monitoring meters, and ^{60}Co single source radiation facilities are an important resource to produce this reference radiation field. Uniformity and scattered photons are the most important criteria for reference radiation field. The Monte Carlo method was used to calculate the uniformity and scattered radiation of the reference radiation field which was produced by ^{60}Co single source radiation facility. A close-to-reality simulation model of the facility was used to calculate scattered air-kerma along the whole range of the source-detector-distance (SDD) along the central beam and air-kerma off-axis beam profiles at 1 m source-detector-distance (SDD). Other characteristics such as the individual contributions of photons scattered in collimator, floor, walls, mobile platform and other parts of the radiation halls to the total air kerma rate on the beam axis were calculated. Optimal design of ^{60}Co single source radiation facility was accomplished according to the simulation results. A PTW ionization chamber was used to measure the radiation field produced by ^{60}Co single source radiation facility, measured results show that the scattered radiation and uniformity of the radiation field are in good agreement with the simulation results. The total scattered contribution is less than 4.0%, and falls below the ISO 4037-1 requirement of a maximum scatter of 5%. The ^{60}Co single source radiation facility performances meet the design requirements.

Conceptual Development of an Irradiator for Cross-Linking of Cables Using ^{60}Co γ-Rays

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Cross-linking provides significant commercial benefits to wire and cable insulation. Ionizing energy is an efficient means of cross-linking the polymers to improve many cable properties including insulation. In this process chemical bonds are formed between layers of polymer molecule to produce three-dimensional insoluble network. The present methods of cross-linking are thermal, chemical, or EB from accelerators. EB cross-linking is the latest and improves properties like fire resistance, flame properties, abrasion resistance, stress crack resistance, etc., however, there is a limitation of EB penetration in large diameter cables ($>$ 30 mm diameter) restricting its application. Therefore, the feasibility of processing multicore cables of large diameters with γ-rays was explored. The insulation jacketing of multicore cables are made of PVC or PE. The dosimetric aspects were studied for a cable irradiator design which has been made in such a way that the cable will move through a pipe housed in γ-irradiation cells (GICs) each of which have ^{60}Co source pencils (BRIT made BC-188) of 7.4 PBq arranged around the pipe in a suitable diameter (PCD). The pipe can accommodate cables of diameters up to 72 mm. The cells have effective irradiation lengths ($\sim$ 1 m) and lead shielding of adequate thickness. The objective of the study was to evaluate the dose profile in cables when irradiated in a γ-irradiation cell and to optimize the PCD of source pencil arrangement to get the appropriate dose uniformity ratio with the specified target dose of 100 kGy and to arrive at number of irradiation cells required for a suitable through-put. Based on the results of the study a γ-irradiator with multiple number of irradiation cells is under development in BRIT, a unit of the Department of Atomic Energy, India.

Assessment of Safety Systems Design of Industrial Irradiation Facilities in Brazil

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Accidents occurring in irradiation facilities have demonstrated that these facilities have safety-critical systems, which should be designed to meet proper safety requirements. The IAEA's publication SSG 8 provide specific and practical recommendations on the safe design and operation of irradiations facilities, for use by operating organizations, the designers of these facilities and by regulatory bodies. The first industrial irradiation facility in operation in Brazil was designed in the '70s. Since then, minor modifications and upgrades, as sensors replacement, have been introduced in order to reduce the technological gap in the control and safety systems, however, in the case of safety systems in irradiation facilities, the requirements concerning safety and reliability are of ultimate importance. This work evaluates the adequacy of existing safety systems and their sensors at Brazilian irradiation facilities, taking into account the recommended IAEA's design requirements.

The study is based on an assessment of the licencing process of irradiation facilities, as well as the experience of regulatory inspections in these facilities. It was also taken into account the knowledge, concepts and solutions developed to upgrade existing safety system in facilities throughout the world. Irradiation facilities can be defined on the basis of its design and, in particular, the accessibility and shielding of the radioactive source. The Brazil facilities can be categorized into 9 panoramic γ irradiators (4 dry and 5 wet storage) and 4 panoramic irradiation facilities using generators.

Notable findings arising from this study include: a) Some sensors are not interlocked with the irradiator central controls unit, thus they not act automatically when a predetermined value is exceeded, this condition is normally observed, basically, on the radiation monitor of the water treatment system and on the fire protection system; b) In older irradiators the seismic detector is not installed; c) Redundant systems in the personnel access door can be improved, using pressure mats combined with optoelectronic barriers.

Additionally, it was considered if the irradiation facility can be operated only if all safety systems are in place and functioning. It was carried out a diagnosis of the "state of the art" of safety systems of Brazilian industrial irradiators, taking into account the national regulations and the latest IAEA´s recommendations.

Some sensors of safety systems in oldest Brazilian irradiators can be improved, basically for automatic actuation, thus the upgrade of control systems in irradiator facilities would use the advances in computer technology, old control units based on relay logic should be replaced with a new one based on redundant programmable logic controllers, however, it should be emphasized that the operating organization should obtain the approval of the regulatory authority before implementing any modifications on the irradiator that may have significant implications for radiation protection.

Measurement of Residence Time Distribution of Wastewater in a Constructed Wetland System Using Radiotracer Technique

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Constructed wetlands (CW) are human engineered systems that utilize natural process for treatment of wastewater. They have been highly applicable in developing countries, due to their characteristics like utilization of natural processes, simple construction, operation and maintenance, process stability, and cost effectiveness. The design of constructed wetland requires multidisciplinary inputs involving biological and ecological sciences, aquatic chemistry, engineering hydrology and flow hydrodynamics. The CW are heterogeneous in nature. Thus, they are prone to show deviation in the designed flow pattern and residence time for the treatment of wastewater. The aim of the present study is to measure mean residence time (MRT) and flow patterns of CWs using radiotracer technique.

The wetland is 13.0 m long, 3.0 m wide and 0.7 m deep. The geometric volume of the system is 27.3 m^3. The system walls and bottom were lined to prevent leakage. The wetland has slope of 1% at the bottom and an average porosity of 52%. About 100 MBq of ^{99m}Tc (half-life $\tau_{1/2} = 6.6$ h, γ energy 139 KeV) as sodium pertechnatate was used in each run. The radiotracer concentrations monitored at different planes across the width and outlet using NaI(Tl) scintillation detectors were connected to a computer controlled data acquisition system (DAS), itself set to record tracer concentration once per minute at the outlet and across the bed of the system.

The RTD data was treated and analyzed using a RTD analysis software. The data treatment includes background subtraction, tail correction, radioactive decay correction, zero shifting, smoothing and normalization. The data was used to calculate MRT, dead volume of system and hydraulic efficiency of the plant. A four-parameter model, i.e., tank in series exchanging with dead volume model prefixed with plug flow component, was used to simulate the RTD data.

The radiotracer experiments were successfully conducted in an artificially constructed wetland system and mean residence times and dead volumes were determined at different operating conditions. No bypassing or short-circuiting was observed in the CW. The proposed four-parameter model was found suitable to describe hydrodynamics of wastewater in the wetland. The hydrodynamic parameters indicate that the CW works efficiently at a bed height of 0.6 m, wastewater flow rate 2.3 m^3/s and with a two point distributor geometry. However, the results of the study also indicate that on increasing the number of injection points, the efficiency of the CW will increase.

Application of Low Energy Electron Beam in Microbiological Decontamination Process

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Food preservation with ionizing radiation has about 100 years of history. To date, more than fifty countries have given approval for over sixty products to be irradiated. The most popular application uses γ-irradiators. Increasing interest is also observed for the application of high energy electrons as well as X-rays. New trends in the application of this technology is related to the use of low energy electron beam, characterized by limited penetration depth. In the process with the use of high energy electrons, the whole food volume is irradiated. Since microorganism reside mostly on the surface of dry food, irradiation of the external layer should be sufficient to eliminate food-borne microorganisms. Additionally, operational safety issues are relevant, since low-energy EB machines are equipped with local compact shielding and can be installed along with other industrial machinery in the same room.

This study concentrates on the determination of microbiological decontamination process efficiency with the use of an EB of energy between 100 and 300 keV. Two electron accelerators installed in INCT were be used in the experiments. Elektronika (10 MeV, 10 kW) was used for irradiation with high energy electrons. Accelerator ILU-6 is a resonant type machine whose nominal beam operating range covers energies from 600 keV to 2 MeV. Low electron energy was achieved by reducing the accelerating RF voltage. For the need of this study, the modification of the pulse power supply system, electron gun arrangement and accelerator beam sweep system of ILU-6 was made to lower the energy of emitted electrons to below 300 keV. The energy of the resulting beam was controlled using B3 dosimetric film stacks.

In the experiments, the microbiological load reduction was tested for food products, irradiated with doses from 1 to 10 kGy. Selected samples of spices, dries herbs and seasonings with different density and porosity were tested to control the total amount of aerobic bacteria and mold. The relationship between dose of radiation for different energies of electrons and effectiveness of the process was established. The effects of irradiation with low energy electrons were compared with effects for high energy electrons.

The work was supported by Polish Ministry of Science and Higher Education under the project "Investigation on application of low energy electron beam for microbiological control of food and agricultural products" and by the IAEA under the Coordinated Research Project D61024.

Core Neutronic and Source Strength Analyses of ^{60}Co Production in Local Power Reactors

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A detailed analytical study on the feasibility of local production of ^{60}Co in power reactors of Pakistan, C-1 & C-2 (Chashma Nuclear Power Plant, unit-1/unit-2, PWR type), has been made by irradiating metallic pencils of ^{59}Co in-core and out-of-core locations. In the first scheme, four fresh fuel assemblies with four guide tube locations per fuel assembly have been selected for in-core ^{59}Co loading. A total of about 150 kCi of ^{60}Co have been produced in these locations over a period of one fuel cycle ($\sim$ 385 days). Detailed neutronic analysis of C-1/C-2 core was carried out in order to determine the effect of sample irradiation upon core performance at full power. The reactivity calculations show that fuel cycle length would be slightly shortened, approximately by one day, without affecting the safety parameters due to ^{59}Co loading at in-core locations. The estimated specific activity of a cobalt pencil at the end of one year is 19.25 Ci/g.

Alternatively, in C-1 & C-2 reactors, the four out-of-core vacant locations on the outer surface of the reactor core barrel, which were earlier occupied by the now-withdrawn surveillance capsules assemblies (SCAs), have been selected for ^{60}Co production. In this scheme four bundles in the form of stainless steel tubes, each tube containing 18 concentric cobalt pencils, would be loaded in the SCA hanger assemblies. An estimated 30 kCi of ^{60}Co are produced in these locations over two core cycles ($\sim$ 770 days). Since cobalt targets are placed in the same ex-core locations that earlier contained the stainless steel and other RPV material samples in SCAs, the cobalt loading would have no impact on nuclear reactor safety. In order to determine the effect of ^{59}Co irradiation upon core reactivity, a detailed neutronic analysis of the C-1/C-2 core was also carried out at full power. The core design calculations show that there is no significant effect on critical core parameters and reactor operation, and fuel cycle length is not reduced. The calculations show that the estimated specific activity of capsule at the end of two years is 0.83 Ci/g at the cobalt loaded SCA location. For a total mass of 35 kg in 72 ^{59}Co samples, the total activity from the production of ^{60}Co is estimated to be 30 kCi. Detailed shielding analysis and dose rates of irradiated ^{60}Co pencils have also been carried out. Thicknesses of shielding materials have been optimized based on the surface dose rate criteria of $\leqslant$ 2 mSv/h. Based on these analyses, the cylindrical shielded transport containers with different loading combinations have also been designed for safe transportation.

From these analyses, feasibility of ^{60}Co production at the in-core and out-of-core vacant locations of SCAs in the power reactor has been demonstrated without any major modification in reactor core or imposing any serious impact on reactor core performance and plant safety.

PA1

RI-Biomics Technology for the Advance Radioisotope Application in Modern Life

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The RI-Biomics Center opened at ARTRI in the fall of 2013, and is a facility dedicated to improving the quality of life by developing advanced radioisotope applications in domains from basic biological sciences to the pharmaceutical industry. The RI-Biomics Center supports the research interests of a wide range of investigators from multiple disciplines, including academic biomedical sciences and the pharmaceutical industry, to elucidate the phenomena of life and evaluate the pharmacokinetics of drug candidates and medical bio-materials. We designed, build, and have put into routine use a radioisotope based total analysis system to handle the needs of a wide range of experiments from classic ^{3}H, ^{14}C based pharmacokinetic studies to small-animal molecular imaging studies using micro-SPECT/CT/PET, 7.0 T small-animal MRI, fluorescence optical imaging devices and autoradiography, etc.

The centre was designated as an Advanced Research Center for Nuclear Excellence in 2012 for development of RI-Biomics Bio-sensing application technology such as evaluation technology of life phenomena using 3D-ADMET(3-dimensional absorption, distribution, metabolism, excretion, toxicity study as advanced pharmacokinetic research), development of high value drug/functional food/medical devices or materials as well as advanced technology including GLP-like non-clinical study for the contribution on the improving quality of human life. The goal of RI-Biomics technology is to contribute to the peaceful application of radiation and radioisotopes through the development of advanced technologies for enhancing understand life phenomena. In pursuit of this goal our research focusses on the development of new technologies such as: a) SPECT/PET based 3D-ADMET study and classic ^{14}C/^{3}H based ADME study for support the pharmacokinetic information of new drug or toxicant from small synthetic chemicals to big biologics such as antibody, biomolecules, nano-materials and polymers); b) Radioisotope based biosynthesis of high value herbal resources used to alternative medicine to support the advanced evaluation for traditional medicines; c) Study of radiation effects on the living organisms such as microorganisms, cells, plant and experimental animals such as fishes and rodents; and d) Development of experimental systems for the study of radiation or radioisotope application such as screening the highly radiation-sensitive experimental animals, etc.

In addition, we are involving the professional and public education systems with the University of Science and Technology (UST), Korea Association for Radiation Application (KARA) and National Research Foundation of Korea (NRF), etc., to contribute the enhancing public acceptance for radiation. In the future, we will start a programme sharing the effects of radiation on living organism and environment to enhancing the public acceptance of nuclear & radiation technology. After the Fukushima Daiichi nuclear disaster the public were seized with fear surrounding nuclear and radiation application. Currently we propose convergence research to enhance the public acceptance.

Effect of γ-Ray and Electron Beam Irradiation on Reduction of Graphene Oxide Suspension in Aqueous Alcoholic Solution

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Enormous scientific and technological progress has been in graphene applications, since its unique properties were unearthed by Andre Geim and Konstantin Novoselov in 2004. To realize the commercialization of graphene, the cost-effective and scalable production has been of great important and still considered as one of key issues in the graphene community. In this context, the wet chemical method based on the reduction of graphene oxide (GO) has been the most popular way to produce graphene because it probably offers large scalability and production of solution-processable graphene that can facilitate its many applications. Thus, numerous chemical-, heat-, and light-based reduction strategies has been exploited. However, these strategies have drawbacks such as a necessity of toxic and explosive reducing agents, high temperature processing, and less scalability. Hence, there still is a high demand for the development of a cost-effective and large-scale method.

This research investigated the reduction of GO suspension in aqueous ethanol (EtOH) through γ-ray or electron beam (EB) irradiation with the advantages of no need of reducing agent, room-temperature processing, and mass-producibility. For radiation-reduction of GO, a solution of GO suspension in 50 v/v% EtOH/water prepared by diluting a 5 mg/ml GO solution in H_2O was added to a glass vial, sealed with a rubber septum, and purged with nitrogen gas. The resulting vials containing the GO suspension were irradiated at room temperature by γ-rays from a ^{60}Co source or EB from a 10 MeV UELV-10-10S electron accelerator located at KAERI, at various absorbed doses ranging from 50–100 kGy. The dose rate for γ-ray irradiation was 10 kGy and the scan rate for the EB irradiation was 10 kGy/min. The resulting reduced GOs (rGO) were systematically characterized in terms of optical, chemical, thermal, morphological and electrical properties.

From the results of UV-Vis, FT-IR, TGA, and TEM analyses, it is clearly confirmed that GO suspension in aqueous EtOH was effectively reduced by γ-ray and EB irradiation, and the thermal, chemical, and thermal properties of the resulting rGO was dependent on the absorbed dose. Noticeably, based on the electrical conductivity measurements, the rGO prepared by the EB irradiation exhibited similar magnitude of the electrical conductivity to that prepared by the γ-ray irradiation at the same absorbed dose, indicating that the EB irradiation can reduce GO more quickly than the γ-ray irradiation.

In conclusion, the reduction of GO suspension in aqueous EtOH can be successfully achieved by both γ-ray and EB-irradiation. More importantly, EB-based reduction is much faster than γ-ray irradiation. Therefore, this EB-irradiation reduction is promising for the cost-effective and large-scalable production of graphene.

Radiation Shielding Analyses of a 10 MeV LINAC for Electron Beam and X-Ray at KACST

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The King AbdulAziz City for Science & Technology (KACST) in the Kingdom of Saudi Arabia plans to build a 10 MeV, 15 kW LINAC for electron beam and X-ray applications. The design and construction of the accelerator building will be conducted with the cooperation of KACST and EB Tech Co., Ltd. This report presents the shielding analysis of the accelerator building using the MCNP Monte Carlo radiation transport code. In order to improve the accuracy in estimating deep radiation penetration and to reduce computation time, several variance reduction techniques, including the weight window (WW) method, DXTRAN spheres were considered. Radiation levels were estimated at selected locations in the shielding facility running MCNP6 for particle histories up to 1.0×10^8. The final results indicated that the calculated doses at all selected detector locations met the dose requirement of 50 mSv/yr, which is the U.S. NRC requirement.

Optimizing the Size and Composition of Solid State/EPR Dosimeters

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In the last few decades, the alanine/ Electron paramagnetic resonance (EPR) dosimetric system has been accepted by the IAEA as a secondary (transferring type) dosimetric system. In order to increase the sensitivity of the solid state/EPR (SS/EPR) system, several new materials have been studied. Sucrose has been studied for a long time as a dosimeter in radiation accidents and in high-dose dosimetry by using different analytical techniques. In parallel, optimization of the shape and size of the dosimeters may increase the sensitivity of the system.

In the current study, an attempt to improve the sensitivity of SS/EPR dosimetry is made. In view of this, cylindrical dosimeters of different diameters, both in presence and absence of internal standard Mn/MgO_2, have been prepared and tested. Sucrose and alanine were used as radiation sensitive materials in the dosimeters. The influence of the diameter of cylindrical dosimeters on the EPR response was studied at 1 mW microwave power and 0.2 mT modulation amplitude, in other to avoid some interference of the instrumental parameters. In the absence of Mn in MgO_2, the EPR signal intensity increased with larger dosimeter diameter at equal doses, a normal effect given the increase in material. In the samples composing internal standard the ratio of the EPR intensity of the signal (I_s) to intensity of the manganese standard (I_{Mn}) is used. In this case the EPR response is independent of the dosimeter diameters.

The effect of size and composition of dosimeters used in SS/EPR dosimetry on their response also is studied. It has been found that in the absence of internal standard Mn/MgO_2, the EPR intensity increased linearly with the absorbed dose up to 20 kGy, after which it is saturated. In dosimeter diameter dependence, the slope is different. It is biggest in case of 3 and 4 mm diameter. Further increase of the diameter of the dosimeters is not recommended since the increased penetration of the dosimetric material into the electric component of the microwave field in the EPR cavity decreases the EPR response. In presence of internal standard (Mn/MgO_2) into the dosimeter (so-called self-calibrated dosimeter) the EPR signal intensity increased linearly with the dose in the all investigation region of dose (3–80 kGy). It can be concluded that the best results give self-calibrated cylindrical dosimeters.

PA1

Degradation Characteristics and Transformation Products of Iodinated Contrast Media Using Ionizing Radiation

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In the present study, the degradation of iodinated X-ray contrast media (ICMs) using ionizing radiation was investigated. ICMs (radiocontrast agents containing iodine for enhanced visibility of vascular structure and organs) are a widely used diagnostic pharmaceutical compounds. ICMs are considered as persistent pollutants in the watershed due to continuous release into aqueous ecosystem and low degradation efficiency in conventional treatment processes. Therefore, various advanced oxidation processes (AOPs) have been currently applied to treat non-degradable pharmaceuticals including ICMs. Radiolysis is a new treatment technology to eliminate a variety of non-degradable compounds, showing higher degradation efficiency. Although studies considering degradation of non-degradable compounds with AOPs have been increased, there has been insufficient information of byproducts produced by the treatment, especially ionizing radiation. Therefore, the aim of this study was to evaluate the degradation characteristics of ionizing radiation treated ICMs, and to identify the radiolytic transformation products.

The target compounds were treated using ionizing radiation, with the absorbance doses from 0.1 to 5 kGy (1 kGy =1 kJ/kg). Ionizing radiation was achieved using a high level ^{60}Co source at KAERI. LC-QTOF-MS (Agilent Technologies, USA) and LC/ESI-MS/MS (Agilent Technologies, USA) were used for qualification and quantification analysis of degradation byproducts. To confirm that the byproducts of irradiated ICMs originated from the radiolysis, the variation of parent compounds in dark control was estimated. There was no relevant change of target compounds in dark control for 40 days, indicating that hydrolysis of target compounds were negligible. Target compounds were rapidly declined with absorbance doses, showing the rate constants (k_r) of 1.7299 kGy^{-1} (ioversol), 1.5485 kGy^{-1} (iohexol), 1.3745 kGy^{-1} (iopromide), 1.3522 kGy^{-1} (diatrizoate), and 1.2726 kGy^{-1} (iopamidol) ($r^2 > 0.99$). Degradation of ICMs led to sequential release of iodide, indicating that reductive deiodination is one of the major degradation mechanism of ICMs. Deiodinated degradation byproducts of iopromide including TP665 ($C_{18}H_{25}I_2N_3O_8$), TP540 ($C_{18}H_{26}IN_3O_8$), TP414 ($C_{18}H_{27}N_3O_8$) were also detected in qualification analysis.

Structural Characterization of γ Irradiated $GdBO_3$/Silica Composite Obtained by Sol Gel Process

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Samples of $GdBO_3$/Silica composite were prepared by the sol gel process. After elaboration, the samples were irradiated at room temperature with γ-rays using a ^{60}Co radioisotope source in the dose range from 1 to 5 kGy. The irradiation effects on the structural properties of the synthesized powders were investigated before and after γ-irradiation using several techniques. DSC analysis reveals that the characteristic temperature of crystallization (T_c) increases as γ dose increases up to 2 kGy and, then, decreases with γ-ray dose up to 5 kGy but remains higher than the temperature reached by an un-irradiated sample. XRD and TEM results reveal that γ-ray irradiation reduces the crystallite size from 55 nm to 30 nm. Moreover, it is found from the FTIR study that the absorption bands intensity assigned to structural groups containing BO_4 and BO_3 units as well as the banding of Si–O–Si bond increases with γ-ray dose up to 5 kGy. From these results, it is concluded that the γ-ray irradiation up to a dose of 5 kGy improves the structural properties of the synthesized material.

PA1

Research on Conversion of Natural Wastes to Useful Products by Application of Radiation Processing for Agricultural Sector of Myanmar

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Myanmar is an agricultural-based country and its economic development depends mainly on agricultural sector productivity. People are trying to improve the productivity by using a variety of fertilizers. Some kinds of fertilizers cause a decline of soil fertility and leave fertilizer traces in food, thus are the main problems for our country. Moreover, average temperature of our country is increasing yearly due to global warning, which is challenging for our agricultural sector since water is essential for agricultural sector.

Radiation technology can be used to produce useful products to solve these problems and the main aim of the research is to produce plant growth promoter and super water absorbent material (SWA) from natural wastes by application of γ-radiation. Myanmar has many streams and rivers as well as coconut trees in all part of country. Therefore, natural wastes such as prawn shell and coconut (coin dust) shell were used as raw materials. The first step for the production of irradiated chitosan (plant growth promoter) is a deproteinization and deminerization processes. Effects of sodium hydroxide concentration and temperature on the deproteinization process and the effect of hydrochloric acid concentration at ambient temperature on the deminerization process were studied. Characteristics of products are determined by Fourier transformed infrared spectroscopy (FT-IR). The best chitin was used for the production process of chitosan in which different radiation dose and different concentration of sodium hydroxide were applied to obtain optimum condition for the deacetylation process. The degree of deacetylation (DD) was determined by band ratio method of FT-IR spectra. It was found that the degree of deacetylation (DD) of chitosan decreased with increase of radiation dose. Coir dust cellulose was produced from coin dust shell by using soda process in which various concentration of sodium hydroxide and various temperatures were used to determine the best cellulose. The resulting cellulose was applied for SWA production by using potassium hydroxide, acrylic acid and γ-radiation. Effects of acrylic acid concentration and radiation dose on SWA production were studied and determinations of their characteristics were done. The characteristics of the cellulose and SWA were determined by scanning electron microscope (SEM) and FT-IR. It was noticed that useful properties of SWA increased with radiation dose.

Production of useful products such as plant growth promoter and SWA for the agricultural sector were studied in the research. Field or pot test of the two products will be studied. It can be concluded that the research is effective not only for agricultural sector but also for environmental monitoring since raw materials used in the research were natural wastes.

Dose Increase System in a γ-Irradiator

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In China, many γ-irradiator users encounter a problem, i.e., the product kinds are various, but each product quantity is small. The absorbed-dose for each kind of product is usually different. When processing these products, the user has to wait for the completion of one product kind, the emptying of the source pass mechanism, changes to the master time, and only then start to irradiate another kind of product. This causes the throughput and source efficiency to be lower. To solve this problem, in the new BFT-type γ-irradiators in China, we have designed a dose increase system. This system includes joint roller, stopper, barcode reader etc., which is set inside the maze. Barcodes are attached on all totes. For different products, the master time is set according to the absorbed dose common divisor. For example, there are three kinds of product whose absorbed doses are 10 kGy, 15 kGy and 25 kGy. In order to process them at the same time, the master time can be set to make one cycle of irradiation to reach 5 kGy. So the totes loading these products should be irradiated for 2, 3 and 5 cycles, which are related to their barcodes. During the irradiation, when a tote is conveyed to the outlet of the maze, the barcode reader will send its barcode to the control system. The control system will decide the next motion by the tote's total cycles and its finished cycles: if the finished cycles are less than the total cycles, the tote will be moved to the joint roller and be conveyed back to the radiation room; if the finished cycles equal to the total cycles, the tote will be moved to the unloading station. The dose increase system has been applied in many BFT type γ-irradiators. The result shows that the system solves the problem of dealing with many kinds of small batch products. The system improves the throughput and source efficiency greatly.

Human Resource Development for the Application of Radioisotope Techniques to Industry in Myanmar

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Competent and efficient manpower is one of the main sectors for the application of radiation science and technology. The Department of Atomic Energy (DAE) has been conducting E&T and R&D in the nuclear application field, cooperating with local institutions and international societies. Two technological universities have been offering academic programmes for nuclear engineering (B.Tech, B.E., M.E. and Ph.D.) under the supervision of DAE.

To provide professional development, skill development and to have opportunities for career advancement and future job prospects, a human resource development programme in radioisotope techniques for application in industry has being carried out through national TC project cooperating with IAEA since 2012. The Radioisotope Techniques Laboratory was established under the DAE to transfer technology and implement radioisotope techniques into practice.

The basic theory of γ-ray transmission, γ-column scanning and γ-computed tomography techniques were introduced to students. The simulation of γ-column scanning is conducted by using model of distillation column made of iron. Two computed tomography system, GORBIT first generation CT system supported by IAEA and field-used BATAN CT system provide by BATAN, Indonesia, are used to practice the computed tomography technique. To conduct experiments in the radiotracer technique, an in-house pipe line system and water flow-rig for simulation of chemical reactors provided by IAEA are used as compact and useful tools.

Each of the tools has been adopted to the specific need of the country to achieve desired HRD results and to assist individuals in learning more effectively with the goal of improving performance. From the development of industry-driven education and training programmes, students can develop designs and software adaptable for need in the application to local industries.

Application of Ionizing Radiation for Treatment and Valorization of Cork Wasterwater

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The wastewater produced from the cork industry has a high concentration of undesirable cork extracts such as phenolic acids, tannins and 2,4,6-trichloroanisol. These compounds are difficult to degrade by conventional treatments, which make this water a toxic and recalcitrant effluent that constitute a risk for the ecosystem and thus requires treatment before being discharged into the environment. This work represents a comprehensive study of the use of γ-radiation as an advanced oxidation process for wastewater treatment. This work was carried out aiming to degrade recalcitrant compounds, although it was also assessed the potential valorization of the cork industry wastewater through the selected recovery of the valued antioxidants. The irradiations were performed at room temperature in a ^{60}Co chamber at the absorbed doses: 20, 50 and 100 kGy and dose rate range of 1.6–2.4 kGy/h. Parameters of pH, COD, BOD and TSS were determined according to the Standard Methods for the Examination of Water and Wastewater. Total phenolic content (TP) was quantified by Folin–Ciocalteau method. The antioxidant activity was measured by DPPH radical scavenging activity, reducing power and inhibition of β-carotene bleaching. The identification of the phenolic compounds and its radiolytic products was carried out by HPLC-DAD-ESI/MS. To test the hypothesis that the radiolytic effect of γ-radiation could promote the biodegradability of phenolic acid products, microbial culture growth experiments were performed using a microbial population of four bacterial strains naturally present in cork wastewater sedimentation tank samples. Recovery studies of antioxidant compounds present in cork wastewater were carried out by adsorption/desorption experiments using a synthesized mesoporous carbon. The toxicity of irradiated cork wastewater and its radiolytic products was evaluated by the cellular growth inhibition method using different prokaryotic and eukaryotic cells.

Cork wastewater indicated a low pH of 5.14, a high value of COD (2903 mgO_2/ℓ) and a low biodegradability (BOD5/COD $=0.136$), that can be explained by the presence of hardly biodegradable natural compounds. The TSS and TP values are 134 mg/ℓ and 680 mg gallic acid per litre, respectively. The most abundant phenolic compounds identified were: gallic, protocatechuic, vanillic and syringic acids, that presented high antioxidant activity. After irradiation, the results suggested that γ-radiation is a potential technology for wastewater treatment. The BOD and TSS values are greatly reduced ($\geqslant 45\%$) at 100 kGy. TP and antioxidant activity increase around 33% which opens the possibility of recovery of the added value compounds to be utilized in other industries. Concerning adsorption/desorption studies, a 40% recovery of vanillic and syringic acids using activated carbon was achieved. Non-treated cork wastewater seems to be non-toxic for the majority of the studied cells. The γ-radiation treatment affected the toxicity of cork compounds for prokaryotic and eukaryotic cells, which could be related to a cytotoxicity effect of radiolytic products of cork compounds. Further studies are being carried out to understand these radiolytic mechanisms and alternative adsorbents will be tested for selective extraction of the valuable antioxidants.

Detoxification of Aflatoxin B1 and Ochratoxin A by γ-Radiation

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Mycotoxins aflatoxin B1 (AFB1) and ochratoxin A (OTA) are widely distributed food contaminants that have adverse effects to animal and human health. In order to reduce mycotoxin contamination and protect animal and human health, various strategies are applied. Some studies indicate that γ-irradiation is effective in reducing mycotoxin contamination. Therefore the aim of this study was to investigate the effect of γ-irradiation on the AFB1 and OTA degradation as well as toxicity of mycotoxin radiolytic products in vitro.

Mycotoxins stock solutions in methanol (50 mM) were γ-irradiated with doses of 5 and 10 kGy and dose rate of 140 Gy/min using panoramic ^{60}Co source in the Radiation Chemistry and Dosimetry Laboratory at the Ruđer Bošković Institute. The dose rate was established using the ethanol-chlorobenzene dosimetry system. Molecule structure analysis of non-irradiated and irradiated AFB1 and OTA was performed by liquid chromatography tandem mass spectrometry (HPLC-MS/MS). Toxicity of non-irradiated and irradiated AFB1 and OTA (in concentration 1–500 μM; 24 h) was tested on HepG2, SH-SY5Y and Pk15 cells by quantitative colourimetric MTT assay.

AFB1 and OTA molecules were effectively degraded even at 5 kGy of γ-irradiation. The signal intensity for non-irradiated AFB1 was 16 times higher than for irradiated AFB1 (5 kGy) and signal intensity for non-irradiated OTA was twice higher than irradiated OTA (5 kGy). These results indicate that AFB1 has greater susceptibility than OTA to γ-irradiation. Besides of fragment ions of AFB1 or OTA with a mass less then the parent ion, several radiolytic products with mass higher then the parent ion were detected. These results strongly indicate the contribution of addition reactions caused by free radicals generated in solution during γ-radiolysis. Results on cytotoxicity indicate that radiolytic product of irradiated AFB1 and OTA are less toxic to HepG2, SH-SY5Y and Pk15 cell lines than non-irradiated mycotoxins (parent compounds).

Based on the AFB1 and OTA structure modifications induced by γ-irradiation, free radical mechanisms are operative in the irradiation of mycotoxins. Additionally, cell viability assay demonstrated that mycotoxins radiolytic products are less toxic to cells than parent non-irradiated compound. Based on these results γ-irradiation can be considered as an effective method for the detoxification of mycotoxins.

Dosimetric Evaluation in Industrial Gammagraphy Operations

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In this work, we developed a dosimetry study in industry in order to examine the parameters influencing the operators dosimetry in Gammagraphy interventions. These parameters are determined in a description of the practice and are subject to individual measures in real working conditions, using TLD dosimeters for estimation of the whole body dose [$H_p(10)$] and the extremities and bone surface dose [$H_p(0.07)$]. This approach established a dosimetric estimate including various phases of radiographic testing under real conditions of the intervention, but also during the phases of transport and handling γ-radiography, in order to prevent and reduce the risk of exposure to these operators.

PA1

Application of Isotopic Techniques Using Mathematical Models in Environmental Process

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During the last few decades, the use of tracer techniques in dealing with a variety of hydrological and hydrogeological problems have proved their value in improving the assessment and development of water resources. In this regard, the methodologies based on observations of temporal and spatial variations of naturally occurring isotopes, often referred to as "environmental isotope techniques", are widely employed as an integral part of the routine investigations related to various hydrological systems, and particularly in regional groundwater aquifers.

A substantial amount of isotope data was so far collected and published from hydrological applications of natural isotopes, however, it is often used for qualitative inferences to be made of the system under study, and improve understanding of processes and dynamics of water circulation. The need for improved methodologies for quantitative evaluations to be made from isotope data with regards the relevant physical parameters of the system has been recognized. This has been the main motivation to improve the progress on mathematical models for quantitative evolution of isotope data in hydrology.

Isotope-hydrology (stable and radio isotopes) has been previously used to investigate water resources, interconnection between different aquifers, relationships between surface and groundwater as well as direction of recharge, etc. Currently, mathematical modelling using isotopes is used in modern ecosystem studies to investigate the source, direction, quantity and transport of pollutant, moisture isotope fluxes in present and past climate systems, as well as transit time estimation in catchments hydrology.

Focusing our discussion on the use of environmental tracers in water molecule itself such as, ^{18}O, ^{2}H, and ^{3}H. These ideal tracers are applied by precipitation and are generally distinct isotopically, which makes them reliable tracers of subsurface flow and groundwater recharge mechanism. Two case studies were chosen, the first case illustrates the calculation of the mean residence time for groundwater in the investigated area, using tritium. The age of groundwater was found in the range from few tens to several hundreds of years, reflecting the recharge mechanism and possibility of contamination. The second case study was applied using deuterium isotope balance approach to separate evaporation and seepage rates per year in lake area.

The Numerical Simulation of Cultural Heritage Radiation Treatment by Monte Carlo Method

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Radiation processing techniques are in wide use in for disinfection and consolidation of archived materials and cultural heritage artefacts. The maximum dose ($D_{\max}$), which can be absorbed by product without changing its properties, is known from research phase. So, minimal absorbed dose ($D_{\min}$) should be transferred to the product to achieve disinfection and this dose shouldn't be more than maximum dose. The location and magnitude of the dose minimum and maximum is critical to process control, optimized irradiation configurations as it affects both disinfection and product properties. Reliable product dose-maps are necessary for identification of these critical process parameters and may involve time consuming and laborious dosimetry. In some cases determination of the dose-maps is difficult to produce by experiment. Such cases are very often occur during cultural heritage artefacts radiation treatment. In such situations numerical simulation can be used. After consideration of all possible software toolkits for passage of ionization radiation through the matter, GEANT4 was chosen. The CADMesh library was implemented in developed code to input complicated geometry. The radiation sources (plaque and cylindrical) were input into the code. Their activities, loading date into operation can be loaded from .csv file. The comparison between measurements and simulated results were made, with the simulated results showing good agreement with measured data.

Upgrading of ^{60}Co in Temporary Pool for Dry Storage Irradiation Facility SIBO INRA/Tangier Morocco

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In any irradiation facility, upgrading of ^{60}Co activity is one of the most important maintenance operations, which should be done periodically to maintain the dose rate in the irradiation process given the decay of ^{60}Co. In general there are two kinds of irradiator with either wet storage or dry storage of ^{60}Co in the facility. For wet storage facilities, the ^{60}Co upgrade receives the cobalt in a supplier provided shipping container and the source is transferred into the pool of the facility to the source rake of the irradiators. For dry storage, cobalt upgrade is done at the supplier facility by shipping the entire cobalt irradiation container, which serves also as transport container, back to the supplier to upgrade the source ^{60}Co.

The Station d'ionisation de Boukhalef (SIBO), is a panoramic irradiator with dry storage of ^{60}Co in a container which is also used as the transport container in the first loading. We have been faced with a problem of the container transport and we need to find a solution to upgrade the ^{60}Co. Our proposed solution is to bring cobalt in a supplier container and transferring the new sources to our facility container using a temporary pool fabricated in the facility.

The objective of this paper is to show a case study experience. This operation has been considered as a success story by the IAEA and opened this solution method for similar irradiators in other countries which have the same problem. Its execution was a real application of the nuclear security system installed in the facility and during the transport of ^{60}Co.

Enhancing Safety and Control Features of Radiation Processing Facility SIBO INRA/Tangier Morocco

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The automatic control system is one of the central parts of all irradiation facilities. The level of this control is always implemented to achieve strict safety procedures in routine facility use. However, sometimes the system is limited to the minimum legal regulation required due to economical restrictions; some commercial systems are generally made by manufactures of industrial facility and considered in the price of the irradiator. In some cases there is some specific irradiation facility with specific control system. For this kind of irradiator the control system can be developed and upgraded according to feedback from operating experiences and in accordance with industrial experiences. These upgrading procedures are also used as input by others to upgrade their systems.

The objective of this paper is to share a local experience in upgrading the safety systems and special upgrading of ^{60}Co for the irradiator. This work has been done with other works related to security and ^{60}Co upgrading which are published in other scientific paper and concerns 1) Upgrading of ^{60}Co in SIBO irradiator in Tangier (an operation made in collaboration with the IAEA and has been a success story of the year 2014 during the general conference of IAEA), and 2) Installation and upgrading of the security system in accordance with the Global Threat Reduction Programme to reduce the threat of a Radiological Dispersion Device (RDD) in collaboration with The United States Department of Energy's National Nuclear Security Administration (NNSA).

The Efficiency of Radiation Processing by the Tunisian ^{60}Co Industrial Irradiator after 16 Years of Use

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Since its commissioning at 1999, the Tunisian ^{60}Co irradiator has been mainly used for sterilization of single use medical devices and decontamination of agro-food products. Now at its third half-life, the irradiator has a low source activity. This activity leads to a very low dose rate and requires a very long processing time. Therefore, it becomes judicious to study the absorbed dose distribution in the processed product. In this study, evaluation of the irradiator performance was carried out by placing multiple Fricke dosimeters. Dose mapping in the front and back planes of the irradiated product has been carried out and microbiological analysis has been established.

Taking into account its huge virtue in different diseases (cancer, heart-vascular, Cholesterol-lowering effect, etc.) and the short time required for their irradiation, garlic *Allium sativum L* was considered in this study. Boxes containing garlic, with dimension of $24 \times 20.6 \times 15.5$ cm^3, were irradiated with 50, 100 and 150 Gy during 7, 18 and 29 min, respectively. The determination of radiation doses measured by Fricke dosimeters are performed using UV-visible spectrophotometer. Thus, yeast, mold and mesophilic bacteria were quantified at different doses.

The cartography performed using Fricke dosimeters allowed the determination of the dose uniformity ratio ($D_{\rm max}/D_{\rm min}$). Two-sided (front and back) irradiation resulted in a dose uniformity ratio of about 1.5 for garlic and 1.13 for rock wood (used for cartography). For the front and back planes, the results showed a symmetrical distribution relatively to the horizontal XY plane. The maps showed that the absorbed dose reached the maximum in the centre and decreased slightly keeping the same order of magnitude. Statistical uncertainty of Fricke dosimeters is about 2% and systematic error related to the source activity is below 10%.

Results obtained for the microbiological analysis of the irradiated and nonirradiated garlic showed that irradiated garlic with known absorbed doses harboured bacteria. The high dose irradiated samples (150 Gy) were free of viable bacteria. According to the FAO permissible limits, irradiated garlic never exceeded these permissible counts. Considerable number of yeast and mold (20000 cfu/g) were detected only in nonirradiated samples. After 50 Gy irradiation dose, the number of these microorganisms decreased to (61 cfu/g) and continue to be absent for all other doses. The number of total aerobic mesophilic bacteria decreased by the irradiation. This is in agreement with literature for different food commodities.

Performed studies showed that the irradiation facility at third half life gave an uniform absorbed dose rate distribution, but, the processing efficiency of the actual source to preserve fresh food (fruits, vegetables, salads and meat products) in terms of microbiological safety is not reliable regarding the very low absorbed dose rate and the required long irradiation time. However, preserving food with low irradiation time requirements (garlic, onion, …) is possible at the current activity while waiting for the ^{60}Co source pencil reloading.

Measurement of Voidage/Holdup in Industrial Process Systems Using γ-Ray Densitometry

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Multiphase flow reactors are commonly used in industry. One of the requirements for the efficient operation of these reactors is to have intimate contact or mixing between the different phases. Any spatial nonuniformity of the phases will adversely affect the process efficiency. Therefore, it is important to characterize the void fraction and holdup, and their spatial distribution in multiphase flow reactors. The γ-ray transmission technique commonly known as γ-ray densitometry is one of the commonly used techniques for measurement of voidage or phases holdup in multiphase flow systems because of its noninvasive nature and applicability to opaque systems. In γ-ray densitometry, a collimated radiation source (usually ^{137}Cs) and a scintillation detector are mounted in a horizontal plane across the diameter of the flow system under investigation. The narrow mono-energetic beam of the γ-rays with an incident intensity passes through the system (walls and material within the system). A fraction of the incident beam is attenuated within the system and the transmitted intensity of the γ-rays is recorded by the detector connected to a radiation counting system. Let us consider an industrial process system, i.e., gas-solid fluidized bed system and record intensity of transmitted γ-rays at three different conditions of operation, i.e., with empty system (with air), with solids and with two phase flow (fluidized condition), then the line averaged void fraction of the fluidized bed is estimated using equations detailed in [1]:

The technique was used for estimating voidage/holdup in pilot-scale two phase flow systems, i.e., fluidized beds and bubble column reactor to evaluate mixing of the two phases [1, 2]. The results of the studies helped to understand the flow dynamics of the phases and validate or improve the design of the system.

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Dosimetric Characterization of the ISOGAMMA LLoCo Irradiator

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All irradiation facilities must, before being put into operation, perform dosimetric characterization of the radiation field. This data obtained from the commissioning dosimetry is used to determine the irradiation times necessary so that irradiated products receive the required absorbed dose value, and establishes the facilities operational parameters, such as dose uniformity ratio, and maximum and minimum dose positions.

The ISOGAMMA LLCo radiation facility at CEADEN had no such procedure carried out during commissioning by the manufacturer. Thus, it was necessary to perform dosimetric trials to characterize the dose distribution in the irradiation chamber of the facility, to contribute to the correct operation of the facility, and ensure the quality of future radiation process.

The experimental measurement points were selected taking into account the geometry of the irradiation chamber and dosimeters were distributed in the areas where the maximum and minimum dose values were expected. Initially, the Fricke dosimetric system was used to determine dosimetric characterization, and considering the cylindrical geometry of the irradiation chamber and its dimensions, the chamber was divided into three study zones. The dosimeters were measured by using the spectrophotometric method. Later, the alanine-ESR dosimetric system was employed to determine the dose distribution and the chamber was divided into six study levels, and alanine dosimeters were measured by using the electron spin resonance (ESR) technique with MiniScope 400 equipment.

In this experimental work, the dosimetric characterization of the ISOGAMMA LLCo radiation facility was measured with two different dosimetric systems. The measured dose distribution has a similar profile for both dosimetric systems and the highest dose values are observed in the central part of the radiation chamber and the lower dose values in the upper and bottom parts.

γ-Irradiation in Protection of Cultural Heritage: Effects on Model Cellulose Based Textiles

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Cellulose-based textiles are very common materials in cultural heritage (CH) collections (garments, upholstery, etc.) and in art (painting canvases). Natural textile fibres are susceptible to biologic damage, particularly by insects and fungi which is a serious problem in the preservation of such CH objects. Art canvases as well are commonly coated with animal glue what makes them more susceptible to fungal attack.

Ionizing radiation has been recognized as a fast and efficient treatment against attacks by living organisms, particularly insects. At the Radiation Chemistry and Dosimetry Laboratory of the Ruđer Bošković Institute, radiation treatment of CH items has been ongoing for about 25 years. Along numerous wooden, paper and leather objects, textile artefacts (mostly of ethnological significance) were efficiently disinsected by irradiation to 2 kGy or less. However, the application of higher doses needed for the control of fungi has to be justified, particularly considering the effects on aged and deteriorated materials. Because of that, this study is aimed at assessing whether there are irradiation side-effects on cellulose-based textile fibres and to identify the type and the extent of damage type if present. The role of glue-coating on radiation sensitivity of model canvases is also investigated.

The study consists of two parts. The first part was intended to identify the effect of irradiation and ageing. A set of cotton and linen model textile samples were irradiated and a part was also artificially aged. Two γ-irradiation doses were selected: 6 kGy that is often used in treatment of fungi and a much higher dose of 120 kGy that is not used in radiation treatment but is expected to cause detectable side-effects. The samples were irradiated in contact with air at the dose rate of 2.8 Gy/s. In a second part of the study, linen samples as a model for painted canvas were coated with animal glue prior to irradiation. Those samples were exposed to a range of doses between 2 and 50 kGy at dose rates 0.1 and 9.8 Gy/s, also in contact with air. Before the postirradiation analysis, the glue was removed. The samples were studied by FTIR-spectroscopy, microscopy and thermal techniques.

Slight changes due to irradiation of model cotton and linen textiles were observed only at the higher dose of 120 kGy but were comparable or lesser that those brought in by ageing. Although the process of glue removal from the model canvas samples might have somewhat obscured the results, it seems that the coating reduces radiation sensitivity of model canvas.

Since doses up to 10 kGy are needed for control of the most common fungi on CH textile materials the results are encouraging. Efficient radiation treatment of fungal contamination should case no undesirable changes and thus be acceptable to conservator specialists.

Dosimetric Calibration of a Panoramic ^{60}Co γ-Ray Source

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The panoramic ^{60}Co source at the Ruđer Bošković Institute is the only irradiation facility in Croatia suitable for a variety of applications: from medium range doses used in radiobiology and accident dosimetry to high doses pertaining to radiation processing and research in radiation chemistry. In November 2015, thanks to IAEA support, the source was upgraded with an additional 3.5 PBq. The results of precise dosimetric calibration and determination of dose distribution curves typical of the cylindrical γ-ray panoramic source geometry are presented.

Because of the cylindrical shape of the source, the radiation field also has a cylindrical symmetry and is best described by cylindrical coordinates. Radiation field mapping was performed with the ethanol-chlorobenzene (ECB) dosimetry system which was developed 50 years ago in our Radiation Chemistry and Dosimetry Laboratory and subsequently accepted as an international standard (ISO/ASTM 51538). The commercial 5 cm^3 pharmaceutical ampoules were used for irradiations. Irradiated ECB dosimeters were analyzed for chloride ion concentration by two methods: oscillometry before opening; after opening aliquots were taken for mercurimetric titration. Oscillometry was performed by an oscillotitrator Model OK-302/1 (Radelkis Electrochemical Instruments, Budapest). After measurements, the doses were evaluated from the previously determined calibration curves. For mercurimetric titration, the standardization of Hg^{+2} solution used for titration with standard NaCl solutions was performed daily before the analysis of irradiated dosimetric solutions. All doses were expressed as "absorbed dose to water". For dosimetry calibration and "transit" dose measurements an ionization chamber type 2581 and a Farmer Dosimeter type 2570 (NE Technology Limited, England) were used.

Dose mapping in horizontal and vertical planes was performed with ECB dosimetry system, as follows: a) A check of the radiation field angular symmetry was performed inside the annular space enclosed by the source rack; b) The dependence of the dose rate D on radius r from the axis of the cylinder was measured at two heights: at $h = 0$ cm (the horizontal plane passing through the centre of the source cylinder) and at $h = 100$ cm; c) The dependence of dose rate D on height h was measured at two radii: $r = 50$ cm and $r = 100$ cm from the source axis, both in vertical planes through the axis. The "transit dose" was measured at different radii at $h = 0$.

It was shown that the radiation field of the cylindrical γ-ray panoramic source is fully describable by using only two parameters, radius r from the axis and distance h from the reference horizontal plane.

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EPR Dosimetric Potential of Ammonium Oxalate Monohydrate in Radiation Technology

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This study aims to examine the dosimetric properties of the ammonium oxalate monohydrate $(COONH_4)_2H_2O$ under low and high radiation doses. The EPR spectra of ammonium oxalate have the spectroscopic splitting g-factors of 2.0095 and 2.0047. Results indicate that the dose-response curves have a good linearity in the range between 10–1000 Gy for low doses. Slight sub-linearity has been found in high dose region up to 25 kGy. The effects of temperature and humidity on the EPR signal amplitude of the irradiated samples are studied. Stability of the irradiation rods upon storage (signal fading) was also investigated. Energy dependence has been found within 38% at the range below 100 keV. Slightly energy dependence within 4% over the energy range 6–10 MeV has been recorded. The overall uncertainty of this dosimetry system is 4.64% (2σ) in low dose range and 3.67% for the high dose range.

Development of a Digital Model for the Dosimetry of the ^{60}Co Irradiator at the National Polytechnic School of Ecuador

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This project presents the development of a digital model using the MCNP programme to simulate the dosimetric distribution of the ^{60}Co irradiation facility of the National Polytechnic School of Quito, Ecuador, with a 100 kCi installed capacity. First, a map of absorbed dose was obtained with Fricke dosimeters distributed through the irradiation chamber, at five different distances fixed from the source (20, 40, 60, 100, 165 cm). An irradiation time based on the time required for a dose of 300 Gy at 20 cm from the source was set to measure the dose. This time was fixed for all the distances. The irradiation process was performed three times. To define the input data for the model it was necessary to establish the geometry, dimensions, materials and chemical compositions forming the irradiation chamber. To calculate the absorbed dose, a quantizer data or "tally" was used to determine the energy deposited in a given area, called cell. In order to characterize the twelve pencils composed the ^{60}Co source, the SDEF code was applied to simulate a fixed source and photons. Several changes at the starting model input data were needed to set and improve the performance. The final digital model was achieved with an error of less than 15% when compared with data obtained by Fricke dosimetry, therefore this model was validated.

γ-Irradiation for Cultural Heritage: Treatment of Selected Fungi on Linen Textile

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A common carrier for paintings is glue-coated linen that is vulnerable to fungal biodeterioration. The study aimed to assess antifungal effect of γ-irradiation doses and dose rates against naturally occurring mycobiota and artificially inoculated fungal colonizers common for cellulose materials like linen. The composition of natural mycobiota on glue-coated linen (initial level) and eventual postirradiation recovery of mycobiota were analyzed.

The initial level of common fungal colony-forming mycobiota on model glue-coated linen textile was determined by plate count method upon 7 days of incubation (at 25°C and 70–80% r.h.) and the data expressed as the number of colony-forming units per gramme (cfu/g). Next, linen samples were separately inoculated with selected primary (*Aspergillus jensenii*), secondary (*Cladosporium spaherospermum*) and tertiary colonizers (*Trichoderma harzianum*) at concentration of 10 000 cfu/g. Inoculated linen and controls were incubated as described. One group of samples was analyzed immediately upon the incubation while the rest of the samples were irradiated via ^{60}Co source at RCDL to doses of 2, 7, 20 and 50 kGy, at dose rates of 0.1 and 9.8 Gy/s and analyzed after incubation for 0, 7, 14 and 28 days.

Alternaria spp., *Aspergillus spp.*, *Cladosporium spp.*, *Fusarium spp.*, *Penicillium spp.* and yeasts comprised naturally occurring mycobiota, in initial concentrations of 1000 cfu/g (moulds) and 10 000 cfu/g (yeasts). These fungi were non-homogeneously dispersed on glue-coated linen. On incubation in humid atmosphere the concentration of mycobiota increased for four orders of magnitude. Similar increase was obtained for non-irradiated artificially inoculated samples. All applied doses and dose rates were effective against primary and tertiary colonizers but not for secondary colonizers and linen mycobiota. Doses of 2 and 7 kGy was ineffective in reduction of linen mycobiota to the initial level; after 28 days of incubation fungi were recovered up to 1 000 000 and 100 000 cfu/g, respectively. Dose of 20 kGy (0.1 Gy/s) reduced *Cladosporium spp.*, and *Alternaria spp.* to 10000 cfu/g; *Penicillium spp.* was reduced to the initial level while yeasts, *Aspergillus spp.*, and *Fusarium spp.* recovered in concentrations below initial. For both 7 and 20 kGy dose rate of 9.8 Gy/s was more effective in fungal elimination than 0.1 Gy/s, while for 2 kGy the dose rate effect was inconsistent. Upon exposure to 50 kGy sterile white mycelia was recovered on few plates *C. sphaerospermum* survived radiation with 2, 7 and 20 kGy, showing the similar recovery pattern as obtained for *Cladosporium spp*. After treatment with 7 and 20 kGy (0.1 Gy/s) *cladosporia* recovered between 7th (or 14th) and 28th day in concentrations between 1000 and 1 000 000 cfu/g. The same doses applied at 9.8 Gy/s inhibited recovery of *C. sphaerospermum*.

For successful γ-radiation reduction of fungal contamination on cultural heritage it is essential to determine mycobiota composition and to irradiate at an appropriate dose rate.

Personal Radiation Dosimetry at Radiological Facilities, Nepal

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The saga of using ionizing radiation is long back in Nepal especially in medical sector. With the introduction of radiation therapy and nuclear medicine, it has been felt the need of monitoring occupational radiation exposure. Only few hospitals three to four are monitoring their staff by sending thermoluminescent dosimeter (TLD) badges to Bhabha Atomic Research Centre, Mumbai, India. Over 95% radiation workers are never been monitored for their radiation dose. However, it is a mandatory by ILO that every radiation worker should be monitored for radiation exposure. To meet this requirement from the overwhelming requests from various hospitals, the Nepal Academy of Science and Technology (NAST) initiated this work in 2013 with the assistance provided by the IAEA.

The government of Nepal has assigned NAST to provide the dosimetry service for radiation workers in Nepal. For this service, a dosimetry setup comprising a Harshaw 6600 Plus TLD Reader along with TLD cards (TLD 100 LiF:Ti.Mg) has been installed in December 2015 at the Physical Science Laboratory, NAST. The complete dosimetry system became operational in March 2016 with the help of IAEA expert mission. Under a test service, Manamohan Memorial Cardiovascular and Transplant Centre (MMCTC) was chosen where 22 TLD cards were earlier provided to the personnel to wear and the cards were read out for dose assessment. The first personal dosimetry report for one month was issued in March 2016 for this hospital. The penetrating dose Hp(10) and skin dose Hp(0.07) of individuals have been reported. The absorbed dose distribution of personnel show that few radiation workers received significant radiation in that duration.

Electron Beam Techniques for Air Pollution Control

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Various technologies such as absorption, adsorption, incineration, biofiltration and advanced oxidation have been developed to treat air pollutants. However, these methods have some limitations such as a high pressure drop, short lifespan, large site, economics and formation of secondary pollutants. To solve these problems, recently, advanced oxidation processes have been studied. An electron beam (EB) technology is one of the most promising advanced technologies due to its special characteristics. The EB technologies for volatile organic and odorous compounds treatment are introduced in this paper. The removal efficiency of these compounds by an EB processing is discussed in diverse conditions, such as different initial concentrations, background gases, absorbed doses, relative humidities, etc. Furthermore, the characteristics and effects on new EB hybrid technologies designed to overcome problems of only EB system are reviewed. In additional, the limitations and potentials of EB technology for air pollution treatment are also discussed.

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PA1

Dosimetric Properties of MgB_4O_7:Ce and MgB_4O_7:Ce, Li for Thermoluminescence Dosimetry Applications

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Thermoluminescent dosimetry is known as a well-established technique for monitoring radiation dose in medical practices. Some most used thermoluminescent dosimeters (TLDs) are: LiF:Mg,Ti (TLD-100), CaF:Mn, $CaSO_4$:Dy, $Li_2B_4O_7$, and aluminophosphate glasses. Recent studies have demonstrated that borates can be very useful for TL dosimetry because their compounds may be more sensitive to radiation than the commercial dosimeters as TLD-100. Furthermore, compounds with ^{10}B allow the detection of thermal neutrons ($E < 0.25$ eV). They also have other good dosimetric properties, such as linear dose response over a large absorbed dose range, effective atomic number close to that of human tissue, and a simple TL emission curve with a single peak. However, there is not much discussion about preparation routes for dosimeters based on borates and on the structure of their compounds. Among these, we examined thermoluminescence properties of magnesium tetraborate doped with cerium (MgB_4O_7:Ce) and co-doped with lithium (MgB_4O_7:Ce,Li). Some important TL properties were investigated such as: dose response for γ and β, fading and kinetic parameters of TL curves. To study TL response, the material was investigated in pellet format (3 mm diameter) that were irradiated with sources of β particles (^{90}Sr/^{90}Y) and γ-rays (^{60}Co) with different absorbed doses. The TL responses were measured using an TL/OSL reader (TL/OSL reader Riso). The results showed that the materials have great potential for TLD dosimetry, presenting low fading of TL signal ($< 3\%$ in one month) and prevalence of first-order TL peak. The dose response curves also show that saturation occurs at higher doses (up to 1000 Gy) and the kinetic parameter shows TL curve follow kinetic of first order.

Radiolysis Induced Degradation of Fluoroquinolones

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The fluoroquinolones are synthetic antibiotics and inhibit very effectively gram-negative bacteria, but do not totally degrade during common wastewater treatments, hence, they will be released in the environment. The environmental exposure of the fluoroquinolones can lead to bacterial resistance. Because these compounds do not degrade during the common wastewater treatments radiolysis as an advanced oxidation process was investigated.

Gamma-radiation induced degradation of two frequently used fluoroquinolone antibiotics, ciprofloxacin and norfloxacin was investigated with UV-Vis spectrophotometry, with HPLC-UV and with organic sum parameter measurements (chemical oxygen demand (COD) and total organic carbon (TOC)). The samples were irradiated with doses between 0.2 and 10 kGy. The HPLC analysis was performed on a C18 column, with gradient elution and with diode array detection. In the case of UV-Vis spectrophotometry the solutions were saturated with nitrogen, air or dinitrogen-oxide before the γ-radiation. In some cases *tert*-butanol was applied to scavenge the hydroxyl radicals. At the measurements of organic sum parameters and the HPLC analysis, the fluoroquinolone solutions were saturated with air. The degradations of ciprofloxacin and norfloxacin were also investigated with pulse radiolysis technique. Microsecond pulse radiolysis experiments were performed with 4 MeV accelerated electrons, with electron pulse length of 800 ns. The detection was kinetic spectrophotometric. An optical filter was used because of the bleaching below 400 nm in the case of fluoroquinolones. Transient absorption spectra of the intermediates produced by reactions with hydrated electrons were calculated.

The hydroxyl radical-induced degradation was the most efficient comparing to the other reactive radicals like hydrated electron and hydrogen atom formed during water radiolysis. The reaction with hydrated electrons was also effective, in this case yellow degradation products were formed. Based on the literature these products were presumably isatin analogues. The COD values decrease approximately linearly with the dose. The decrease was faster for low doses, presumably because the more easily degradable compounds degrade first. The TOC values decreased also approximately linearly with the dose and the results in case of ciprofloxacin and norfloxacin were very similar. HPLC analysis with diode array detection showed that three intermediates were produced by γ-radiolysis. The parent compound and one of the intermediates were totally degraded, and two other intermediates were partially degraded with the increasing dose. The concentration of the parent compound decreased strongly with the absorbed dose. Pulse radiolysis experiments showed that hydroxyl radical reacts with the parent compound and one radical intermediate was produced during 5 μs, and then it degraded. In the case of hydrated electrons, presumably two radical intermediates were produced, and then it degraded in microsecond timescale.

The experiments showed that the degradation and mineralization of fluoroquinolones linearly depends on the absorbed dose. The removal of fluoroquinolones from water was effective in the case of γ-radiolysis and also in the case of pulse radiolysis.

Tunisian Experience Assessment of Installing a Pilot ^{60}Co Source for Irradiation

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Radiation processing technology started in Tunisia by the installation of a pilot plant γ-irradiator in 1999 in National Centre for Nuclear Science and Technology (CNSTN) situated at about 20 km north of the capital Tunis. This facility was established with the support of the IAEA in the frame of the technical co-operation assistance programme and the French Atomic Energy Commission (CEA).

The facility is equipped with ^{60}Co source with dry storage and an initial activity of 100 kCi in 1999 (10 kCi in 2016). The source consists of telescopic ^{60}Co source (08 of C188 pencils-from Nordion), this french design was logged in a concrete shielding room about 1.7 m of thickness.

This irradiation facilities are designed to be used for the promotional activities of radiation processing applications, in particular for conservation of foodstuff, sterilization of medical devices conservation of art objects and also dedicated to play a great role in enhancing research and development work and providing services to industries mainly in the fields mentioned above and to gives more competitiveness for products dedicated for export to European Union countries.

In this reason Tunisia has implemented a regulation that authorizes radiation sterilization of various pharmaceuticals and foodstuffs. The poster will focus on the activity of radiation technology by Tunisian pilot plant, and show the socio-economic advantages in industry and scientific research during fifteen years of this technology in the country, and discuss the goals achieved.

γ-Radiation-Co-Cryogelation Induced Synthesis of Macroporous rpCryogels for Bioengineering Applications

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Polymeric porous scaffolds are a key component in several bioengineering and biomedical applications. In a recent development, we have introduced a novel approach for the designing of macroporous matrices by combining γ-radiation with cryogelation technology. This new prototype has been optimized and compared with the classical cryogelation technology. The acrylic derivatives like acrylamide (AAm) and N-(2-hydroxyethyl) methacrylamide (HEMA) have been used in our study as the model precursor units considering their inert behaviour and selective biocompatibility. In the process of radiation-co-cryogelation, optimum radiation dose causes polymerization of monomers, which do not require addition of any reaction initiator and activator for free-radical polymerization. However, simultaneous cryogelation allow the phase separation which leads to the formation of water ice crystals (porozens) at sub-zero temperature. The optimum process parameters like radiation dose, temperature, monomer's concentration, physical/chemical molding, volume and incubation time, are providing suitable environment to fabricate an ideal porous radiation-cryopolymerized cryogel (rpCryogel). This new approach is suitable to fabricate scaffolds with controlled physico-chemical properties like variable pore sizes, pore interconnectivity and desired mechanical integrity and rheological properties by varying the dose of γ-radiation and temperature at constant polymer precursor's ratio. The scanning electron microscopic observation of AAm and HEMA rpCryogels shows presence of interconnected pore morphology having pore size range of 20 to 200 μm at different doses of irradiation. Like classical cryogel, the rpCryogels showed similar behaviour of various physico-chemical properties like hydraulic permeability (10^{-4} $m^4N^{-1}s^{-1}$), density (1 to 1.5 g/cm^3), water uptake kinetic (reach to equilibrium within 1 min) and water retention capacity (more than 10 times its dry weight). Mechanical stiffness of rpCryogel showed a steep decrease (10 times reduction in compression modulus) upon hydration in distilled water suggesting its hydrophilic nature and soft material like property, which is preferable in many bioprocesses. These monoliths can be compressed up to 70% of their original length without showing permanent deformation presenting their high elastic behaviour. Importantly, unlike classical cryogel which require approximately 18 h for synthesis, this novel integrated approach requires only 3 h for the fabrication of rpCryogels in different formats. The transitional changes between dry and wet state did not show change in its physico-chemical properties, which describe long term storage stability of these rpCryogels in dry state and wet state. Thus, the designing of elastic and macroporous monoliths by integrated controlled radiation and cryogelation process provides novel speedy approach for the fabrication of macroporous rpCryogel for various bioengineering application and could meet the supply requirement for commercial utilization. At present, we are investigating the successive use of macroporous polymeric cryogels for biomolecules immobilization, bioprocessing, tissue-engineering and environmental applications.

Kinetics of Free Radicals Decay Reactions in Cellulosic-Based Heritage Materials Disinfected by γ-Radiation

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Disinfection by γ-radiation of cultural heritage artefacts and archived materials has been successfully applied in recent years. Radiation processing used for cultural heritage disinfection has several advantages when compared to conventional methods (e.g., chemical gases) mainly related to the safety, efficiency, reliability, capacity, process time and safety for users and the environment. However, more research is still required to study undesirable effects (side-effects) which may appear in sensitive materials as a function of the absorbed radiation dose. Some conservators and restorers are frequently worried about possible long-term effects in irradiated materials (post-effects). During the irradiation process, some energetic and unstable chemical species called free radicals appear in the treated matter. They disappear in different ways, interacting either with each other or with the artefact compounds thus becoming responsible for disinfestation and irradiation side-effects.

The kinetics of free radical decay reactions depend on the absorbed dose, the properties of irradiated material among others. In this study, contemporary paper samples were irradiated using γ-radiation from ^{60}Co with different absorbed doses. The absorbed dose range was chosen taking into account the effective values to promote insect eradication, fungal disinfection and sterilization. The decay kinetics of the cellulose free radicals induced by irradiation was analyzed using electron paramagnetic resonance. Several spectra were obtained at room temperature for each applied absorbed dose immediately after irradiation as reference measurements. To understand the free radical decay process, additional spectra were obtained for different decay times up to almost 50 days after irradiation. De-noising treatment of the original obtained spectra signals were performed using wavelets. Free radical populations, proportional to the spin concentrations, were found by integrating the electron paramagnetic resonance signal curves. Comparison of spectra was done by normalizing the calculated area corresponding to cellulose spin concentration, taking first measurement after irradiation as 100%. Further analyses and calculations were made to study the half-life and the kinetics models of the free radicals created. X-ray diffraction was carried out to identify crystalline phases and the effect of ionizing radiation on the crystalline structure of cellulose in paper. Scanning electron microscopy and scanning electron microscopy energy dispersive spectrometry were performed to analyze structure modifications induced by ionizing radiation, identifying cellulose fibre agglomeration zones and to quantify chemical elements.

Results show that for the sterilization dose, 80% of the cellulose free radicals induced by ionizing radiation disappear in almost 40 days and for disinfection dose in 8 days. It can be concluded that if no modifications (side-effects) appear in the irradiated material after the radical decay time, the material will stay stable for the remaining lifetime. Results showed that the proposed method using electron paramagnetic resonance is suitably to study the behaviour of radicals on cellulosic-based cultural heritage materials.

Feasibility of Using Irradiation to Degrade a Toxic Dye Compound

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Crystal violet (CV), is widely used for dyeing cotton, silk and paper. It has carcinogenic and mutagenic effects other than antimicrobial properties. The toxicity of this wastewater represents a great risk to the ecosystem and must be treated before being discharged into the environment. However, the complex aromatic molecular structures of CV make them more stable and more problematic to degrade. Therefore, the removal of this synthetic dye is of great concern because of the difficulty in treating such effluent by conventional methods. In this study γ-radiation was investigated as a method for removing CV from water. Absorbance, concentration, toxicity in eukaryotic cells and bacteria were analyzed.

The CV solution (300 mg/ℓ) in glass bottles were irradiated in a ^{60}Co γ-radiation facility. Absorbance (1/10 dilution) and concentration were measured in a UV-vis spectrometer. Cytotoxicity was tested in Vero cells after 24 h of treatment with different concentration of CV solution irradiated. Cellular viability was determined with CV staining assays and absorbance analysis at 570 nm. Cytotoxic concentration 50% (CC50) was calculated comparing treated cells with cellular control. Antimicrobial susceptibility were analyzed using the NCCLS guidelines for the microdilution method and minimum inhibitory concentration (MIC) was defined.

The absorbed doses of CV solution were 1.1, 2.2, 3.1, 4.5 and 5.2 kGy, the absorption spectra showed very small shift of the major peaks at about 300 nm and 580 nm but a reduction in the height as the dose increase, indicating that the concentration of CV is reduced. However, an small peak appears in the irradiated solution at 359 nm, indicating the possible formation of an intermediate metabolite 4,4′-bis(dimethylamino) benzophenone, as was reported by other authors. The absorbed dose strongly affects the degradation of CV in water, at 1 kGy 66% was still remaining, and 20% with 5.2 kGy.

The cell viability results from CV 0 kGy demonstrated the severe inhibitory effects by these chemicals; the CC50 was 8.8 mg/ℓ. In contrast, the treatment of the solution with the incremental doses of γ-radiation reduced the toxicity. The results showed that with 1.1 kGy the CC50 was 85.6 mg/ℓ and 109 mg/ℓ for the solution treated with 5.2 kGy. Antimicrobial activity of the CV solution showed a reduction in a dose-based effect in all the microorganisms tested. *Staphylococcus aureus* MIC increase from 1.5 mg/ℓ to 37.5 mg/ℓ for the solutions 0 kGy and 5.2 KGy. Similar results were obtained with *Bacillus cereus* (6.25 to 100 mg/ℓ) and *Escherichia coli* (50 to $>$ 150 mg/ℓ). This study provided both a reference for radiation degradation of CV without producing undesirable intermediate metabolites and an alternative treatment processes for dye wastewater.

Toroidal Electron Source

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Electron beam sources are important for a very broad field of applications. Sterilization of surfaces, irradiation of polymers for degradation, polymerization, grafting and cross-linking, as well as hardening of lacquers and disinfection of seed are an abstract of applications where electron beams are the state of the art. The penetration depth of accelerated electrons on atmosphere is very limited. The electrons lose their energy on air. To apply an homogeneous dose on 3D shaped products is difficult with existing line emitters or scanners with flat window geometry. Current state-of-the-art is the usage of 2 or 3 line emitters to reach every surface point on these kind of products.

FEP has developed an innovative toroidal-shaped electron emitter that emits electrons to the centre of the source. The base of this source is the splitting of electron generation and electron acceleration into two separate process steps. The first step is the generation of the electrons: A plasma generates ions, the ions hit a cold aluminium cathode, thus electrons are generated by ion bombardment of a cold cathode. In the second step the electrons are accelerated by an negative potential on the cold cathode in direction to the electron exit window. The first laboratory machines are designed in ring shape. The inner dimension on atmosphere is 180 mm. Even more difficult shapes or are much taller inner dimensions are possible.

The research and development of initial plasma and the generation of an homogeneous electron beam are part of scientific investigations and will be shown during ICARST. FEP will present adjustment of dimensions, pressure and current for reach stable plasma conditions and dosimetric analysis of treated products like 3D shaped SCF tubs that shows proof of improvement in comparison to state of the art processes.

γ-Radiation Induced Decolouration and Degradation on Aqueous Solutions of Indigo Carmine Dye

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The textile industry has long been one of the largest water users and polluters. Wastewater released by textile industries contains toxic refractory dye stuff at high concentration. Most of the dyes in the textile industry are non-degradable, therefore, effective treatment of dye waste effluent has not been achieved by ordinary processes. Ionizing radiation has been considered a promising process for the treatment of textile dye waste effluents.

In this study, the possibility of using γ-rays to degrade or decolourize a reactive dye in water was investigated. A reactive dye (indigo carmine) in aqueous solutions was irradiated at doses from 0.1 to 5 kGy at 47.62 Gy/min dose rate. The change of absorption spectra, chemical oxygen demand (COD), and the degree of decolouration were examined. The absorption bands at 248, 285 and 606 nm decreased rapidly with increasing irradiation dose. The COD reduction for the dye solutions attended 90% at 5 kGy. Finally, a kinetic study based on spectrophotometric measurements showed that the degradation process is pseudo first order with an apparent constant k_{app} equal to 2.693/min.

PA1

Electron Accelerator for R&D Study and Radiation Processing

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Upgrading of radiation facility located at the Institute of Nuclear Chemistry and Technology (ICHTJ) in Warsaw has been performed towards higher technical and economical effectiveness, better operational characteristics suitable for radiation processing and research programmes. The radiation facility located at ICHTJ was established in 1993, when a 10 MeV, 10 kW magnetron powered linear accelerator was installed in a separate building and equipped with an appropriate conveyor system. During facility exploitation, spare part availability and cost become a major problem in the maintenance of continuous service as required by facility customers. The project objective, partly supported by the IAEA, was the construction of a 10 MeV, 10–15 kW linear electron accelerator equipped with the microwave source based on TH 2158 klystron (Thales, France), and standing wave accelerating section (manufactured by NIIEFA, St. Petersburg, Russia).

The following stages of the design have been followed: electron gun, microwave system of accelerator, auxiliary systems including klystron stand, pulse power supply stand, driving generator stand and waveguide system, control, vacuum and water cooling systems. The triode electron gun with spherical impregnated cathode was selected as a source of electrons. The gun parameters were optimized to meet requirements of standing wave accelerating structure (distance between cathode and grid, distance between grid and anode, additional beam focussing to obtain proper beam dimensions). The nominal parameters of accelerator gun: 0.3 A; 50 keV; pulse repetition rate up to 300 Hz; pulse duration 20 μs. Fibre-optic synchronization and triggering circuit based on pulse generator as reference source were applied as triggering track of electron gun modulator, klystron modulator, and microwave amplifier. Klystron modulator was designed on the based of semiconductor switch (current load 1600 A, with voltage up to 18 kV). The modulator has been constructed to fulfil requirement of TH 2158 klystron including safety (shutdown) circuit for protection against current overload which may appear at semiconductor switch. The modulator is switched off, and modulator load current falls to zero if value of overload current surpasses 900 A.

The microwave system of the accelerator is assembled from standard S-band components including microwave isolator which was used to separate klystron against reflected wave after breakdown occurs in accelerating section. SF_6 isolation gas is used in waveguide elements to improve isolation properties. The main accelerating section parameters are as follow: electron energy 10 MeV, energy spectrum $\pm 2\%$, average beam power in the range 10–15 kW, pulse microwave power < 5 MW, frequency 2856 MHz, electrical efficiency up to 58%, electron beam capture coefficient up to 85%, pulse output beam current 210 mA in nominal conditions. Accelerator control system is equipped with Siemens microprocessors and modules type Simatic S7-300, with communication channel Profibus and as SCADA tool (supervisory control and data acquisition) WinCC. The vacuum system consists of three ion vacuum pump type (pumping velocity 60 ℓ/s) and turbomolecular vacuum pump which is used to start ion pumps at certain vacuum level. Accelerator is installed in vertical position and equipped with beam scanner 60 cm wide.

PA2: Posters PA2: Radiation Creation of Materials from Fundamentals to Application

PA2

Developing a Simple Method Using Ionizing Radiation to Produce Polyacrylic Acid Based Nanoparticles

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The present work aims at synthesizing polyacrylic acid-based nano-particles using ionizing radiation without surfactants. In this regard, acrylic acid in a solution in the presence of polyaliphatic ester polymers like polycaprolactone and polylactic acid was exposed to ionizing radiation at different dose rates to produce chemically cross-linked polyaliphatic ester /PAAc nanoparticles. Particle size and swellability of the prepared nanoparticles can be controlled by irradiation dose, irradiation atmosphere, and feed copolymer composition and concentration. Characterization of the prepared nanoparticles including morphological structure, pH sensitivity and rheological characteristics was carried out using dynamic light scattering (DLS), viscometry, transmission electron microscopy (TEM) and atomic force microscopy (AFM) techniques.

Synthesis by γ-Radiation and Characterization of Poly(Vinylpyrrolidone) Nanogel

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The synthesis of polyvinylpyrrolidone (PVP) nanogels by ionizing radiation techniques (γ irradiation), for their evaluation as potential system of drug delivery was the aim of this research. Solutions were prepared with water purified by distillation and in order to remove any dust particles and/or polymer aggregates, solutions were filtered subsequently through filters of 0.45 and 0.22 μm pore size. The γ-irradiation was carried out with a panorama ^{60}Co source at dose ranging from 5 to 25 kGy.

Particularly, the polyvinylpyrrolidone nanogels can be obtained by γ-radiation, based not on polymerization, but on intramolecular cross-linking of polymers chains, in aqueous solutions. The nanogel characterization was performance by electron microscopy (TEM, SEM), DRX, spectroscopy (UV-visible and IR), light scattering, viscosimetry, delivery of an active agents and cytotoxicity trials.

The results showed that in dependence on the polymer concentration and the rate dose two different cross-linking reactions can take place. Irradiation experiments at room temperature in diluted solution with further increasing of the radiation dose lead to the formation of PVP nanogels due to an intramolecular cross-linking reaction. By using both light scattering and TEM the PVP nanogels were measured, these showed a size distribution of 50.10 nm. They have lots of advantages over conventional systems since they enhance the delivery, extend the bioactivity of the drug by protecting them from environmental effects in biological media, show minimal side effects, demonstrate high performance characteristics, and are more economical since minimum amount of expensive drugs are used.

PA2

Application of γ Radiation and Physicochemical Treatment to Improve the Bioactive Properties of Chitosan Extracted from Shrimp Shell

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The aim of this study is to improve the different bioactive properties of chitosan extracted from chitin by different physicochemical treatments including γ-radiation. Chitin was prepared from shrimp shell upon deproteination, decalcification and oxidation with 4% NaOH, 4% HCl, and 2% H_2O_2 respectively. To find out a more efficient, economically reasonable and time saving chitosan extraction method other than existing methods, eight different physicochemical treatment methods (designated as A, B, C, D, E, F, G and H) varying different parameters were applied for chitosan extraction. Chitosan produced by these extraction methods were compared with commercially available chitosan and assessed with respect to degree of deacetylation (DD-value), molecular weight, antimicrobial activity and solubility. DD-value of chitosan extracted by method A, B, C, D, E, F, G and H were $75.0 \pm 0.28\%$, $92.0 \pm 0.34\%$, $81.0 \pm 0.51\%$, $89.0 \pm 1.34\%$, $69.0 \pm 0.05\%$, $87.0 \pm 0.35\%$, $82.0 \pm 1.4\%$ and $92.0 \pm 0.92\%$ respectively whereas the DD-value of the commercially available product was $\sim 75.0\%$. Viscosity-average-molecular-weights were found $1.77 \times 10^5 \pm 0.28$, $1.6 \times 10^5 \pm 0.50$, $1.82 \times 10^5 \pm 0.46$, $1.19 \times 10^5 \pm 0.39$, $2.25 \times 10^5 \pm 0.39$, $1.41 \times 10^5 \pm 0.67$, $1.77 \times 10^5 \pm 0.28$ and $1.16 \times 10^5 \pm 0.69$ Dalton, respectively. Antimicrobial activity of all chitosan samples was found insignificant and all the samples could be dissolved completely at minimum 0.5% of acetic acid solution.

For further quality improvement, chitosan with highest DD value (prepared by method B) was irradiated with different doses (5.0, 10.0, 15.0 and 20.0 kGy) of γ-radiation and again assessed for different quality parameters. Though no significant changes in DD value of chitosan was observed upon irradiation, it causes significant changes in the molecular weight of chitosan samples. Molecular weight gradually decreased as the radiation dose increased. Molecular weight of the samples treated with the radiation doses of 5.0, 10.0, 15.0 and 20.0 kGy were 1.786×10^3, 1.518×10^3, 1.134×10^3 and 1.046×10^3 Dalton, respectively. Radiation treatment of chitosan samples also increased the antimicrobial activity in concentration dependent manner. One and half (1.5%) percent chitosan solution treated with a radiation dose of ~ 10.0 kGy showed highest antimicrobial activity.

Repeated alkali treatment (20 M NaOH) and autoclave for 30 minutes was found to be the best extraction method and irradiation of chitosan solution with 5.0 to 10.0 kGy further increased its bioactive characteristics including enhanced antimicrobial and solubility properties.

Predicting the Behaviour of a Biomaterial as Bone Replacement

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When an artificial material is implanted into the body, a fibrous capsule may appear separating the material and the tissue. But when the material is bioactive, this capsule doesn't appear, and the biomaterial conducts the formation of an interfacial bonding between the implantable device and living tissues, called apatite. The bioactivity is defined as the biologic positive answer in a determined biological environment (human body or a simulated human environment). To evaluate the feasibility of new biomaterial development, it is important to know their bioactivity because this may predict the bone-forming ability of an implantable material for bone tissue replacement. Another property that helps in this prediction is the bio-evaluation of these materials, where the initial evaluation involves the cytotoxicity, which determines the possible toxicity produced on cells by the device, and also considers the nature of body contact and duration of contact. The objective of this study was to analyze the bioactivity and cytotoxicity of a bone replacement biomaterial, consisting of high density polyethylene (HDPE) with a load of hydroxyapatite (HA).

Biomaterial samples were prepared by extrusion as flat and rectangular specimens composed of HDPE and different loads of HA (100:0; 90:10; 70:30; 50:50); and they were irradiated with different γ-radiation doses (15, 30 and 45 kGy). Radiation is used to promote cross-linking to minimize wear under physiological conditions, and for sterilization. To assess the bioactivity a blood similar solution was used (ISO 23317). The samples were incubated for 30 days. Their surfaces were analyzed by scanning electron microscopy (SEM) and the crystallinity of the HA produced on the surface was determined by X-ray diffraction (XRD). Citotoxicity was conducted using the MTT assay determining the cellular viability (ISO 10993-5). The results obtained by XRD and SEM showed an homogeneous formation of HA crystals, without differences between compositions and irradiation doses. Only in the samples 100% HDPE did not present apatite crystals on its surface. All samples showed viability higher than 70%, indicating that no cytotoxicity was generated in any condition.

Based on the obtained results, the biomaterial samples composed of HDPE and HA were bioactive and non-cytotoxic. Therefore the biomaterial seems to be a good bone tissue implant. These studies carried out, showed to be very useful, as a preliminary or screening step, before starting with the clinical trials. They can reduce costs, when the composition or the process has to be changed before going forward. On the other hand, when the results are satisfactory, they can predict that these materials will generate an appropriate beneficial cellular or tissue response in that specific situation. It has been demonstrated that materials that possess favourable hydroxyapatite layer formation integrate more successfully in the body. Additional tests are underway on this biomaterial to define which the best composition is and which is the optimal radiation dose that generates a simil-bone biomaterial, with similar mechanical properties, and with minimal degradation debris.

PA2

Electron Beam Synthesis of Inulin Hydrogels Extracted from *Helianthus Tuberosus L.*

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Obtaining hydrogels from various classes of natural polymers has undergone significant growth over time especially for applications in the biomedical field. Hydrogels made from natural polymers have the advantage of being biocompatible and biodegradable. In this context, an important role is played by inulin-based hydrogels, which is a natural polysaccharide. In our study we describe a method for extracting inulin from Jerusalem artichoke (*Helianthus tuberosus L.*) while current methods imply obtaining inulin form the root of chicory (*Cichorium intybus*).

Inulin form Jerusalem artichoke was supplied by S.C. Hofigal Export Import S.A. The concentrated inulin extract was obtained after three consecutive extractions in vacuum. The Ar-saturated inulin extract was irradiated with an electron beam at the dose rate of 2–4 kGy/min up to 25 kGy in "paste-like" conditions and in the presence of tannic acid (TA) and glycidyl methacrylate (GMA). Sol-gel analysis was performed in order to determine the polyssachride-gel conversions ratio, the radiochemical yield of cross-linking and degradation. In order to follow the formation of a 3D hydrogel network and its composition, dynamic rheological measurements and FT-IR analysis were performed. The swelling capacity was determined in deionized water and phosphate buffer solution pH=7.4 at 37°C.

The resulting gel fraction is dependent on the absorbed dose and on the increasing concentrations of TA and GMA. The value of radiochemical cross-linking yield was larger than degradation yield. The rheological measurements revealed the obtaining of a gel with $G' > G''$, where the G' value has decreased with dose. The maximum value of swelling capacity for the inulin hydrogel was found to be around 10 000%, with smaller values for gels that were swollen in phosphate buffer solution. This gel offers a promising route of administration for various drugs with anti-inflammatory and analgesic properties. This study will be continued by embedding natural extracts obtained from arnica, pepper, aloe vera and Echinacea, in the inulin hydrogel, in order to obtain a product with applicability in treatment of chronic colon disease.

Recycled HDPE/Vulcanized EPDM Mixtures Obtained by Irradiation Processes

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Recycling polymers process includes techniques that present solutions to the problem of plastic waste in the environment. This process is important to improve the economic sector in many countries, like cooperative societies. Primary recycling is related to the reuse of plastic waste directly from the production site in the industry, that carry on some advantages besides the low cost involved in the reuse of this waste: the raw material is free from dust of many kinds (metals, different powders and plastics). Among this polymeric waste, packaging dominates this scenario, covering 62.2% of the total, where polyolefins account more than 50% of the packaging production. In the same way, the recovering of sulfur-cured rubber contribute to release the environment from this almost non-degradable rubber. The goal of this work is to produce an alternative recycled product composed by mixing twenty-times reused HDPE (by primary recycling process) with vulcanized EPDM rubber. The twenty-times recycled thermoplastic was reached by extrusion, which intention was to simulate a polyolefin like a scrap. The EPDM rubber was fragmented and incorporated to the thermoplastic matrix in proportions of 1% and 5% w/w, from both kinds of rubber, like received and after a thermal treatment. One of the thermal treatment of rubber consisted in an oven ageing in the temperature of 100°C; the other was a simultaneous heating under irradiation process by electron beam at 130°C and at 100 kGy absorbed dose (at 22.4 kGy/s dose rate). The final mixture was obtained by injection molding and specimens from injection process were γ-irradiated at 50 kGy and at 100 kGy. Mechanical analysis of stress-strain, infrared FTIR spectra and thermogravimetric degradation were performed to evaluate the final product. The obtained product showed heterogeneous; the rubber without thermal treatment was better incorporated to thermoplastic matrix and the irradiated samples present mechanical resistance that suggests this new material intended to be viable to industrial use.

Determination of the Radiation Dose Required to Obtain Desired Viscosity Average Molecular Mass Using Commercially Available Chitosan and Signification of this Technique in its Applications

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Radiation processed chitosan polymers are used in many applications in the field of agriculture such as plant growth promoters, elicitors, fungicides and self-life extending coatings for fruits, etc. Radiation or chemical degradation techniques or a combination of both methods can be used to convert higher molecular masses of chitosan to its different low molecular masses. The applicability of the chitosan in the above applications highly depends on the molecular weight of chitosan. However, viscosity average molecular masses of commercially available chitosan (CAC) show huge variations and these variations arise due to the use of different techniques in the extraction process. This variation of the molecular masses of the CAC makes it difficult to determine the correct radiation dose to obtain the desired molecular weight. The main objective of this study is to construct a correlation between the variation of viscosity average molecular mass of CAC samples versus irradiated doses. The above correlation enables the determination of the radiation dose required to get the desired molecular weight from a known initial molecular weight. The viscosity average molecular mass is the key factor of the performance of the products developed using chitosan.

CAC samples with similar degree of deacetylation (DDA) and various molecular masses were irradiated at different radiation doses using GC-5000 Gamma Cell under 3.4 kGy/h dose rate. The viscosity average molecular mass of these irradiated samples were analyzed using capillary viscometric method. AVS 470 Visco system with a standard solvent system (0.25 M CH_3COOH/ 0.25 M CH_3COONa at 25°C) and Mark-Houwink-Sakurada equation were used for the determination of viscosity average molar masses. The relationship between the varying viscosity average molar masses versus absorbed dose was constructed using regression analysis and desired molecular weight was obtained using this relationship.

Oligo chitosan with selected molecular masses are used in the production of some agro-products and the above technique can be used as an initial step of the production of oligo chitosan with required molecular weight using CAC. Oligo chitosan can be produced using a combination of chemical and γ-irradiation techniques (synergistic technique) in aqueous media. However, a standard procedure cannot be followed in the production of oligo chitosan due to the dissimilarities of the molecular masses of CAC. Therefore, a fixed initial molecular weight (compatible with existing standard procedure) should be produced using CAC in order to follow a standard procedure based on the synergistic technique. The regression curve developed under this study was used to find out the required dose to produce fixed molecular weight using CAC. Therefore, the procedure developed through the above study can be utilized to derive the fixed low molecular weight chitosan to follow the standard procedures used in pilot and commercial scale productions of agro products which are based on oligomer/low-molecular-weight chitosan.

The Effect of Radiation Environment on Electrical Insulation Materials

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Due to recent renewed interest in reactor safety and many reactors approaching end of useful lifetime, emphasis on durability of power and instrumentation electrical Insulating Materials is growing. While current materials have shown suitable radiation tolerance in lab testing, combined effects of radiation, temperature, and water at normal or abnormal conditions have led to cable failures. Effects of radiation types and dose rates on selected cable insulating materials have been studied. Effects of dose-rate temperature during radiation on service endurance are considered. Dielectric materials used to fabricate various parts of electrical equipment systems, nuclear and electronic devices often operate in ionizing radiation fluxes, problems of radiation resistance and changing of insulating materials and devices are urgent. It is necessary to develop ways to improve the radiation resistance.

Radiation damage to dielectric and insulating materials is a function of temperature and atmospheric conditions as well as the radiation environment. Many materials are more resistant to radiation in the absence of oxygen or moisture and at lower temperatures. Because of this influence of environmental conditions it is impractical to attempt to compile detailed information that would be directly applicable to all circuit requirements and environmental conditions. The fabrication method used by the manufacturer can also be a factor in the amount of damage that occurs from radiation. Both temporary and permanent changes occur in the characteristics of organic insulating and dielectric materials as a result of exposure to a radiation environment. Enhancement of the electrical conductivity is the most important of the temporary effects with increases of several orders of magnitude being observed. The conductivity increases exponentially in response to ionizing radiation until it reaches equilibrium at a value that is determined by the rate of exposure and ambient temperature for a specific material. Following the termination of the irradiation the induced conductivity gradually decreases. Other temporary effects, in addition to the enhanced conductivity, are a reduction in breakdown and flashover voltages, increases in AC loss characteristics, and variations in dielectric constants. These changes in electrical characteristics, however, are often not large enough to prevent the use of the insulators in a radiation environment, particularly if allowances are made to minimize their effect on the circuits' performance.

Permanent effects of radiation on organic insulating materials are normally associated with physical changes, including decreases in hardness, tensile strength and melting point, and greater solubility. This physical degradation in the advanced stages is disastrous in that the insulating material breaks, crumbles, or powders thus losing structural integrity and causing failure. Changes in dissipation factor and insulation resistance have also occurred as permanent effects, but they are normally quite small and offer few problems except in the most uncommon applications. A comparison of the relative radiation resistance of organic insulating materials to permanent effects is presented. Gas evolution, a secondary reaction that occurs when organic insulators are irradiated, is a problem because of pressure buildup in confined enclosures.

PA2

Radiation Synthesis of Acrylic Acid onto Poly(tetrafluoroethylene-perfluorovinyl ether) Film: Chemical Modifications and Electrical Conductivity

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Graft-polymerization of acrylic acid (AAc) monomer onto poly(tetrafluoroethylene-perfluorovinyl ether) copolymer film was carried out using γ-irradiation techniques to synthesize graft copolymer membranes PFA-g-PAAc (PFA-COOH). The effect of the irradiation dose on the degree of AAc grafting onto PFA films was investigated. The results showed that the degree of grafting increases with increasing irradiation dose. The grafting yield 19, 47 and 73% of the prepared films [PFA-COOH] were selected for chemical modification by reaction with aniline to produce modified membrane [PFA-CO-NH-ph] followed by sulfonation reaction to introduce sulfonic acid (SO3H) groups to get other modified membrane [PFA-CO-NH-ph-SO3H]. The chemical structures of the grafted and modified membranes were characterized by FT-IR, XRD, and SEM techniques.

It is of particular interest to measure the AC conductivity of flexible chemical modified membranes as a function of grafting degree. The modified membranes of the grafting yield 40 and 80% exhibited AC electrical conductivity. The electrical conductivity increases with increasing grafting degree and by chemical modification especially aniline modified grafted films. The electrical conductivity of modified membranes considered for use as semiconductor materials in fuel cell applications.

Sorption of Iodine on Ion Exchange Resins

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One of the most important applications of radiation in the field of chemistry is the modification of polymeric species for the purpose of separation and purification of radioactive species is radiation induced graft polymerization (RIGP) and emulsion polymerization both in which various factors affect the polymerization process most important of which is the radiation dose. The monomer glycidyl methacrylate (GMA) has been polymerized by radiation induced graft polymerization on polyethylene tubes with optimum solvent concentration, radiation dose, radiation time, and also GMA has been polymerized by radiation emulsion polymerization influenced by the irradiation dose rate and the type of emulsifier namely TWEEN 80 in this study. The GMA is a significant monomer due to the presence of the epoxy group which can further modified for purpose of ion exchange.

Ion exchange is the optimum technique for treatment of radioactive wastes and or purification of produced radioactive isotopes especially for medicinal uses, so the development of lost cost ion exchange resins that are capable of adsorbing ions in interest from high volumes of effluent on the least amount of adsorbent with high adsorption capacity and low amount of solid waste.

Radioactive isotope production facilities have been established all around the world for manufacturing of radioisotopes for pharmaceutical uses either by neutron activation or by fission of uranium as ^{99}Mo, ^{99m}Tc and ^{131}I.

The PolyGMA prepared by both techniques was modified using triethyl amine for embedding with tertiary amino groups for acting as an anion exchanger for purification of ^{131}I produced from other fission products. A comparative study for the adsorption of ^{131}I in the form of iodide between the synthesized resins and four commercial anion exchange resins namely (Biorex 5,Dowex 1–8x (20–50 mesh), Dowex 1–8x (100–200 mesh) and Dowex 21) by the radiotracer technique using radioactive ^{131}I manufactured locally. Characterization of different stages of anion exchange was performed by Fourier transformation infrared and scanning electron microscope incorporated with EDX, scanning electron microscope and EDX image of PolyGMA in iodide form.

The polyGMA prepared by TWENN 80 showed no adsorption for radioactive iodine, while the polyGMA prepared by radiation induced graft polymerization on polyethylene tubes showed adsorption of about 30% which was verified with infrared and scanning electron microscope and EDX all resins obeyed the pseudo second-order rate of reaction indicating chemical sorption of iodide ions, and obeyed Langmuir and Freundlich equations.

Verde

PA2

Distinct Polymeric Based Materials Prepared/Functionalized by γ-Irradiation for Biomedical Applications and Roman Mosaics Preservation

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Polymeric based materials are being successfully prepared, modified or functionalized by ionizing radiation processing techniques targeting an increasing number of specific applications in different areas. We have been particularly focussed in two reactional systems:

1. Chitosan based copolymeric biocompatible and biodegradable matrices to be used as skin scaffolds for tissue regeneration processes; and,
2. PDMS-Silica ormosils (organically modified silicates) hybrid materials for medical applications (bioactive component for bone substitution, reparation and consolidation for orthopedic and dental surgeries) and for the consolidation of ancient Roman mosaics (additive with biocide activity for the composite materials used in ancient mosaic panel conservation processes).

Regarding chitosan based copolymeric biocompatible and biodegradable matrices, a methodology involving freeze-dry of (co)polymeric solutions followed by γ irradiation from a ^{60}Co source was tested. In order to compare the performance of matrices concerning cell-matrices interaction, the effect of matrices content in poly(vinyl alcohol) and gelatin was evaluated in terms of matrices' structural properties and cellular viability. Results evidence that for the same radiation dose matrices' composition can be used to tailor the matrices' surface in terms of porosity/roughness. Moreover, in vitro tests revealed that cells adhered and proliferated in all irradiated matrices.

Concerning the preparation of hybrid materials by γ-irradiation, we have been investigating the system PDMS-TEOS-PrZr (polydimethylsiloxane, tetraethylorthosilicate and zirconium propoxide, respectively) in different conditions. Materials are prepared by direct energy deposition on a mixture of PDMS silanol terminated (33 wt% fixed content), TEOS and a minor content of PrZr that varied from 1 to 5 wt%, in a closed system under nitrogen atmosphere, using γ-radiation from a ^{60}Co source. The samples, dried in air at room temperature, are bulk, flexible, transparent and nanostructured. Depending on the polymer Mw and on the amount of PrZr, it is possible to tailor the size and distribution of the oxide regions as so the hybrid porosity. Results obtained evidence, although relatively low, their natural bioactivity and biocide activity. The introduction of new components in the hybrid formulation to improve these properties seems to be effective, without compromising their natural affinity and compatibility with the materials to which they are intended to "work together". Preliminary results shows good perspectives for their intended use.

PA2

Synthesis of Cross-Linking Films Based of 3-(Trimethoxysilyl) Propyl Methacrylate Silanized Xanthan Gum/Lignin and their Cross-Linking by γ-Radiation, to Potential Application and Films Packing

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The production of biodegradable and edible films based on biopolymers has attracted attention and represents one of the most advanced challenges in the field of food packaging and coating. Polymers derived from natural products offer the greatest opportunities as component of edible films since they are biodegradability and environmental friendly [1]. Xanthan gum has been used in a wide variety of foods (in many low fat food systems due to its water binding capacity) for a number of important reasons, including emulsion stabilization, temperature stability, compatibility with food ingredients and its pseudo-plastic rheological properties [2]. Xanthan gum is classified E415 in the European List of Permitted Food Additives. According to JECFA (Joint WHO/FAO Expert Committee on Food Additives), it has the status of ADI-nonspecified (Acceptable Daily Intake), i.e., no quantitative limitation is stated, and, as such xanthan gum is recognized as a non-toxic additive for human consumption. Lignin, a natural biopolymer, mostly derived from wood, is an enormous and renewable reservoir of latent polymeric materials and aromatic chemicals. Due to their very complex structure, lignins are amorphous polymers with rather limited industrial use. They are usually seen as waste products of pulp and paper industry and often used as fuel for the energy balance of the pulping process [3]. Unfortunately, the use of biopolymers as food packaging materials has drawbacks such as poorer mechanical, thermal, and barrier properties as compared to the conventional non-biodegradable materials made from petroleum. The incorporation of nanofillers such as silicate, clay, and titanium dioxide (TiO_2) to biopolymers may improve not only the biopolymers' mechanical and barrier properties but also offer other functions and applications in food packaging such as antimicrobial agent, biosensor, and oxygen scavenger [4].

In this work, the xanthan gum/lignin mixture was silanized with 3-(trimethoxysilyl) propyl methacrylate, and consequently cross-linking by γ-radiation. The best conditions to prepared hybrid biofilms were 95/5 ratio of xanthan gum/lignin, 5 wt% of organosilane at 20 kGy at 5 kGy/h of dose and dose rate respectively. By FTIR-ATR and NMR spectroscopy was possible confirm the silanized reaction. The morphological aspect and size dimension were determined by SEM and TEM. The thermal behaviour was analyzed by DSC and TGA.

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Monodispersed Polypyrrole Nanoparticles Prepared via Water Padiolysis and their Photothermal Therapy on Cancer Cells

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The combination of NIR photothermal therapy and chemotherapy is considered as the promising technique for the future cancer therapy [1]. The key point for this technique is the design and synthesis of photothermal agents with high-efficiency photothermal effect and high chemical drug loading capacity [2]. Herein, submicron-sized raspberry-like hollow-structured polypyrrole microspheres (H-PPy) were easily prepared through the in-situ polymerization of pyrrole on monodispersed polystyrene (PS) template microspheres with a diameter of 220 nm, followed by the chemical etching of the PS templates. The prepared H-PPy microspheres show rapid and remarkable photothermal effect in water under the irradiation of NIR laser (808 nm) only for 5 min. Further, a model small molecular drug, (S)$-$(+)-camptothecin (CPT), were loaded into the void core by a simple dispersion-permeation process through the micro-pores on the raspberry-like PPy shell, with a load capacity of 0.14 mg/(mg H-PPy). The MTT assay and the in vitro NIR-laser triggered release behaviour indicated that the pure H-PPy microspheres have good biosafety, but the release of loaded CPT in H-PPy microsphere can be achieved with remarkable spatial/temporal resolution after NIR laser irradiation, which results in the excellent synergistic effect of photothermal and chemical ablation on HeLa cells, as proved by the fluorescence microscopy. This work provides a convenient synthesis of a promising cancer therapy agent with high drug-loading capacity and efficient NIR light photothermal effect, which can perfectly achieve the synergistic NIR photothermal therapy and chemotherapy of PPy microspheres.

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Obtention and Characterization of γ-Irradiated Recycled HDPE/EPDDM Blends

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Elastomeric materials have specific properties that allow the development and use of a variety of products. The application of elastomeric compounds in the automotive industry has increased considerably; due this, high volume of parts are disposal and among these, thermosetting materials, that are not easily recyclable. High density polyethylene (HDPE) is a commodity material with a wide range of uses in the industry. What make this polymeric material so interesting to the market are its unique properties such as good conformability, high resistance to heat and chemicals, and a relative low cost. Another characteristic for this material is its good reprocessability, which is the ability of being recycled many times. Thus, the environmental impact of both materials is evident, thereby promoting essential damage.

In the present work the HDPE matrix has been recycled four times from original substrate and mixed to EPDM rubber not vulcanized in proportions from 1% to 10%. The γ-irradiation process was applied at 50 kGy and 100 kGy in both original and recycled blend samples; in this way, mechanical properties and morphologic characteristics were evaluated. The results shown EPDM in quantities of 1% bring high tensile strength and yield strength to recycled non-irradiated blends compared to higher concentration of 10%, that present high impact resistance. Irradiation process applied to these samples carried an increase in these parameters and the recycled blends presented higher tensile strength values than pristine HDPE samples. Blends are homogeneous and presented no specific morphologic aspects that suggests HDPE and EPDM are miscible and compatible components; crystallinity is higher in low EPDM content blend and at a dose value of 50 kGy the crystallinity reached the maximum value of 79.5% compared to 72.2% for pristine HDPE. These results suggest irradiated blends formed by recycled HDPE with 1% of EPDM present high viability for industrial use due its high mechanical performance compared its low production cost.

γ-Radiation Enhancement of Photocatalytic Activity of Conducting Polyaniline-TiO_2 Nanocomposites for Degradation of Methyl Orange Dye under Visible Light Irradiation

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Environmental pollution on a global scale, as well as the lack of sufficient clean energy sources, have drawn much attention to the need for developing ecologically clean chemical technology, materials, and process. Synthetic dyes are used almost in all branches of the consumer goods industry. About 10 000 tons of dyes are produced per year. Inevitably, there are dye losses (approximately 12% of used amount) during manufacturing and processing operations. The effluents from these operations are usually highly coloured, toxic, carcinogenic or mutagenic. As the most of the synthetic dyes are resistant to light or other degradative environmental conditions, it is necessary to remediate these effluents before they are released to the environment. However, common wastewater treatment plants are ineffective in removal of dyes from the wastewaters. One of possible options to modify these facilities to get better outcome is an application of the advanced oxidation processes (AOPs), i.e., chemical methods based on generation of highly reactive hydroxyl radicals.

In current research, a series of polyaniline-modified TiO_2 nanocomposites for photocatalytic degradation of dyes, have been successfully synthesized by sol-gel reactions on TiO_2 followed by the chemical oxidative polymerization of aniline using ammonium persulfate (APS) as an oxidant. Fourier-transform infrared spectra (FT-IR), thermal gravimetric analysis (TGA), X-ray diffraction (XRD), and UV-vis spectra, were carried out to characterize the composites with different TiO_2 contents. The UV-vis spectra confirmed that the optical absorption for PANI-TiO_2 nanocomposite was more intensive than that for pristine PANI and TiO_2 nanoparticles in the visible light region. The intensive visible light absorption and effective charge separation owing to the heterojunction built between TiO_2 and PANI lead to remarkable improvement of visible light photocatalysis.

The photocatalytic activities of the prepared nanocomposites were evaluated by photocatalytic degradation of methyl orange (MO) aqueous solution under visible light irradiation. The results showed that the surface polyaniline sensitization had no effect on the crystalline structure but aggravated the agglomeration of TiO_2 nanoparticles by forming multi-particles. After being sensitized by PANI, the light response of TiO_2 was extended to visible-light regions and the photocatalytic activity of the composite photocatalysts was enhanced. MO could be degraded more efficiently on PANI-TiO_2 than on the bare TiO_2 when the weight percent of TiO_2 was 10 wt%. Since γ-irradiation is able to modify the electronic properties of the photocatalyst, the influence of γ irradiation on the photocatalytic performance was investigated. A notable enhancement in degradation efficiency and time was found when irradiated nanocomposites were used. It can be included that γ radiation plays an important role in the photocatalytic activity of PANI-TiO_2 nanocomposites.

Radiolytical Synthesis and Mechanism of Gold Nanoparticle Formation

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Gold nanoparticles (AuNPs) are widely used in analytical chemistry, biomedicine and catalysis. Reducing agent is very important parameter in the synthesis of AuNPs, however, hypothesis of this study is that AuNPs could be synthesized without using reducing agents, i.e., that due to very low affinity of gold for oxygen, AuNPs could be synthesized under highly oxidizing conditions. AuNPs were synthesized in a microemulsion water/TritonX-100/1-pentanol/cyclohexane using various reducing agents: i) strong chemical reducing agent ($NaBH_4$), ii) γ-irradiation under moderately strong reducing/oxidizing conditions, and iii) synthesis under highly oxidizing conditions (with addition of NaOH aqueous solution). All were performed at room temperature (RT). The size, size distribution, aggregation and stability of AuNPs in the microemulsions depend on the strength of reducing agent. When a strong chemical reducing agent $NaBH_4$ was used AuNPs are not well-stabilized and rather polydisperse. Rather small and monodisperse AuNPs were obtained using γ-irradiation (30 kGy, 8 kGy/h). γ-irradiation was able to produce AuNPs in air-saturated microemulsions under highly oxidizing conditions. Smaller AuNPs were obtained by irradiation in the presence of N_2 in comparison to the air. The γ-irradiation of nitrogen-saturated microemulsion at acidic pH produced AuNPs about 10 nm, which aggregated under isolation by centrifugation. The microemulsion stirred at RT and at pH<7 under oxidizing conditions did not produce AuNPs, while at pH>7 (stronger oxidizing conditions) well-dispersed 12 nm AuNPs were formed. Synthesis of AuNPs in 1-pentanol by adding NaOH aqueous solution at RT without using microemulsions and irradiation confirmed that oxidation of alcohols was responsible for AuNPs formation. Based on these findings we propose the base-catalyzed alcohol oxidation at RT as a new, simple and versatile synthesis route for obtaining gold nanoparticles.

In order to further exploit the oxidation of organic molecules for AuNPs synthesis we studied the radiolytical synthesis of AuNPs in the presence of citrate. The γ-irradiation of Au(III)/citrate precursor solutions produced well-dispersed and highly concentrated gold colloids in the presence of dissolved oxygen, without adding any reducing or stabilizing agents. AuNP size can be controlled by saturating gases (air or nitrogen) present in the precursor solution. AuNPs synthesized in the presence of air (10 nm) were approximately two times larger than AuNPs synthesized in the presence of nitrogen (5 nm), as determined by UV-vis spectroscopy. An easy radiolytical reduction of Au(III)/citrate precursor solution in the presence of dissolved oxygen could be explained by enhanced radiolytical oxidation/decarboxylation of citrate to dicarboxyacetone, acetone and other products. Thus, we confirmed that classical approach of using a reducing agent to synthesize AuNPs is not a determining factor, since diametrically different approach can be used, namely in stimulating the oxidation of organic molecules close to gold ions. However, the mechanism of oxidation of organic molecules during the synthesis is not clear and due to these reasons we introduced NMR spectroscopy in order to study the oxidation products of alcohol and citrate ions during the AuNPs synthesis.

Functional Properties and Ecotoxicity of Bionanocomposites Based on PHBV/PLA Blend under Electron Beam Irradiation

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Aseptic food packaging material is essential to preserve food quality over time. For biodegradable packaging, these materials have to be sterilized or decontaminated prior to use to protect against possible microbial contamination. Since our knowledge about polyhydroxyalcanoates (PHA) for food packaging is rather limited, the challenge is to produce biodegradable primary packaging materials which remain stable without affecting mechanical and barrier properties as well as not resulting in toxicological side-effects during both storage and usage. Therefore, the present article reports some experimental data on the oxidative degradation under EB irradiation of neat poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV), neat polylactide (PLA) and PHBV/PLA blend (50/50 w/w) with and without organo-modified montmorillonite, i.e., Cloisite 30B (C30B) (3 wt%) at absorbed doses of 1 and 10 kGy. The changes in the chemical structure, the molecular weight, the thermal, mechanical and barrier properties as well as the morphology were evaluated. The data showed that EB irradiation of PHBV/PLA blend leads to oxidation reactions involving ester groups in both neat PLA and neat PHBV resulting in the formation of hydroperoxides groups. The presence of C30B in the polymer blend has no influence on the nature of the degradation process. However, the good dispersion of C30B nanoparticles provides more stability to the molar mass and the thermal, mechanical and barrier properties of PHBV/PLA blend. At absorbed dose of 10 kGy, the irradiated samples are completely safe. Though there were drastic changes in the chemical structure of the blends, there was no resulting toxicity as measured using the luminescent bacteria-based bioassay (Microtox).

PA2

Studying the Biological Efficacy of Radiation-Treated Radiolabelled DOTA-Bombesin-Decorated Nanoconstructs as Potential Nanosized Drug Delivery Systems

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The over-expression of neuropeptide receptors in human breast or prostate cancer leads to potential application of these peptides as agents for cancer diagnosis and therapy. In this study, we have developed ^{177}Lu-labelled bombesin (BBN) based albumin nanoparticles (Alb-NPs) and papain nanoparticles (Pap-NPs), thus resulting highly specific radiolabelled nanoconstructs decorated with DOTA-BBN, and used as emerging novel "nanotheranostics" for preclinical imaging. The synthesis of gold nanoparticles was developed using green technology, via stabilization with natural gums (Arabinoxylan-AX isolated from ispaghula seed husk). As a part of IAEA CRP, the albumin nanoparticles (Alb-NPs) were prepared in Argentina while papain nanoparticles (Pap-NPs) were prepared in Brazil by ionizing radiation cross-linking. Particle size of Alb-NPs was tailored by changing the water/ethanol ratio in the protein solution, reaching particles in the range of 20 nm to 40 nm. The biological efficacy of DOTA-Bombesin-(Alb-NPs) was tested in Pakistan after labelling with ^{177}Lu. The quality control was performed by using ITLC-SG strips as stationery phase. There was a good separation with radiochemical purity (RCP) of 97.3%. The biological efficacy of ^{177}Lu-DOTA-Bombesin-(Alb-NPs) was tested by determining in vivo uptake through imaging scintigraphy in normal rabbit models and biodistribution in normal mice. A solution of ^{177}Lu-AlbNPs-DOTA-Bombesin (2 mCi/mℓ) was injected intravenously into the ear vein of rabbits ($n = 3$). Dynamic study acquisition comprised of 10 frames of 60 s each. It was followed by anterior and posterior whole body static images acquired at 15 min, 24 h, 48 h, 72 h, and 96 h, post injection. All of these protocols have been established and are further applied to novel bombesin-derivatized (radiation-treated) nanoconstructs from other partner labs.

Radiolabelling and quality control was established for ^{177}Lu-Alb-NPs-DOTA-Bombesin. The effect of activity on labelling efficacy was studied by varying the amount of activity from 5 mCi to 30 mCi by keeping all parameters constant. Similarly, the effect of volume over labelling efficacy was studied by varying the amount of volume from 10 to 200 $\mu\ell$. The maximum labelling efficacy was found at 10 $\mu\ell$ and beyond 50 $\mu\ell$, the solution became turbid. Regarding imaging scintigraphy in normal rabbit models, immediately after the injection of radiolabelled nanoconstruct, activity was observed to form the blood pool that was visible in dynamic study of 15 min. In static images, it was further observed that the compound showed a slower uptake with a significantly higher retention time in liver and spleen, thus leading to sufficient renal excretion to allow absorption of the labelled compound into tumor, with rapid body clearance.

In summary, this approach might be further extended to tumor-specific targeting by using BBN derivatives as carrier of chemotherapeutic agents. Imaging studies performed with ^{177}Lu-Alb-NPs-DOTA-Bombesin demonstrate its ideal therapeutic potential to be further developed as a feasible theranostic agent, during this CRP.

Fabrication of Advanced Soft Magnetic Nanomaterials Using the Radiation

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Soft magnetic materials have been investigated for applications in magnetic devices such as transformers, inductor, electromagnetic (EM) wave shielding, etc. Its magnetic properties are determined by composition, crystal structures and size. Many kinds of research are focussed on the control of material size chemically and mechanically. Synthesis of particles using an electron beam (EB) irradiation provides stable and high quality. In this study, we synthesized the iron oxide particles using a 10 MeV EB irradiation. This material has fine nanosphere with Fe_3O_4 phase in the result analysis of FE-SEM and XRD. And it also possible to fabricate the α-Fe_2O_3 phase with different precursor compositions. As increasing the EB irradiation dose, the saturation magnetization of particles dramatically increased up to 300 kGy. This result is related to the growth of crystal phase. To evaluate the uses of this material in high frequency, the complex permittivity and permeability of composite were measured by network analyzer from 300 kHz to 8.5 GHz in forms of composite in wax matrix. This material shows the high return loss (over than -40 dB) near 6 GHz. These results clearly demonstrate that the radiation is a good candidate for the nanoparticle fabrication and industrial applications.

PA2

Development of Advanced Scaffolds and Polymeric Systems for Improved Cell and Tissue Growth

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The recent concern related to skin compromised patients, apart from the nature of the condition itself, such as wounds, chronic ulcers, or burns among others, has triggered and highlighted the importance of the development of artificial skins available in allogeneic donor tissue banks and/or scaffolds, composed by a wide variety of biocompatible, biodegradable and bioactive biomaterials. Within this context, tissue engineering has been in expansion as an attempt to overcome difficulties faced in such situations. The application of scaffolds, produced or not by nanotechnology, in the skin of a patient induces cells to proliferate and get organized on extracellular matrix regenerating tissue. Ionizing radiation is a particularly useful technology capable of promoting sterilization and cross-linking of the scaffold structure thus offering several possibilities for the development of advanced systems suitable for cell growth. Taking into account the variety of clinical applications of tissue engineering, the aim of this study was to investigate by means of histological tests, chemistries and non-destructive tests, the interaction of mesenchymal stem cells grown in vitro in conjunction with different frameworks in order to understand how the mesenchymal stem cells behave in different niches. Among those collagen, PVA, chitosan, PDLLA scaffolds were the systems of choice and γ-irradiation was applied for sterilization of the systems, as well as cross-linking for the PVA based scaffold. Thus this work allowed the achievement of dermo-epidermic matrices populated by epidermal cells that make up the skin and will contribute to the development of a more robust and useful material to be used in several treatments.

Mechanical Characteristics and Antibacterial Properties of Ag-Poly(Vinyl Alcohol)/ws-Chitosan Hydrogel Nanocomposites Synthesized by γ-Irradiation Combined with Freeze/Thaw Cycles

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Hydrogels have been used successfully in many biomedical applications including scaffolds for wound healing applications or soft tissue implants. A problem for the biomedical application of hydrogels is that microorganisms may grow in hydrogels due to their natural biocompatible properties. Improvement in application of hydrogels is often achieved by the addition of natural polysaccharide or non-specific antimicrobial species such as Ag nanoparticles. The antibacterial bio-synthetic hydrogel nanocomposites consist of blends between water soluble derivatives of radiation processed chitosan (ws-chitosan) and poly(vinyl alcohol) cross-linked by γ-irradiation (via ^{60}Co source) and radiation in situ incorporated Ag nanoparticles (AgNPs). Chitosan is a copolymer composed of glucosamine and N-acetyglucosamine sugars, linked by 1–4 glucosidic bonds, both of which are constituents of mammalian tissues. Chitosan degradation by ionizing radiation gives structural diversity which contributes to its wide application in biomedicine. The radiation technology platform allows synthesis by environmentally friendly and biocompatible radiolytic products of water. The postirradiation hydrogel freeze-thaw procedure was performed to enhance mechanical properties and to prevent liking of un-grafted ws-chitosan during AgNPs synthesis. The thus obtained ws-chitosan, poly(vinyl alcohol)/ws-chitosan polymer matrix and nanocomposites were subjected to molecular weight determination (by Zetasizer), FT-IR, NMR, SEM, elemental analysis and mechanical characterization by thermomechanical analysis, in static stress/strain and dynamic mode. The antibacterial properties against *Escherichia coli* and *Staphylococcus aureus* were assessed by using the agar diffusion test. Results revealed the partial formation of Maillard reaction products during radiation degradation of chitosan. The non-linear stress-strain data from unconfined compression test were fit by the Kennedy equation and by an elastic model (Rige and Wright). The results indicated changes in matrix mechanical resistance upon incorporation of ws-chitosan. In contrast, AgNP incorporation decreased the polymer matrix elasticity while increasing the cross-linking density of polymer network and provides more rigidity to the structure which increases the values of storage modules (obtained in dynamic mode) and, as a consequence, causes a better mechanical stiffness of the network. The antibacterial activity of Ag-poly(vinyl alcohol)/ws-chitosan hydrogels show enhanced antibacterial potential in comparing with poly(vinyl alcohol)/ws-chitosan hydrogel matrix only. For investigated hybrid hydrogel, zone of inhibition is greater against *Staphylococcus aureus* than for *Escherichia coli*. This is important for the treatment of wound infections in diabetic patients which are dominantly caused by aerobic Gram-positive cocci. These promising results give possibility for development and optimization of synthesized antibacterial Ag-hydrogel nanosystems.

PA2

Dyestuff Free: Colouring Fabrics by Graft Polymerization

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Laundering durable functional fabrics are obtained by means of radiation-induced graft polymerization methods, via the graft polymerization of functional monomers or co-graft polymerization of the monomers and certain nanoparticles [1–4]. The laundering durability lies in the formation of the covalent bonds between the cellulous macromolecules and the graft chains or together with the nanoparticles, which is the most advantage of the radiation methods in fabric modification.

Dyestuffs, normally referring to the organic molecules which can be dissolved or dispersed in solutions, are used to colour cotton fabrics since they can be absorbed by the nanoporous structure and the non-crystalline zone, or even the lamella of the crystalline zone of the fabrics. Reactive dyestuffs can react with the hydroxyl groups on the cellulous macromolecules under high temperature and basic conditions. Although dyestuffs are well-developed chemical products and the dying process is mature too, the long treating period and high pollution of the waste water needs to be solved.

In our previous study, we found that radiation-induced graft polymerization methods will be a dyestuff-free way to colour the cotton fabrics by co-graft polymerization the colourful nanoparticles. For example [5], MIL-101, a typical metal organic framework (MOF) which comprises a nontoxic chromium(III) cluster and benzene-1,4-dicarboxylate ligand, was co-graft polymerized onto nylon fabric with 2-hydroxyethyl acrylate (HEA), owing to the abundance of benzene rings in MIL-101 which favours free radicals generation on its surface. The colour of MIL-101 is dark green, and the colour of the grafted nylon fabrics is green and darkens with the increasing degree of grafting of MIL-101. More important, the robustness of the product was demonstrated by 30 hours dry-cleaning test using tetrachloroethylene as the organic solvent, and most of the MIL-101 particles still adhered to the nylon fabric after the washing.

Base on the above facts, we are now developing the dyestuff-free colouring fabric procedure by fixing pigments micro- or nanoparticles onto the cotton fabric under radiation-induced co-graft polymerization methods.

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Influence of the Coolant Chemistry on the Structural Materials Surfaces Exposed into the Candu NPP Primary Circuit

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One of the most important NPP plant systems is the primary heat transport system (PHTS) having in view its role in active zone cooling and heat transfer to steam generators. In PHTS, chemical control is directed to keep chemical parameters within specified limits in order to mitigate the corrosion of the key equipment and related piping, to control the corrosion rate and impurities concentration, such as corrosion and fission products and to minimize activity transport and heat transfer surfaces fouling. By operation in aqueous environment at high temperature and pressure, the structural materials from PHTS cover with protective oxide films, which maintain the corrosion rate in admissible limits. Many potential factors exist, which conduct to degradation of the protective films and consequently to intensification of the corrosion processes. The existing experience of different nuclear reactors shows that the water chemistry has an important role in maintaining the integrity of the protective oxide films. In order to minimize the adverse effects, an optimal water chemistry control and corrosion monitoring programme were established. The understanding of the corrosion degradation phenomena that conduct to failure of some components from PHTS of CANDU NPP implicates the investigation of the structural materials corrosion processes, in different conditions of water chemistry and temperature. To investigate the corrosion process of some structural materials from PHTS (Zr and Ni alloys) of CANDU 6 reactor were performed the following activities:

- out of pile corrosion experiments in different conditions of water chemistry;
- corrosion experiments in autoclaves assembled in by-pass of CANDU 6 reactor PHTS;
- corrosion analysis performed on some corroded components.

The gravimetric method, optical metallographic microscopy, XRD analysis, as well as electrochemical measurements have been used to evaluate the corrosion behaviour of the pressure tube and steam generator tubing materials. The obtained results allowed us to establish the contribution of the water chemistry in the initiation and evolution of some accelerated corrosion processes.

Radiation-Induced Oxidation in γ-Irradiated UHMWPE Modified with Hydroxyapatite

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The medical use of ultra-high molecular weight polyethylene (UHMWPE) as bone replacement as well as the manufacture of sterile sealed cases and envelopes require detailed investigations on the chemical stability over long time wear. To impart high similarity to substituted hard parts of osseous system, the addition of hydroxyapatite to the polymeric material is an attractive option. The present study investigates three polymer composites consisting of UHMWPE and LDPE to which hydroxyapatite (HAP) was added in the concentration of 10%. Some of samples were stabilized with rosemary extract powder (0.5%). Films and flat plates were obtained by melting in a BRABENDER Plastograph, under a mixing temperature of 180°C for 10 min and screws rotation rate of 40 rpm followed by the thermal processing in a laboratory press type POLYSTAT 200 at the following conditions: temperature: 165°C, pressing time 3–6 min, pressure of 125–150 atm and cooling time of 30 min. Accelerated degradation by γ-exposure was carried-out in air inside of the Ob Servo Sanguis (Hungary) ^{60}Co irradiator, whose dose rate was 1.1 kGy/h. The stability and structural characterization were done by isothermal (180°C) and nonisothermal (heating rate: 10°C/min) differential scanning calorimetry in inert and air environments and by ATR-FTIR spectroscopy. The influence of hydroxyapatite and rosemary powder is noticed by the improvement in the kinetic parameters: the decrease of oxidation rates and the extension of total oxidation periods. The progress in the ageing degree is described by the carbonyl index, whose variation is connected to the inhibition promoted by the large surface of hydroxyapatite particles playing the role of adsorbent of free radicals and by the scavenging activity of rosemary components, where the predominant active principle is carnosic acid. In spite of the difference in the behaviour of polymeric components relative to the oxidative degradation the evolution of oxidation looks similarly in respect to the accumulation of initiators, hydroperoxyl radicals. The oxidation resistance of studied blends is ameliorated because the both polymeric components are regarded as sources of free radicals, but the addition of hydroxyapatite and rosemary powder makes possible the manufacture of products with long term applications. The contribution of HAP and rosemary additive is significant not only on the early stages of ageing, but also during the exposure to a severe energetic transfer.

The efficiency in the oxidation delay in UHMWPE/LDPE blends can be expected when the stress agents are less strong than γ-radiation. However, the comparative study involving indoor weathering degradation is foreseen, because the oxidation strength of these compositions including hydroxyapatite allows the extension of usage ranges in several areas as outdoor components of industrial devices.

Optimization of Electron Beam-Induced Synthesis of Polypropylene-g-poly(Glycidyl Methacrylate) for Cr(VI) and Cd(II) Adsorption Using Full Factorial Design

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Graft copolymerization is an efficient and attractive method to impart a variety of functional groups to commercially available polymers. This method allows the development of new materials that cannot be synthesized using conventional processes. In this work, carboxylic acid- and amine-type adsorbents were developed from polypropylene nonwoven fabric (PP NWF) using the emulsion phase radiation-induced graft polymerization (RIGP) technique. The set of optimum parameters (e.g., absorbed dose, reaction time, monomer concentration) for grafting glycidyl methacrylate (GMA) on PP trunk polymer was determined using full factorial design. Post-grafting reactions of the poly(glycidyl methacrylate) (PGMA) grafted on PP NWF with ethylenediamine (EDA) and iminodiacetic acid (IDA) imparted approximately 3.0 and 1.2 mmol functional groups per gram-adsorbent, respectively. These covalently bonded chemical groups serve as active sites in the removal of Cr(VI) and Pb(II) from aqueous solutions. Preliminary data suggest that the EDA and IDA functionalized PP has high affinity for Cr(VI) and Cd(II) ions, respectively.

Radiation Development of (Polyvinyl Pyrrolidon/Acrylic Acid)-Silver Nanocomposite for the Disposal of Phenolic Compounds from their Aqueous Solutions

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Nitroaromatic compounds are considered to be amongst the most prevalent organic pollutants in wastewater. They are intermediates or side products of many industrial products such as dyes, pharmaceuticals, agrochemicals, cosmetics, photographic chemicals, additives, chelating agents, and other products. 4-nitrophenol (4-NP) is a notorious industrial pollutant exhibiting a high solubility and stability in wastewater. The direct exposure to these pollutants causes inflammation of eyes, skin and respiratory tract and prolonged contact with skin may cause an allergic response. Much effort has been expended to develop methods for removing the aromatic pollutants from wastewater. The reduction of nitroaromatic compounds to the benefit amines is considered to be the most efficient, green, and economical approach to disposing of the nitro-compounds. The reduction product, 4-aminophenol (4-AP), can be reused because it is important intermediate for the synthesis of drugs and dyes. Therefore, various nanoparticles have been employed as an effective catalyst for the reduction of nitroaromatic compounds in aqueous solutions under mild conditions. The main issue hinders the pervasive use of homogeneous metal nanoparticles as a catalyst is their high tendency to aggregate as a result of the size and high surface energy of metal nanoparticles. Moreover, the problems in separating the products contaminated with unstable residuals and recycling the expensive catalysts. To prevent aggregation of metal nanoparticles, diverse supportive materials such as hydrogels are widely employed. Hydrogels are hydrophilic polymeric three-dimensional networks capable of absorbing a large amount of water. The catalytic reactions can take place within the boundaries of hydrogels, no need to change many reactor conditions in industrial applications; just a right choice of hydrogel-composites can supply all the necessary conditions.

In this study, poly vinyl pyrrolidone/acrylic acid (PVP/AAc) hydrogels were prepared via γ-irradiation technique. (PVP/AAc) hydrogel was utilized as a supporting material to stabilize Ag nanoparticles by employing in situ method to obtain (PVP/AAc)/Ag nanocomposite. The catalytic activity of (PVP/AAc)/Ag nanocomposite was investigated in the reduction of (4-NP) in sodium borohydride solution ($NaBH_4$). Parameters that affect the reduction rate were investigated. It was found that the reaction proceeded with the conversion exceeding 99.8% at a reaction time of about 5 min for (PVP/AAc)/Ag nanocomposite loaded with 231.76 mmol/ℓ Ag. The rate of the reduction reaction decreased with increasing the concentration of 4-NP and the optimum concentration of $NaBH_4$ was found to be 0.164 mol/ℓ.

A Comparative Study of Radiation Sterilization of Cell Culture Media and Filtration Sterilization Method in Cell Culture Laboratory

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Cell culture media is uses in biopharmaceutical processes to stimulate the natural environment of the cell. Media used in cell culture have a balanced salt solution; the most commonly used is sodium bicarbonate with a pH of 7.2–7.4 at 37°C that the optimal growth of cells. Filtration is a safe method used for media sterilization in cell culture laboratory; it helps to removes the microorganisms, but is unable to separate microorganisms that have the same size. The most common types used in tissue culture has a pore size 0.2 μm. The aim of this study is using γ-radiation to sterilize media in cell culture laboratory compared to filtration sterilization method.

For media preparation, RPMI-1640 media in powder form, containing vitamins, minerals, amino acids and red phenol, was added to $NaHCO_3$ and dissolved in distilled water, and a pH meter was used for pH determination. A ^{60}Co γ-irradiator was used for dose irradiation of 5 kGy and 20 kGy at 1.26 kGy/h dose rate. The irradiation was carried out at the Chemistry and Physics Institute of the Sudan Atomic Energy Commission.

Testing of bacteria included total viable aerobic count and total coliform count. Cell viability testing was made by adding 0.5 mℓ of lymphocytes to 4.5 mℓ from RPMI media, 1.2% penicillin/streptomycin, 1% fetal bovine serum, 30 μmℓ Phytohaemagglutinin glutamine, and then incubated for 24 hours in CO_2 incubator. Cells were then counted using jumper.

A γ-radiation dose of about 20 kGy was found to be enough to destroy most type of bacteria rather than 5.0 kGy, but not suitable for sterile media cell culture in laboratory because increasing the probability of poor cell growth. While a dose of 5 kGy does not completely sterilize the media and cell growth observed. Physiology of media environment is summarized as follows for Lymphocytes growth and pH control for γ radiation dose and filtration for sample media:

Media Sterilization	Cell Death (24 Hours)	Cell Growth (48 hours)	pH (pre)	pH (post)	Media Colour
5 kGy	50%	50%	7.2	7.2	change
20 kGy	70%	10%	7.2	8.0	colourless
Filtration	10%	$>$ 60%	7.2	7.3	no change

Media can be sterilized by γ-radiation with doses larger than 5 kGy, but red phenol that indicator pH of media was degraded with increases the γ-dose. This result suggests that γ-doses larger than 5 kGy and less than 20 kGy should be tested to achieve the dose range accepted for cell culture media sterilization without affecting cell integrity. Then, radiation sterilization among RPMI media may useful for liquid RPMI media without red phenol, used in stem cell. Further research on red phenol degradation by γ-radiation, and amino acids concentrations post-γ irradiation is strongly recommended, and might help in sterilization and modifications of media for various cell culture applications using γ-rays.

PA2

Simultaneous Radiation Grafting of Acrylic Acid on Polypropylene Films: Optimization, Biodegradability and Evaluation of Ecotoxicological Impact

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Polypropylene (PP) is used as a packaging material because of low cost and water resistance properties. However, it has been much criticized for its lack of degradability. Simultaneous radiation grafting is a versatile method by which acrylic acid (AAc) has been grafted on the surface of PP. From our previous work, it was found that the biodegradability of AAc grafted PP did not significantly improve beyond 34% degree of grafting. Now, there is a need to optimize the grafting condition for $\sim 35\%$ degree of grafting, and study the effects of process parameters on it. It is also important to know the ecotoxicological impact of biodegradation product of grafted PP films.

Simultaneous radiation grafting was done with ^{60}Co γ-radiation. Experiments were designed based on response surface methodology (RSM) to optimize the monomer concentration (6.88–13.52 wt%), radiation dose (6.74–13.42 kGy), inhibitor concentration (0.01–0.11 M) and solvent concentration (0.12–0.36 M) for the 35% degree of grafting. The grafted PP films were characterized by tensile test, fourier transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC) and biodegradability. Ecotoxicological impact was evaluated by microbial test and plant growth (corn and tomato) test as per the OECD test #208 guidelines.

The number of experiments reduced to 30 only for the optimization of grafting conditions for the 35% degree of grafting. The suggested optimized conditions for 35% degree of grafting were monomer concentration 12.09 wt%, radiation dose 12.40 kGy, inhibitor concentration 0.07 M and solvent concentration 0.12 M, it was also experimentally verified in triplicate and average degree of grafting achieved was 34%, which is almost same as suggested 35% by the RSM. Grafting of AAc onto PP films was confirmed by FTIR. Tensile strength of PP18 (35% grafted) was 21.1 MPa which is suitable for packaging applications (as against 38.8 MPa of PP). The crystallinity of PP18 (26%) was lower than PP (59%) shown by DSC. The biodegradation achieved was 5.5% at 35% degree of grafting by following the guideline of American Society for Testing and Materials (ASTM D 5338-11). Ecotoxicological test indicated that biodegradation products were non-toxic in nature.

Grafting conditions were optimized by RSM for 35% degree of grafting and experimentally verified. Biodegradation 5.5% was achieved with 35% grafted PP film. Eco-toxicological test confirmed that no degradation product of grafted PP has any environmental toxicity.

Metal Surface Modification with Fatty Acids Using Ionizing Radiation

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Various metals and alloys are commonly used in medicine. As such they are often exposed to aggressive environments and thus subjected to corrosion, i.e., dissolution. Thus, modification of the metal surface is interesting since the resistance to corrosion can be increased and the durability of the object can be prolonged.

Medical equipment, in most cases, must be sterilized and a common method uses ionizing radiation. While ionizing radiation does not markedly influence the properties of the metal it can influence the protective layer that is formed on its surface.

Fatty acids are non-toxic compounds which have an affinity for self-assembling on metals and therefore lately they have been investigated as possible protective layers on metals. The influence of ionizing radiation on the formation of such layers is needed to determine whether it changes the properties of the protective layer or maybe even enhances them.

Procedures for adsorption of self-assembling layers of fatty acids on metals exist in literature. This work studies influence of ionizing γ-radiation on the process of assembling such a layer and the efficiency of the outcoming layers in corrosion protection.

Various variables are studied. The most important variables are the applied γ-irradiation dose, as well as the dose rate at which it is applied. The quality and efficiency of the obtained layers in corrosion protection are studied by electrochemical methods.

The results have shown that the layer of fatty acid that forms on the surface of the metal using ionizing radiation offers additional protection to the bare metal making it more resistive to corrosion. For successful formation of a protective layer on the metal it is essential to determine the proper molecule which has good adhesive properties and to irradiate with an appropriate dose, at an optimal dose rate.

PA2

Irradiation Effects on Structure and Spectroscopic Properties of Sugar Doped Sol-Gel Silica

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Silica xerogel doped sucrose was prepared via sol-gel process and exposed at room temperature to different doses of ^{60}Co γ-irradiation. Changes in the physical properties of the xerogels before and after irradiation were characterized by using UV-visible and FTIR spectra of pristine and irradiated xerogels with varying of γ-ray dose, showing a variation in the gap energy. It was found that the γ-irradiation influences the optical properties and modifies the network structure. Then, results indicate that the gap energy of the investigated silica xerogels decreases with increasing γ-dose. Thereby the irradiated samples reveal behaviour changes, from an insulator ($E_g \sim 5.8$ eV) towards a semiconductor with ($E_g \sim 3.5$ eV).

Ionizing Radiation Engineered Functional Nanogels for Biomedical Applications

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Nanoscale therapeutic systems have emerged as novel therapeutic modalities for cancer treatment and are expected to lead to major advances in cancer detection, diagnosis and treatment. At Nuclear Malaysia, we have developed a nanoplatform that would be suitable to use for the targeted delivery of imaging and therapeutic agents.

Nanogels are nanoparticles consisting of internally cross-linked hydrophilic polymers of sub-micrometer size. The polymeric nanogels used in this study were synthesized via irradiation of polyethylene glycol-diacrylate (PEG-DA) using electron beam. Radiation induced synthesis of nanogels not only ensures polymer cross-linking, but also particle size control, chemical functionalization and sterilization of the product material. In addition it has the advantage of ease of scale up and the absence of potentially toxic monomers and cross-linking agents. With superior colloidal stability, inertness in the bloodstream and high drug loading capacity, nanogels make an ideal nanocarrier for biomedical applications.

The prepared nanogels were characterized by scanning electron microscopy (SEM). Their size and zeta potential were measured using dynamic light scattering and zeta potential analyzer respectively. Biocompatibility of the nanoparticles were assessed by MTT assay.

To assess the applicability of the nanogels as a drug carrier, a tumor targeting peptide is appended to the nanoparticle to endow it with tumor homing/targeting capability. Additionally, to track its biodistribution in vivo, it was radiolabelled with a suitable positron emission tomography (PET) radioisotope and scanned using a PET camera to assess its tumor targeting capability and accumulation.

Effect of γ-Radiation on the Physico-Mechanical Properties of Gelatin-Based Films and Jute-Reinforced Polymer Composites

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Gelatin, a natural protein, is insoluble in water and is solubilized by hydrolysis. Gelatin based polymeric films were prepared in aqueous medium by casting. The mechanical properties were evaluated by proper method. The tensile strength was found to be 27 MPa. Gelatin films were soaked in different formulations containing 2-hydroxyethylmethacrylate (HEMA), methanol and photo-initiator and then irradiated under γ-radiation. Again, a series of gelatin solutions was prepared by blending varying percentages (10–50 wt%) of HEMA and then films were prepared and irradiated under γ-radiation. It was found that tensile properties of gelatin films improved significantly. In another investigation, jute fibre reinforced polypropylene (PP) composites were prepared by compression molding. Composites were fabricated with varying percentages of jute and irradiation dose. Total radiation dose varied from 250–1000 krad and composites made of using 500 krad showed the best results.

Ionizing Radiation as a Tool to Affect Polymer Biodegradation

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The great stability and durability of conventional synthetic plastics and their outstanding properties have allowed a wide range of potential applications among which packaging constitutes the larger market segment. However, due to the specific function, packaging rapidly becomes waste that increasingly accumulates in the environment. Therefore, nowadays the need of biodegradable polymers is growing and great efforts have been devoted to optimize the use and the disposal of conventional non-biodegradable plastics favouring their degradation in the environment. Aliphatic polyesters have attracted considerable attention combining biodegradability and biocompatibility features with physical-chemical properties comparable with some of the most extensively used polymers. It is well known that ionizing radiation can modify polymers and enhance or degrade their properties, affording many practical applications. In particular, γ-radiation can facilitate material degradation by inducing oxidative fragmentations of polymer backbone. In this viewpoint, experimental activities have been addressed to investigate if a radiation treatment of bio-based plastics in an ambient promoting or accelerating degradation, could represent an effective pretreatment for improving their biodegradation.

Commercial and synthesized polymers, such as polyethylene (PE) and polybutylene succinate (PBS), have been irradiated by ^{60}Co sources and the impact on the rate of biodegradation in compost has been evaluated. Polyesters, in films up to 200 μm, have been irradiated at absorbed doses up to hundreds of kGy in air and aqueous solution, and examined by different techniques. Radiation-induced changes of the chemical properties have been evaluated as a function of the absorbed dose and the effect of the oxidative ambient has been compared with that of irradiation in air. The molecular weight data obtained by gel permeation chromatography indicate that biodegradable polymers show a more significant loss of molecular weight with respect to PE as the dose increases. On the contrary, the thermal behaviour investigated by differential scanning calorimetry does not seem to be affected by the treatment at these absorbed doses. In addition, the surface properties have been carefully evaluated in order to correlate their changes to the biodegradability in compost. In the case of PBS systems water contact angle measurements show that the hydrophilicity is affected already at the lowest absorbed doses, coherently with the remarkable decrease of molecular weight. The research performed confirmed that the radiation-induced degradation could be considered as an effective pretreatment able to enhance the biodegradation rate of some polymeric systems.

Development of Nanocomposite Coatings by Radiation Curing

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Kencana Fibrecomposite is a manufacturer producing high performance fibre composite derived from a revolutionary green technology. These composites are alternatives to wood and used in building construction. At present, these materials are ready to be used without coating or painting, however they are vulnerable to scratch and abrasion during handling and transportation. Therefore, Kencana Fibrecomposite and Nuclear Malaysia have collaborated to develop scratch and abrasion resistant nanocomposite coating materials. The most appropriate process to cure the materials is using radiation curing technology. The technology offers several advantages such as fast curing, improved productivity and product performance, curing at room temperature and elimination of volatile organic compound (VOC).

In this research work, the incorporation of silica nanoparticles into radiation curable resins is to enhance scratch and abrasion properties of the coating materials while retaining transparency and glossiness. Radiation curable nanomaterials can be prepared using heterogeneous hydrolytic condensation technique. Composite materials that exhibit a change in structure and composition over nanometer length scale have been proven in imparting remarkable property enhancement with respect to stiffness and strength. The technique is also capable of overcoming several major issues related to compatibility between the matrix and the nanoscale component, and also agglomeration of nanosized component during processing. This will produce a homogeneous distribution of nanosilica in the radiation curable nanomaterials. Silico-organic nanoparticles have relatively large surface areas compared to microparticles, therefore modification effects from the polymerization activity should have a great influence on the properties of the composites.

During curing process, electron beam (EB) radiation and ultraviolet (UV) light were used to initiate radical polymerization. These polymerization active nanoparticles were obtained from heterogeneous hydrolytic condensation of the silane to the silanol groups of the silica particles. The above reaction could be verified by the application of FT-Raman spectroscopy (intensity measurement of the C=C vibration band at 1640 cm^{-1}) and gel permeation chromatography to show the impact of polymerization activity of the nanoparticles on the silico/acrylate dispersion. In the curing process, the nanoparticles form cross-linkages to produce radiation cured polymeric composite with improved scratch and abrasion resistance. From Taber abrasion, it can be observed that the weight losses of radiation cured materials are significantly reduced when the amount of silica particles (SiO_2) increases. The nanoparticles added into the coating materials significantly improved the scratch property.

Finally, it can be concluded that polymerization active silico-organic nanoparticles could be prepared by in situ reaction. Formulations useful for technical coating process could be prepared and cured using the low energy electron beam (EB) and ultraviolet (UV) light. The composite materials showed highly improved mechanical properties. These polymeric nanocomposites show excellent resistances toward abrasion and scratch properties when compared to pure materials without nanoparticles.

Swelling and Drug Release Kinetics of Polyacrylamide/Sodium Alginate Copolymer Hydrogels Synthesized by γ-Irradiation

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Hydrophilic hydrogels based on different ratios of polyacrylamide (PAAm) and sodium alginate (AG) were synthesized by γ-irradiation in aqueous solutions. The pH-sensitive character of PAAm/AG hydrogels was investigated in a wide range of buffer solutions of different pH values (2–8). The pH-sensitive character of PAAm/AG hydrogels was utilized for the possible use in drug delivery; the release profiles of chlortetracycline and ketoprofen, as drug models, was investigated. The swelling and release were further analyzed by Ficks power law equation, and the possible mechanisms of the water diffusion and release were suggested. The hydrogels were characterized by different techniques; FT-IR spectroscopic analysis, swelling, drug release measurements and kinetics of drug release.

The drug release from loaded PAAm/AG hydrogel films, in different buffer solutions of pH 2.0, 5 and 8 was studied. Clearly, it can be seen that the drug release from loaded films is very sensitive to the pH of the medium. The release was increased by increasing the pH values depending on hydrogel composition. The high the ratio of AG in the hydrogel composition, the lower was the release. The results were in consistent with the water swelling ratio of non-loaded PAAm/AG hydrogel films in different pH values. As the amount of COO^- on alginate is almost equivalent to the amount of NH_3^+ on PAAm, in the blank matrix film at pH 2.0, the macromolecular chains in the film matrix attract each other inducing a shrink in this system. So, the value of water swelling ratio of blank matrix film was the lowest at pH 2.0. When the equilibrium between the amount of COO^- and NH_3^+ was broken at high pH, the macromolecule chains of the film matrix toke each other apart, increasing the water swelling ratio of the film and accelerating the drug release.

Ketoprofen is a non-steroidal anti-inflammatory drug and it has a $\mathrm{p}K_a = 4.94$. The chemical name for ketoprofen is 2-(3-benzoylphenyl)-propionic acid. When this drug is loaded onto the networks of PAAm/AG hydrogels, it will be reacted through hydrogen bonding inside the network structure of hydrogels. These hydrogen bondings are through the COO^- of AG molecules and those on chemical structure of ketoprofen. For both hydrogel compositions, ketoprofen released rapidly at first and then gradually reached equilibrium release at ~ 3 h depending on the pH of medium. The equilibrium release of ketoprofen from PAAm/AG hydrogel (50/50%) is much higher than the release from PAAm/AG hydrogel (80/20%) and $50/50\%$, irrespective of the pH value. Opposite trends were found in the case of the release of tetracycline drug at similar conditions.

In this study, films of a new pH-sensitive copolymer hydrogel based on polyacrylamide (PAAm) and sodium alginate (AG) was successfully prepared by γ-radiation in the form of interpenetrating polymer networks. The pH-sensitivity of hydrogels affects the drug release.

PA2

Effect of Spatial Confinement on the Radiolytic Efficiency of High-Energy Ions in Polymers

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In this work, the radiolytic efficiency of MeV–GeV heavy ions in polymer thin films has been quantified, following the induced chemical damage as the layer thickness h of the films is systematically reduced ($2 < h < 200$ nm). X-ray photoelectron spectroscopy (XPS) was employed to evaluate bond-breaking in the polymer thin films after ion irradiation. We evaluated the rate of decrease of C−O and C−Cl XPS peaks in PMMA and PVC films as a function of the thickness of the polymer layers. Bond breaking cross sections, estimated from XPS data were found to be insensitive to thickness reductions, even in layers as thin as 5 nm. The damage cross-sections for PMMA were $\sim 1.5 \times 10^{-13}$ cm^2 (for O−C−O bonds) and $\sim 2.3 \times 10^{-13}$ cm^2 (for C=O bonds) for the 2.2 GeV Bi irradiation, whilst for 2 MeV H irradiation the values were $\sim 2.7 \times 10^{-16}$ cm^2 and $\sim 4.4 \times 10^{-16}$ cm^2, for O−C−O and C=O bonds, respectively. Meanwhile, PVC damage cross-sections for C−Cl bonds were estimated as $\sim 1.5 \times 10^{-15}$ cm^2 for 2 MeV H irradiation. These findings indicate that most of the bond-breaking induced by the ions is related to short-range events close to the track core. Films thinner than ~ 5 nm were difficult to analyze, because of the non-negligible influence of the adventitious carbon on the substrate, combined to changes caused by the ion beam (such as roughening and thinning). Our observations are also in contrast to recent studies showing that surface effects, such as mass transport and cratering formation, are substantially weakened, when individual ion tracks are confined into polymeric ultra-thin films due to the suppression of cooperative effects of excited atoms along the ion track. We will also show results on radial dose profile due to the delta rays in thin water layers obtained from Monte Carlo simulations with the GEANT-DNA toolkit. Such simulations provide a first approach to rationalize the impact of film thickness on the energy spread by the secondary electrons, which is directly coupled to the radiolytic efficiencies.

Functionalization of Polypropylene Films with Glycidyl Methacrylate by γ-Radiation

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Polymeric materials with biologically active components immobilized onto surfaces are very important for biotechnological and biomedical applications. However, conventional polymers have no appropriate functional groups (amine, imine, carboxyl, hydroxyl, etc.) to immobilize biomolecules. Indeed the polymeric surfaces should be modified to introduce such functional groups; although there are many possible routes to functionalize surfaces, radiation grafting has advantages such as facility in synthesis process and purification of products, initiators or additives are not necessary, etc. Therefore, a possible alternative to obtain surfaces rich in amines is carry out the surface modification by γ-radiation, grafting monomers with functional groups such as primary amino (allylamine), secondary (acrylamides) and derivatives, which can react with diamines such as hydrazine or ethylenediamine to obtain free amino groups.

Glycidyl methacrylate (GMA) was grafted onto polypropylene films (PP) using γ-radiation. Direct and oxidative preirradiation methods were studied. The evaluated parameters were solvent, monomer concentration, doses, time and temperature. Subsequently, PP-g-GMA films were reacted with amines (ethylenediamine and hydrazine) to obtain functionalized films (amines rich surfaces). Different reaction conditions were tested and optimized. The grafted (PP-g-GMA) and functionalized films were characterized by FTIR, DSC, TGA, angle contact and swelling behaviour.

GMA was successfully grafted onto PP films using oxidative preirradiation and direct method. In both procedures were easy to control the graft percentages (10–200%) varying any parameter such as solvent or dose. The PP-g-GMA was reacted with diamines to obtain aminated films; the introduction of amine groups was confirmed by monitoring the disappearance of epoxy group band at 906 cm^{-1} in FTIR spectra. The radiation grafting technique can be an easy and quick alternative way to functionalize polymeric materials.

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Synthesis and Characterization of PP Films Rich in Primary Amines for Cell Cultures, by γ-Radiation

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Development of biomaterials has been increased, due the necessity to find bio-inert materials able to present a specific cellular response. Biomaterials are very important for tissue engineering. They can be used as bridges to regenerate damaged tissue growth, as well as support for immobilized biomolecules (drugs, fungicides, enzymes, etc.). Polymer surface modification can be carry out by incorporating functional groups on polymeric materials for the appropriate cell adhesion. It is well known that hydrophobic polymeric surfaces cannot add cells, however, hydrophilic surfaces, mainly rich in nitrogen, facilitate the adherence. The amine functional groups (-NH_2) are one of the most important for cells and protein adhesion.

Nowadays, the modification can be carried out by physical or chemical methods. One of this methods is plasma surface modification, even though is the more common, the systems synthesized are partly soluble in water, besides the formation of a great amount of free radicals, which generate the incorporation of oxygen when is in contact with the air. To overcome this problem, the modified films were synthesized by γ-radiation in a two step method. In this work, radiation grafting of acryloyl chloride onto polypropylene (PP) has been applied to insert carboxyl functionalities on PP; and then, the radiation grafted films were reacted with some diamines. Amine concentration was determined and after a period of time, the effect of ageing on the amine functional groups was determined by derivatization with 4-trifluoromethyl benzaldehyde (TFBA), and subsequently characterized by XPS (N/N/C ratios), ATR-FTIR and contact angle.

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Biopolymer-Silver Nanoparticle as a CIELAB Colour Space Dosimeter

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A new purpose of silver nanoparticles (AgNPs) in chitosan (CS) biopolymer is proposed as a radiation dosimeter for application in the dose range of food irradiation. The biopolymer-AgNPs are simply prepared from $AgNO_3$ precursor and CS (DD =90%, $M_v = 580$ kDa) aqueous solution. The optimum formula of biopolymer-AgNPs dosimeter was studied. A series of the prepared biopolymer-AgNPs dosimeter relatively response by colour changing to the electron beam irradiation doses. With this system, the colours were measured in a CIELAB colour space using a colourimeter. The biopolymer-AgNPs dosimeter is exposed to various irradiation doses ranging from 0 to 10 kGy. Based on CIELAB colour space, the colour of biopolymer-AgNPs dosimeter is changed from white to yellow and dark brown by irradiation. The numerically measured colour is presented in the CIELAB colour difference (ΔE_{ab}). The relationship of dose and colour showed that ΔE_{ab} linearly increased with irradiation dose. The colour change is due to the particle size of biopolymer-AgNPs dosimeter. The colours from the developed biopolymer-AgNPs dosimeter can be applied using general purpose scanner and the measured colours were then calculated to their corresponding radiation doses. The biopolymer-AgNPs dosimeter is expected to be a simple, economical, effective and alternative device as the food irradiation dosimeter.

Nanocarbon Based PolyLY(Ethylene-Terephthalate) Nanocomposites and Various Irradiations

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Ionizing and UV radiation produce reactive species in irradiated material. The concentration and distribution of those species depends on the linear energy transfer rate of a corresponding radiation type. Electromagnetic radiation like γ or X-rays has high penetration but form relatively few reactive species relatively far apart. Particulate radiations like protons produce high concentration of ionizations and break many of chemical bonds along their tracks but have much lower penetration. All ionizing radiation types have enough energy to break any type of chemical bonds while UV can induce breaking only of some less stable chemical bonds. The type of radiation and its quantity and dose are not the only factors that determine the response of polymers and (nano)composites. It depends also on the chemical structure of the polymer matrix so the overall outcome can be degradation, cross-linking and/or latent track formation. Poly(ethylene terephthalate) (PET) is widely used thermoplastic polymer with excellent engineering properties and its radiation stability is expected increase on addition of appropriate (nano)fillers.

Pure PET film and two of its nanocarbon containing nanocomposite films, one with nano-diamonds (ND) and the with other combination of nano-diamonds and graphene nanoplatelets (NGP) were studied. One group of samples was irradiated with ^{60}Co γ-radiation in ranges between 0.2 and 1.05 MGy at a dose rate of 2.5 Gy/s, in contact with air. The other group was irradiated with a 3 MeV proton beam delivered by the 1.0 MV Tandetron (at the fluences of 10^{14} p/cm^2 and 10^{16} p/cm^2) in vacuum. The third group was exposed to UVC radiation (wavelength 254 nm, the lamp intensity 9 mW). Irradiation effects were studied using thermal and spectroscopic methods.

Thermal analysis by DSC showed that the crystallinity of PET was just minimally affected by introduction of nanofillers. Various irradiation types produced different outcomes. DSC revealed that ordered amorphous phase of irradiated samples was more influenced than its mobile segment and crystalline was the least affected. Only slight changes were observed in PET and the nanocomposites irradiated up to 0.5 MGy with γ-irradiation. Proton irradiation produced much more damage. Graphene containing nanocomposite was more resistant to proton irradiation than the one containing only nano-diamonds. On the other hand UV radiation produced the most significant degradation in all samples and particularly in graphene containing nanocomposite.

The irradiation outcome of PET and its nanocarbon containing nanocomposites depended primarily on the radiation type while nanofiller had only slight influence. The most sensitive part was ordered amorphous phase of PET matrix. All samples were relatively stable to γ-radiation. Pure PET was significantly degraded by proton irradiation while UV produced the most degradation in graphene containing nanocomposite.

In Situ Deposition of Nanohydroxyapatite within N,O-Carboxymethylchitosan/Polyvinylpyrrolidone Hydrogels: Characterization and Bioactivity Evaluation

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Bone is a natural composite; its primary purpose is to provide mechanical support for soft tissues and serves as an anchor for muscles that generate motion. Although bone has a remarkable ability to regenerate when damaged, treatment of bone defects from various causes is still a clinically confusing problem. Of possible choices, autogenous bone transplantation is the optimum choice. Unfortunately, the limited donor source, the damage and complications that may happen to the donor site are the worse limitations. Currently, bone tissue engineering strategies offer promising alternatives for autografts and allografts using scaffolds for guided tissue regeneration. Scaffolds are synthetic grafts, have the ability to promote bone regeneration within the defect site. Scaffolds should be porous to ensure nutrient and waste transport, tissue in-growth, and biological fixation with surrounding tissue. Also, they should be osteoconductive to facilitate bone formation on its surface. Scaffold should have adequate mechanical strength to support bone in-growth at the site of implantation, maintain structural integrity during in vivo tissue remodelling and it should degrade over time in concert with bone formation. Recently, polymeric composite scaffolds are gaining increased attention as synthetic alternatives for bone grafting materials. They improve the bioactivity and mechanical properties so as to meet the basic requirements for bone repair. The development of bone-like composites with enhanced biocompatibility calls for a biomimetic approach using hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$] as a guide. Hydrogel matrices based on N,O carboxymethylchitosan and polyvinylpyrrolidone (NOCMCs/ PVP) were synthesized using γ-radiation as clean initiator. Alternate soaking method was used to obtain (NOCMCs/PVP)-nanohydroxyapatite composite scaffolds. In vitro bioactivity and biocompatibility evaluation was investigated before and after immersion in simulated body fluids (SBF) to follow the formation of bone like carbonated hydroxyapatite (HCA) layers. After alternate soaking process; the deposition of guided nHA layers onto (NOCMCs/PVP) hydrogels were confirmed using FTIR, EDX, XRD and SEM techniques. EDX analysis confirmed that Ca/P molar ratio (1.62) was very close to the theoretical value of Ca/P molar ratio in human bone (1.67). The development of nHA crystals was confirmed from XRD measurements and the average grain size was found to be in the range of 12–37 nm. The compressive strength for the tested composites recorded comparable values compared to the cancellous bone. Post immersion in SBF, the growth of carbonated apatite (HCA) particles increased by time and the surface appears smooth after 28 days of immersion. By increasing HA content, the weight of blood clot formed and the percent heamolysis decreases and tends to zero. Synthesis of guided nano-hydroxyapatite layer within (NOCMCs/PVP) hydrogels using alternate soaking is a simple and efficient method. Biomineralization process in SBF contributes to the formation of bone like carbonated hydroxyapatite (HCA) layers. In vitro bioactivity and blood compatibility evaluation indicated that nHA-(NOCMCs/PVP) scaffold was bioactive and biocompatible and may be promising for bone repair.

PA2

Morphological, Physico-Chemical and Mechanical Properties of Radiolytically Synthesized Nano-Ag/ poly(N-isopropylacrylamide) Hydrogels

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Hydrogels have unique properties and many potential applications, especially in the field of medicine and biotechnology. The gel porosity and swelling properties, stability and strength, biodegradability and biocompatibility are characteristics which are widely variable and easily adjusted. Stimuli responsive or intelligent hydrogels are special class of these materials which shows significant response to small changes in surrounding environment such as temperature, pH, ionic strength, electric field and light. From a biomedical point of view, thermo- and pH-sensitive polymers are the most frequently studied. Poly(N-isopropylacrylamide) (PNiPAAm) is one of the most investigated thermosensitive polymer with a sharp lower critical solution temperature (LCST) at around 32°C which can be adjusted by copolymerization and/or addition of salts or surfactants to the initial polymer solution. On the other hand, silver nanoparticles (AgNPs) have been the subject of intense interest due to their size-dependent optical, catalytic and electronic properties as well as remarkable antimicrobial potential. AgNPs possess capability to release Ag^+ ions in a controlled manner creating powerful antibacterial action for many bacteria. This controlled release can be provided by incorporation of nanoparticles in cross-linked polymer network. Among many methods for synthesis of nanocomposites, γ-irradiation induced synthesis has been recognized as highly suitable tool. In this work, synthesis of nanocomposites was conducted as two-step process. In the first step, polymerization and cross-linking of polymer chains occurs and PNiPAAm hydrogels with a large number of pores were obtained. In the second step, these pores serve as nanoreactors for reduction of Ag^+ ions and formation of AgNPs. Absorption spectra of nano-Ag/PNiPAAm hydrogel nanocomposites, with characteristic peaks in the range of 390–415 nm, confirm the successful formation of AgNPs inside PNiPAAm hydrogel matrix. Morphological analyses (SEM and micro-CT) reveal the existence of pores with different size, dependent on PNiPAAm concentration, but independent on incorporation of AgNPs. Structural analysis indicates the presence of spherical AgNPs, with the mean diameter up to 20 nm and face centred cubic crystal structure. Swelling processes of investigated systems show thermoresponse with the volume phase transition temperature (VPTT) between 30.5 and 31.6°C. The possibility to apply nanocomposites for controlled release of active silver was investigated by monitoring the release kinetics of Ag^+ ions in a buffer solution (pH 7.4) at 25°C. The results are modelled by applying five different pharmacokinetic models (Korsmeyer-Peppas, Higuchi, Hixson-Crowel, Kopcha, and Makoid-Banakar). The best fit solution gave Kopcha and Makoid-Banakar models, indicating that the release of Ag^+ ions was predominantly controlled by a diffusion process. The results obtained from compression measurements shows that mechanical properties of investigated hydrogels strongly depend on concentration of polymer matrix as well as on concentration of incorporated AgNPs.

Preparation of Selective Hazardous Metal Ion Adsorbents from Acrylic Monomer Grafted PET Films

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Heavy metal pollution has become one of the most severe environmental problems today. The well-known environmental destruction cases caused by heavy metals such as Minamata disease (organic mercury poisoning) and Itai-itai disease (cadmium poisoning) imposed stricter regulation on the treatment of metal contaminated waste water prior to its discharge to the environment. In the present study, acrylic monomer grafted polyethylene terephthalate (PET) films were prepared and examined for selective adsorption of hazardous heavy metal.

The γ-ray induced grafting of acrylamide (AAm) and acrylic acid (AAc) onto PET films were carried out separately. Grafting of AAm and AAc on PET films was characterized by FTIR and SEM. The grafted films were further modified through alkali hydrolysis to improve the metal adsorption capacity. The hydrolyzed AAm grafted PET films containing amide groups were used to study Hg(II) adsorption and the hydrolyzed AAc grafted PET films containing carboxylate groups were used to study Cu(II) adsorption.

The hydrolyzed AAm grafted PET films were investigated for selective Hg(II) adsorption from mixture of Hg(II) and Pb(II) and the absorbent film showed high selectivity for the adsorption of Hg(II) over Pb(II) throughout the entire pH range (2.2–5.6) studied. The hydrolyzed AAc grafted PET films were used to study the selective Cu(II) adsorption from mixture of Cu(II), Co(II) and Ni(II) and the adsorbent film showed high selectivity towards Cu(II) in presence of Cu(II), Co(II) and Ni(II) in the pH range 1.5 to 4.5. Isotherms of selective metal adsorption were analyzed by using Langmuir isotherm model and kinetics of selective metal adsorption were investigated using pseudo-first-order and pseudo-second-order kinetic models. Desorption and reuse of the adsorbent films was also studied. Thus present study indicated that the functional monomer grafted PET films can be effectively used for selective adsorption.

Nanogels of Polyvinylpyrrolidone Obtained by γ-Radiation: Physicochemical and Biological Characterization

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Nanogels are nanoscale polymeric matrices with strong affinity for aqueous media. They exhibit stability, are inert to blood flow and favour the incorporation of medicinal drugs and bioactive molecules improving their therapeutic value by increasing bioavailability, solubility and retention time. The aim of this work was the preparation of polyvinylpyrrolidone nanogels induced by γ-irradiation, for evaluation as potential drug delivery system.

Experiments were performed in absence of oxygen using diluted aqueous solutions of PVP. The synthesis was carried out in sealed vials in N_2O atmosphere irradiated with different absorbed doses on a γ-irradiation facility ISOGAMMA LLCo. The nanogels were characterized by viscometry, spectroscopy (ATR and UV-vis), thermogravimetry (TGA), X-ray diffraction (XRD), electron microscopy (TEM and SEM), dynamic light scattering. Cytotoxicity studies were performed by the of NBT and MTT tests.

The viscometric results show a decrease in intrinsic viscosity with increasing dose accompanied by an increase in molecular weight. Such behaviour indicates the formation of intramolecular cross-linking by nanogels. The nanogels have an average size of 50 nm with a dispersion of 1.04.

The XRD showed certain order in the morphology of the nanogels. Gels are spherical in shape and have a marked protective effect on cell viability. In the interval of concentrations studied (0.001–0.8%) the more dilute systems favoured the formation of nanogels, whereas the more concentrated ones promoted the appearance of microgels IR spectra and thermal behaviour of nanogels coincided with those of the polymer in bulk. Biological test showed a high biocompatibility.

Nano PVP gels were obtained using γ-radiation. It was shown that the degree of cross-linking of the polymer depends on nanogels concentration and the absorbed dose. The obtained nanogels do not exhibit toxicity to cells, and rather have a protective or stimulator effect on cell viability, property which makes them good candidates as platforms for delivery systems.

Chemical Reduction of Nitrate by Zerovalent Iron Nanoparticles Adsorbed Radiation Grafted Copolymer Matrix

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PA2

Nitrate contamination of global water resources due to the globalization of modern agricultural practices is an emerging threat worldwide. In spite of the usefulness of nitrate and nitrogenous compounds as essential elements in life processes, nitrate is potentially hazardous when present in drinking water at sufficiently high concentrations. Due to its high solubility, nitrate may actually be the most widespread and priority contaminant in drinking water. It acts as a precursor for several health hazards ranging from blue baby syndrome to gastric cancer. Treatment of nitrate containing water is challenging due to its stability. Reduction is the only possible way to fully remove nitrate contamination from ground water as it does neither form insoluble minerals that could be removed as precipitates nor does it significantly adsorb under aquifer conditions. The nitrate molecule is a good electron acceptor and hence an efficient electron donor is required for its reduction. nZVI can play a major role in this situation as it is a good electron donor with a high reactivity due to its extremely small size and strong reduction capacity. The results obtained in this work suggest that metallic-Fe can support chemical reduction of nitrate contaminated water. This research specifically focussed on development of novel methodologies to reduce excess nitrate in drinking water utilizing nZVI stabilized radiation grafted copolymer matrix. nZVI was synthesized by borohydrate reduction of $FeCl_3$ and stabilized on a radiation grafted copolymer matrix. Acrylic acid (AAc) grafted non-woven polyethylene/polypropylene (NWPE/PP-g-AAc) fabric was used as the supportive copolymer matrix and ^{60}Co γ-radiation was applied. In previous research, this material has been extensively characterized. The chemical reduction of nitrate by nZVI adsorbed NWPE/PP-g-AAc (nZVI-Ads-NWP) fabric was examined in batch experiments at different pH values with the aim of optimizing ammonia production (ammonia being the major end product) for subsequent conversion to chloroamines upon chlorination. The pH of the solution showed a marked effect on nitrate reduction with enhanced efficiency in acidic conditions compared to the micro-scale iron particles. After about 24 h, at pH 3, almost 96% of nitrate was degraded. According to characterization data for the material, the surface of the nZVI due to the core-shell structure contains ferrous hydroxide and other protective layers. At low pH values, these protective layers can be readily dissolved exposing the pure iron particles for efficient chemical reduction of nitrate. Experimental results suggest that this reduction process is an acid-driven surface mediated process. The nZVI water interface has been fully characterized by the 1-pK Basic Stern Layer Model (BSM) and an Eley-Rideal–like mechanism well described the nitrate reduction kinetics. In accordance with green technology, newly synthesized nZVI-Ads-NWP has great potential in designing a nitrate reduction process required in drinking water industry.

Lifetime Study of Electronic Devices for Extreme Radiation Conditions

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Recent boom in radiation technology development and increasing number of its emerging applications bring new requirements on related devices. Electronic devices connected to all aspects of our lives today proceed presently with highest speed. However, they are sensitive to radiation. The study of radiation effect on electronic devices is important for increasing their lifetime and the reliability of the whole technology, when used in radiation harsh environment like space, large accelerators, nuclear reactors etc. Our University Centre of Electron Accelerators (UCEA) is equipped with modern research linear electron accelerator with X-ray converter. We have studied the effect of both X-rays and high energy electrons on device lifetime when used in extreme radiation conditions. The CERN accelerator component was tested by high energy electrons, the semiconductor devices for the first Slovak satellite were irradiated by X-rays and semiconductor detectors for radiation imaging and dosimetry were tested by high energy electrons and compared to the experimental results obtained by their γ-ray and fast neutron irradiation.

The devices were tested at linear electron accelerator UELR-5-1S with scanning pulsed beam at UCEA in Trenčín, Slovakia with 5 MeV electrons. The repetition rate of the beam pulse can be set in the range from 5 to 240 Hz, which enables the dose rate to be modified. The electron beam has been scanning the width of 40 cm and the irradiated object either moved beneath the scanning beam (CERN accelerator component) or was irradiated in steady mode (small objects). The CERN accelerator component was irradiated by 5 MeV electrons up to a dose of 2 MGy, to reveal its most radiation sensitive parts. Various commercial semiconductor devices for the skCUBE satellite power supply unit were tested by X-rays up to a dose of 1300 Gy representing the dose obtained by satellite on its orbit during more than 3 years. Finally, the semiconductor detectors were irradiated by 5 MeV electrons studying the effect of radiation of their detection properties and compared to the effects of other kinds of radiation: fast neutrons and γ-rays.

Our study has proved the functionality of the CERN accelerator component, the engine for dipole precise positioning, up to 2 MGy. However, plastic parts of the component were destroyed mechanically and had to be removed in final product. The tested satellite voltage references exhibited increasing output voltage with applied dose, spoiling the reference functionality. In the second kind of device degradation, the functionality was preserved, but the input current dramatically increased (e.g., battery chargers). In the case of semiconductor detectors, some of their detection properties improved (energy resolution) at small doses (1–2 kGy) followed by their degradation. However, after 120 kGy dose of electrons, the detectors were still functional with acceptable detection properties.

The Hormetic Effect of X-Rays on Biosynthesis of Gold Nanoparticles by Actinobacteria

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Gold nanoparticles (GNPs) play an important role in medical, health and environmental applications. All kinds of microorganisms were found to be able to synthesize GNPs. This study assesses the enhancing effect of low-level X-rays on the biosynthesis of GNPs by Actinomycetals isolated from Angouran mine in Zanjan province in North West of Iran.

The isolated actinomycetes were grown aerobically in MGYP broth media. The cultures were centrifuged and the harvested bacteria were suspended in 50 mℓ aqueous $HAuCl_4$ in 12 Erlenmeyer flasks in 3 groups of 4. Two groups of samples were irradiated by 30 mGy and 5 mGy X-rays. The third group was considered as control without any radiation. The solutions were shake-incubated for 120 h.

After five days, the colour of first group samples were changed from milky to purple, while the colour changing occurred after 10 days in the second group samples and the control samples. The UV-vis absorption spectrometry of the irradiated aqueous medium by 30 mGy X-rays confirmed the formation of GNPs.

The findings showed that 30 mGy ionizing radiation stimulated the microorganism to form GNPs in a half time in comparison to other groups.

Correlation of Traditional and One-Step Irradiation Process for Chitosan Production from Charybdis Hellerii Crab Shells

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Chitosan is a polysaccharide obtained from chitin's molecule deacetylation, which is the main composition of certain fungi species and crustaceans and insects exoskeleton. The amino groups present in chitosan give it important biological properties such as biodegradability and biocompatibility, activity/immunological effects and antibacterial healing. The deacetylation of chitin is an aggressive process, which reaction processes in 6 to 8 h under hot concentrated alkali solution. In this work, *Charybdis hellerii* crab shells were fragmented and pretreated for chitosan production and each conversion step, from in natura material pretreatment to final chitosan, were investigated in detail. It was observed dose and dose rate applied as in natura as pretreated chitin influence neither pretreatment process nor chitin deacetylation step; at 20 kGy (from γ or electron beam sources), the conversion process was performed in 60 minutes. The obtained chitosan presented low weight and deacetylation degree compared to standard chitosan, considering specific irradiation conditions.

Effect of γ-Irradiation on the Molecular Weight and Structure of Guar Gum

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This work was done in order to evaluate the degradation in polysaccharides structure of food additives guar gum processed with γ-irradiation. The IR absorbance spectra of the material prior to irradiation is a good tool tp determine the molecular weight and molecular weight distribution.

Guar gum samples were irradiated in powder and aqueous solution in two concentration (1 and 0.5 g/100 mℓ prepared at room temperature) with different doses (0, 2.5, 5, 7.5, 10, 20, 30, 40 and 50 kGy) of ^{60}Co γ-rays (0 held as control sample). The changes of molecular weight and structures of the processed samples were investigated and characterized using Fourier-transform infrared spectra (FTIR), ultraviolet-visible spectral (UV-vis). The results showed the molecular weight decreased gradually with increasing irradiation dose.

The infrared spectra of the control and irradiated powder were recorded using Ashemaduze model Fourier transform infrared spectrometer, in the range 4000–350 cm^{-1}. The KBr pellet technique was adopted for recording the spectra. The solid samples were obtained through following the procedure of adsorption measurement. Approximately 2 mg of desired powder sample was thoroughly mixed with 200 mg of spectroscopic grade KBr and pressed into pellets for recording the spectra. The measurement was carried out by transmittance scans of dilute solutions of 0.5 and 1% from control, irradiated powder samples and standard (solutions of 1% Glactose, 1% Mannose) and irradiated solutions concentration (0.5 and 1%) in the wavelength range 250–600 nm.

Results by FTIR and UV-Vis spectra showed that the effect of irradiation on guar gum is random. Especially with high doses FTIR spectra indicated that γ-irradiation introduced no significant changes into the structure and crystal texture, but UV spectra showed an absorption peak at about 265 nm, increasing with irradiation dose, which was attributed to the formation of carbonyl groups or double bond.

γ-irradiation effects on guar gum properties (chemical and physical) depend on the state of the gum when irradiated as powder or solution. The effect of the same dose in low concentrations is more than in high concentrations.

Investigations on Immobilizing Anthocyanin and Betacyanin onto Polyethylene Films

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The use of plastic polymers for food packaging has increased significantly over the past decades and the global market for polymers has increased to about 100 million tons today. Most of the packaging polymers are petroleum-based for cost reasons, ease of application and worldwide availability. However, besides serving as a physical containment for foods there is a growing need for food packaging to have additional properties. These include, but are not limited to, serving as a substrate for antimicrobials and phytochemicals, platform for sensors to detect food spoilage, food deterioration, pathogen presence, potential deliberate contamination, as well as physical contaminants such as glass, metal pieces.

Phytochemicals are the secondary metabolites formed in fruits and vegetables that have a variety of health benefits. Two major phytochemicals present in fruits and vegetables are anthocyanins and betacyanins. Anthocyanins are a large subclass of flavonoids that are distinguished for their strong red to blue colour in a variety of fruits and vegetables. Anthocyanins are potent antioxidants due to their phenolic structure and have antimicrobial function. We hypothesized that anthocyanin and betacyanin can be grafted directly onto PE using varying doses on EB and utilizing different types of extracted phytochemicals (source, and extraction method). We studied the grafting yield as well as the quality and functionality of the grafted phytochemicals. It is concluded that anthocyanin specifically when extracted with alcohol has a relatively good stability to high doses of EB even all the way up to 100 kGy. Anthocyanins can maintain their properties to a considerable degree; however, betacyanins are not resistant to EB irradiation. Polyethylene is a very strong and resistant polymer that even a high dose of 1000 kGy does not affect its surface or its properties. Therefore, polyethylene is not an ideal polymer backbone for grafting organic and phenolic materials.

Shelf Life Assessment of Sliced Bread by Sorbic Acid Based Active Film

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Food waste and food spoilage is a leading issue facing the world recently. Researchers and industries have made continuous attempts to discover ways to minimize food spoilage by making use of active packaging technologies. The development of active food packaging with antimicrobial functionality enables inhibition of microorganism that caused food spoilage and thus, extends food shelf life. Radiation-induced grafting has been used in this study to develop sorbic acid (SA) grafted active film. The SA active film was then use to investigate the performance of sorbic acid (SA) based active film on shelf-life extension of sliced bread. The effectiveness of active film against micro-flora formation on bread, moisture content, weight loss, texture and colour change was elucidated and discussed. The bread packed with SA active film showed lower in moisture content, weight loss, hardness and colour change compared to control. Visual observation of bread packed with SA active film was performed against control film. The SA active film was observed to extend shelf life of bread up to seven days when compared with the control group, indicating significant reduction of microbial count.

Structural Characterization, Antibacterial Properties and Citotoxicity of γ-Irradiation Synthesized Ag-poly(N-isopropylacrylamide/itaconic acid) Hydrogel Nanocomposites

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Silver (Ag) impregnated dressings are intended to promote healing, prevent infection, to produce a sustained, steady supply of active Ag and to meet the challenges about safety. Hydrogels impregnated with nanocrystalline Ag (AgNPs) have the potential to meet most of these requirements. Here hydrogel nanocomposite formulations are based on thermo- (NiPAAm) and pH-sensitive (IA) copolymer hydrogel matrix doped with AgNPs, (Ag-P(NiPAAm/IA), as a system for the controlled release of therapeutically active Ag ions with the aim to obtain the effective smart, antibacterial and nontoxic device. Synthesis of cross-linked polymer matrix (hydrogel) and in situ incorporation of AgNPs is made by biocompatible radiolytic products of water (using a ^{60}Co source) which provides a basis for the wide range of advanced or innovative applications in the biomedical field. The aim of the work was to investigate structural characteristics of the AgNPs, the micromorphologycal and physicochemical characteristics of hydrogel, and biomedical potential of γ-irradiation synthesized nanosystems.

FTIR analysis confirms formation of 3D structure of copolymeric hydrogel with thermo- and pH responses. Swelling experiment was performed at different temperature (25°C and 37°C) and pH (2.2, 4.5 and 46.8) values. Internal morphology, examined by SEM and micro-CT analysis, showed the porous structure, dependent on the IA content, while AgNPs have no influence on the micro-structure. UV-Vis confirmed the synthesis of spherical AgNPs by the peak at around 400 nm. XRD studies confirmed the face centred cubic (fcc) crystal structure of AgNPs with the diffraction maxima at 2Θ angle values that correspond to the Bragg reflections from the crystal planes (111), (200), (220) and (311). The changes of lattice parameter, interplanar spacing, strain, stress, and dislocation density of crystalline AgNPs depend on the pore size and the diameter of AgNPs.

The controlled release of active substances was monitored by the release kinetics of Ag ions in a buffer solution (pH=7.4, $T = 37$°C). The content of Ag ions was determined by Argon arc plasma and obtained results are modelled by pharmacokinetic models (Korsmeyer-Peppas, Higuchi, Hixson-Crowel, Kopcha and Makoid-Banakar). Antibacterial potential against the gram-negative (*Escherichia coli*) and gram-positive (*Staphylococcus aureus*) bacteria was investigated by the disc diffusion and optical density methods. Considering that the basic condition for the biomedical application of these types of materials is absence of toxicity in the surrounding tissue, cytotoxicity of synthesized nanocomposite device was examined by the effect on HaCaT cell line (healthy human keratinocytes). The results show that it is possible to achieve and fine-tune optimal antibacterial activity, below the cytotoxicity level, and without any harmful effects on the surrounding cells.

The Effect of Natural Antioxidants in Thiyl Radical-Induced Lipid Modification Processes

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Polyunsaturated fatty acids (PUFA), major constituents of biological membranes, are sensitive to a free radical attack. The reactions of PUFA with free radicals are known to occur via two main processes: i) lipid peroxidation, and ii) cis-trans isomerization. Lipid peroxidation can be inhibited by thiols, due to their H-donation ability. On the other hand, thiyl radicals are known to catalyse the double bond isomerization in PUFA. Both processes have damaging potential that must be carefully considered for its consequences in a biological systems. Therefore, the protection against lipid degradation under oxidative and free radical conditions is of special interest. The aim of this study is to elucidate the influence of different naturally occurring antioxidants on lipid peroxidation and cis-trans isomerization processes in biomimetic model system under different conditions.

Model system containing mixed surfactant micelles and buffer was prepared by slow solubilization of linoleic acid (LH) in non-ionic surfactant micelles previously formed by mixing Tween®-20 and PB, pH 6.5. The composition of the investigated systems was typically 0.5 mM LH, 0.28 mM Tween®-20 and 5 mM PB (pH$\sim$ 5). Ascorbic acid (AscH), α-tocopherol and resveratrol (ResOH) of defined concentrations were added during preparation of model systems. The addition of the amphiphilic 2.8 mM 2-mercaptoethanol was added to previously prepared micelles just before irradiation. Model lipid systems were irradiated up to the dose of 400 Gy, in equilibrium with air or after saturation with N_2O at room temperature using panoramic ^{60}Co source at the Ruđer Bošković Institute. Accurate dose rates in the irradiating positions were established with the ethanol-chlorobenzene dosimetry system (ISO/ASTM 51538:2009). The concentrations of hydroperoxides of linoleic acid were determined by the spectrophotometric ferric thiocyanate method, and the geometrical isomerization of LH methyl ester was studied by capillary gas chromatography.

Under air-equilibrated conditions the addition of different natural occurring antioxidants retarded the process of lipid peroxidation among which ResOH showed the best antioxidative property. In model systems where process of cis-trans isomerization prevailed, the presence of antioxidants influenced on a decrease of the trans isomerization level; AscH was the the most effective inhibitor of radiation-induced trans-isomer formation. Among the natural compounds analyzed in this work an amphiphilic ResOH has proven to be the most effective antioxidant, also significant inhibitor for cis-trans isomerization process at the low formation rate of initial radical species.

Results indicate that the cis-trans isomerization and lipid peroxidation processes level could be dependent on the hydrophilic/lipophilic properties of particular antioxidant and its localization in model lipid system. This study contributes to the understanding of the role of antioxidants in radical processes which are not only able to prevent peroxidation but can also behave as anti-isomerizing compounds.

PA2

Evaluation of Thorium Adsorbent Prepared by Radiation Grafting and Functionalization with Glucamine

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Adsorption is considered as the most effective and simplest approaches to separate metal and others chemicals from aqueous systems. Activated carbon is one of the most widely used adsorbents and it can be used to remove almost all pollutants and metals. However, activated carbon adsorption suffers from costly regeneration, high attrition rate and low selectivity of pollutants. Low cost adsorbents with good mechanical strength, high adsorption capacities and selectivity have attracted increasing interest from researchers to develop a practical economically adsorbent for separation/extraction of metals. In the past decades, polymeric adsorbents having ion exchanger property have been identified as potential candidate as compared to other adsorbents. This is because it has large surface area, excellent mechanical stability, adjustable surface modification and chemistry, high selectivity and stability after multiple regeneration cycles. Polymeric adsorbents having fibrous structure have been found to perform better in term of its adsorption kinetic and capacity. Radiation induced graft copolymerization is an effective method to prepare adsorbent precursor in fibre form by grafting of monomer onto the fibre and subsequent functionalization to produce fibrous polymeric adsorbents.

Thorium adsorbent was prepared by grafting of glycidyl methacrylate (GMA) onto nylon fibres in methanol mediated grafting system. The degree of grafting was calculated from the weight gained of fibres before and after grafting. The grafting was carried out by electron beam irradiation using the preirradiation grafting method. The GMA grafted nylon fibres were further modified by reaction glucamine. Then, batch adsorption tests were conducted by adding adsorbent to Erlenmeyer flasks containing thorium solution. The remaining thorium in the solution was tested using inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7900) and standard solutions of thorium at 1 ppb, 10 ppb, 100 ppb and 1000 ppb were used to prepare a calibration curve.

Grafting yields of 220% were obtained at 100 kGy absorbed dose, 2 h reaction time, 40°C reaction temperature and 10% monomer concentration. The parameters to obtain glucamine density of 2.2 mmol/g adsorbent were 10% glucamine concentration, 80°C reaction temperature and 1 h reaction time. The new graft copolymers of GMA and incorporation of glucamine onto grafted fibres were confirmed by scanning electron microscope (SEM) and Fourier transform infrared spectroscopy (FT-IR). A thorium adsorbent containing glucamine functionalized onto GMA grafted nylon-6 was prepared and the maximum adsorption of thorium was achieved at pH 2. The fibrous adsorbent showed >98% separation of thorium from aqueous solution using adsorbent dose of 0.5 g at 50 mg/ℓ thorium concentration, 3 h reaction time, 30°C reaction temperature, 200 rpm stirring speed and pH 4.

It can be concluded that the thorium adsorbent having fibrous structure was successfully prepared and can be applied for thorium separation from aqueous solutions.

γ-Ray-Radiation-Scissioned Chitosan as a Gene Carrier and its Improved in vitro Gene Transfection Performance

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Chitosan (CS) has long been expected to be an ideal gene carrier for its high biosafety [1]. However, the low transfection efficiency of the raw chitosan-based vector has long been a problem troubling the researchers in medicine due to its poor water solubility, low electric charge density, dissociation problem, and other disadvantages [2]. In this work, CS with low molecular weight (MW) were prepared through the γ-ray radiation on the acetic acid solution of CS. The CS chains were scissioned under γ-ray radiation. When the absorbed dose was above 30 kGy, the MW decreased about an order of magnitude, i.e., from the original 3.5×10^5 g/mol to 9.0×10^4 g/mol (30 kGy) and 5.0×10^4 g/mol (50 kGy). The γ-ray-radiation-scissioned CS can effectively bind with plasmid (pEGFP) through complex coacervation method, forming pEGFP/γ-ray-radiation-scissioned CS complex particles with a size of 200–300 nm. The complex particles has a good stability and little cytotoxicity. The γ-ray-radiation-scissioned CS can protect pEGFP from being digested by DNase I according to the gel electrophoresis analysis. The in vitro gene transfection efficiency of the pEGFP/γ-ray-radiation-scissioned CS complex particles were investigated by fluorescence microscope and flow cytometry. The results showed that the gene vectors using γ-ray-radiation-scissioned CS as the carrier will possess better gene transfection efficiency than those using natural high-MW CS as the carrier. The higher the absorbed dose, the smaller the MW of CS and the better transfection efficiency of the corresponding gene vector. This work provides a green and simple method on the preparation of CS-based gene vectors with high efficiency and biosafety.

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In Situ Compatibilization of Polyblends and Polymer Based Composites Induced by γ-Irradiation

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Interfacial compatibility is an essential factor for polyblends and polymer based composites, which is traditionally improved by addition of copolymers with grafting structure or coupling agents, and reactive blending. The generation and recombination of macromolecular radicals at interface makes γ-irradiation a potential mean to improve the compatibility of immiscible polymer based multiphase materials. In the present work, polyethylene terephthalate (PET), polylactic acid (PLA), and nylon based polyblends and composites were prepared by melt blending, respectively. γ-irradiation in nitrogen atmosphere with various absorbed dose were employed following sample molding. Morphology, chemical structure and mechanical property changes were investigated by SEM, FTIR, gel extraction and mechanical testing. The refinement of the separation particles, the ductile deformation at cross-section and the rough surface of pull-out fibres indicated the obvious improvement of compatibility. Gel extraction results and FTIR of the gel confirmed the generation of grafting polymer containing each component. Mechanical properties were significantly increased as a result of in situ compatibilization. According to the evidently positive effects on miscibility found in all multiphase materials, γ-irradiation can be widely-used as an innovative solution to immiscible materials.

Low Dimensional Nanomaterials-Based Interfacial Engineering in Organic Solar Cells

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We have demonstrated a facile but efficient preparation of a solution-processable transition metal oxide nanoparticles or nanosheets-incorporated reduced graphene oxide (TMONP/RGO or TMONS/RGO) and excellent organic photovoltaic cells using the TMONP/RGO or TMONS/RGO to function as a hole extraction layer (HEL). The TMONP/RGO or TMONS/RGO, featuring uniformly decorated high-quality TMONPs or TMONSs on RGO, can be synthesized via a simply adding a precursor solution into RGO prepared by an electron beam irradiation method. Compared with the reference PEDOT:PSS-based cells, the TMONP/RGO or TMONS/RGO HELs provide superior performance characteristics as a result of better electrical conductivity and more uniform film quality than that of PEDOT:PSS. In particular, high performance can be realized irrespective of the thermal treatment conditions of a solution-processed TMONP/RGO or TMONS/RGO layer, which is a crucial difference from the previously reported solution-processed metal oxide-based HELs. These results clearly demonstrate that the TMONP/RGO or TMONS/RGO, prepared by a facile and efficient method, is a promising hole-transporting material and a potential alternative to PEDOT:PSS, thus further realizing an efficient and stable OSCs.

Radiochemical Stability and Life Time of LDPE-Based Flexible Composite Filled with Ce-Doped PZT-$PbZrTiO_3$

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Inorganic compounds like mixed oxides doped with certain low amounts of salts play the role of stabilizers for many polymer matrices. This property is related to the crystalline network, where the difference in charge distribution allows the scavenging of new formed radicals. During the irradiation of polymers the basic processes involve free radicals. They must not be consumed in parallel reactions as it is occurred in their oxidative degradation. Under this condition, the doped inorganic phase behaves as an antioxidant. Its protection activity is similar to the synthesis antioxidants, which delay the decay of free radicals by their reactions with molecular oxygen.

The preparation of Ce-doped PZT-$PbZrTiO_3$ was accomplished by heat treatment at 920°C for 4 h of lead oxide, zirconia and titania with four concentrations (0.25, 0.50, 0.75 and 1.25 w/w%) of cerium chloride. After milling and drying, the powder was added in low density polyethylene in various proportions (3 and 5 w/w%). The XRD and granulometry on inorganic compound were done for the depicting the morphological state. The films and plaques were obtained by pressing at 175°C for 5 minutes. γ-irradiation was accomplished in air at room temperature in Ob Servo Sanguis (Hungary) ^{60}Co irradiator, whose dose rate was 1.1 kGy/h. The exposure doses were 25, 50, 100 and 200 kGy which were compared with pristine samples. The stability characterization of modified LDPE samples was performed by FT-IR spectroscopy, isothermal (190°C) and nonisothermal (heating rate 10°C/min) chemiluminescence and thermal analysis.

The increasing dependence of protection efficiency on the concentration of dopant in inorganic filler explains the participation of these structural defects at the coupling of oxidizable free radicals. The oxidation state of basic polymer is described by the increases in carbonyl and hydroxyl indexes, which allow the calculation of the radiochemical yields for these degradation products. The stabilization effect is related to the surface activity of powder, whose grain size distribution influences the amplitude of protection.

The factors that influence the stabilization activity and kinetic parameters of oxidative degradation are doping degree, the filler concentration and the exposure dose, which determine the interaction probability between solid state defects and free radicals prior their oxidation. The expected stabilization feature is the required feature for the preservation of low oxidation level in many organic products like polymers, paints, vanishes, anticorrosive layers, used in different areas of nuclear units especially nuclear power plants or during their radiation processing.

Decolouration and Degradation of Erythrosine by γ-Irradiation

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In this study, the decolouration and mineralization of aqueous solution of the erythrosine dye irradiated under γ-rays from ^{60}Co are investigated. From the results of absorption UV-visible spectra erythrosine solution as function of dose, the concentration of erythrosine decrease exponentially with increasing γ-irradiation dose and the plot on a logarithmic scale against the dose shows a clear pseudo-first-order rate. The apparent pseudo-first-order constant was calculated. The change in decolouration percentage removal of chemical oxygen demand (COD) and total organic carbon (TOC) were investigated with respect to the applied dose influences of absorbed doses. Complete mineralization of erythrosine dye was achieved with γ-irradiation.

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γ-Ray Induced Reduction and Modification of Graphene Oxide

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Graphene has attracted increasing attention due to its striking electronic, mechanical and thermal-conducting properties. Up to now, graphene has been produced by numerous techniques such as micromechanical exfoliation of graphite, chemical vapour deposition, epitaxial growth and the reduction of graphene oxide (GO). Among these, the reduction of GO by γ-ray irradiation has been regarded as the most green, facile and economical method of the large-scale production of graphene and graphene-based composites.

A series of graphene were prepared by γ-ray induced reduction of GO suspension in different solvents, such as H_2O, alcohol, ethylene glycol, N,N-dimethyl formamide (DMF), N-methylpyrolidone (NMP) and p-phenylene diamine (PPD) aqueous solution. Thermogravimetric analysis (TGA), X-ray photoelectron spectroscopy (XPS) and X-ray diffraction (XRD) were used to study the structure of GO after γ-ray irradiation. The results show that GO in these solvents were all reduced. Alkyl groups are attached onto the reduced GO (RGO) in alcohol or ethylene glycol solution due to the recombination of radicals. Besides, the protonated amine groups which generated from the radiolysis of DMF, NMP and PPD are interacted with residual COO^- groups on the edge of the as-synthesized RGO with the driving force of electrostatic interaction. This work provides a new approach to obtain different graphene.

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The Study of Industrial Process with Radioactive Tracer RTD Method Enhanced System Analysis

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The radioactive tracer (RTD) method is one of the most common nuclear techniques used for troubleshooting and optimizing industrial processes involved in different industries such as petroleum, petrochemicals, chemicals, ore mining, cement and waste water treatment. The technique is easily implemented with simple concept of instantaneous, so-called Dirac, impulse response. In the last decades, significant development has been made with the advent of new equipment, electronics, portable computers and software. However, the style and quality of the results themselves has not considerably changed since its beginning. Correct data collection and system analysis, interpretation and reporting are abilities often difficult to go with or require a long time of training and experience. This paper describes our attempts on developing a new approach on the radiotracer RTD technique using $^{99m}\mathrm{Tc}$ radiotracer to measure the RTD of closed circuit water flow rig tank. The data was gathered and treated using both Dirac and non-instantaneous impulse. The paper shows and discusses the comparative results of some experiments conducted.

The Concentrations of Major and Trace Elements in Powdered Milk Using XRF and NAA, and Comparison to Other Techniques

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Milk and dairy products are considering one of the unique sources for children, and even adult, nutrition. They are also the source of some vitamins and many minerals. Furthermore, they are most versatile for natural food in terms of configuration and determine the necessary components for a healthy life. Milk contains more than twenty different trace elements, most of them are necessary and very important, such as copper, zinc, manganese and iron. These elements are the factors involved in many enzymes and play an important role in many physiological functions. The lack of these elements cause disturbances and pathological conditions. In addition, it was noted that the increase in the concentrations of heavy elements such as chromium, cadmium, lead and mercury will cause damage to human origins, such as kidney and liver, and cause anemia. Furthermore, these inspections on the heavy elements are of particular concern as milk is largely consumed by infants and children.

In this study, eight different milk samples were selected from the Iraqi market to measure the concentrations of major and trace elements. The samples that were selected are most widely used by Iraqi consumers. These brands are Ankor, Nan, Similac, Nedo, Gold, Novalac, Kikoz/1 and Kikoz/2.

Different analyzing techniques were used to cover most of the elements that exist in the samples. Techniques such as X-ray fluorescence (XRF), neutron activation analysis (NAA), Kjeldahl chemical analyses and atomic absorption spectroscopy (AAS) were employed to determine the elements and their concentrations. The obtained results were compared with authorized limit by FAO/WHO standards. Necessary to evaluate the contents of “essential” and “toxic” heavy metals on a greater number of milk samples from various supplies and confirm the absence of possible toxicological risks.

Development of a New Ambient Dosimetry Monitor for In Situ Environmental Monitoring at the Nuclear Studies Centre of Maâmora, Morocco

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In this paper, we propose the development of a new data logger system for monitoring the radiation environment in situ of Morocco nuclear studies centre.

This device is used to measure continuously the γ-dose rate for plotting and monitoring ambient radioactivity, and equipped with an alert system to alert the operator in cases which exceed the dose rate threshold limits. It mainly consists of a high-pressure ionization chamber whose response is directly proportional to the ionization intensity created by the radiation.

This paper details the development stages of a radiation datalogger which is associated to a specific monitoring interface for remote measurement of ambient γ-radiation. It starts first with studying the relationship between the dose rate and the output ionization current of the HPIC chamber, followed secondly by the development of digital processing unit for measuring and data recording, and thirdly finishes with the development of a data transfer module, using an XBee protocol of RF transmission, to the host computer. In addition, this paper presents also new software which is associated to the datalogger device, used as data acquisition interface, and was designed and characterized by specific parameters for real time remote monitoring of γ ambient dosimetry.

In fact, environmental radiation dosimetry has been performed with a high-pressure ionization chamber which supplies a current directly proportional to the amount of the incident particles energy. The output ionization current is of the order of 10^{-14} A/Gy/h per cubic decimeter, equivalent to energy absorption of 10 μJ/h and per gramme of the chamber material. This current is DC coupled first to a preamplifier where it passes through a high ohmic resistance of 10^{10} Ω to establish a difference of potential, and followed by a negative feedback linear amplifier circuit.

The output of this amplifier is then connected to the electronic module for digital data treatment and transmission to the acquisition software installed into PC.

Study of Sediments in a Sub-Basin of the Panama Canal Using Nuclear Techniques

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In early December 2010 a storm that occurred was named "La Purisima" the largest storm in the history of the Canal watershed. According to the Panama Canal Authority (ACP, from Autoridad del Canal de Panamá) Yearbook of suspended sediments for 2010, the storm was associated with the interaction of a low pressure centre, the remnants of a stationary front and the intertropical convergence zone in the north-eastern part of the basin of the Panama Canal. The storm produced a record 760 mm of rain in 24 hours. There were more than 500 landslides in the watershed above the Alajuela dam. These landslides resulted in a large amount of suspended sediment upstream of this dam, where potable water facilities for the City of Panama are located. This led to a turbidity of water from the dam of 700 NTU (nephelometric turbidity units), causing the collapse of the water treatment plant, leaving a large part of Panama City without drinking water for nearly two months. On the other hand, waste waters contribute to serious pollution problems not just in Panama Canal basin but also at the Panama Bay influencing marine and coastal environment, and there is not an effective monitoring programme for contaminants in treatment plants wastewaters effluent and coastal marine areas. In addition to this, the sediments are vectors of contaminants such as heavy metals, etc. The ACP must operate efficiently and scientifically to collect an analyze sediments from dredging works (suspension, deposition at some site, etc.) because it is of fundamental interest to maintain and improve water quality both in the Panama Canal river basin as in the urban area. Therefore, a characterization of the dynamics of sediment transport phenomenon using radiotracer and chemical tracers would offer a rigorous and efficient methodology for a national programme of measurements or monitoring plan of transport and behaviour of pollutants into resources water of Panama, including the study of sediments at the biggest Panamanian WWTP.

For sediment transport monitoring, radioactive and chemical tracer technology was selected because it is a very reliable, accurate and non-intrusive procedure. Its use required low amounts of radioactive substance. Also, tracers have high resistance to physical factors, such as temperature and pressure, which make them ideal for this type of studies.

One of the goals of this study is to contribute to reducing the contamination level to international water quality standards, through an efficient sediment transport monitoring programme in the Panama Canal basin and check out the contribution of wastewaters treated at WWTP to the marine and coastal environments. To achieve this goal, it is necessary to study and compare both methods, non-nuclear and nuclear techniques, using nucleonic gauge, and comprehend all the processes involved in sediment transport along the Panama Canal basin, including the contribution of treated waste waters, during dry and rainy seasons, considering also physic-chemical factors.

Tracers of High Altitude Pollution Sources and Impact on Mt. Kenya Ecosystem

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Tracers of pollution sources have been used in atmospheric studies to track sources of long distance transported particulate aerosols in the lower and middle troposphere. To identify the sources of suspected pollutants that are responsible for the degradation of glaciers on Mt. Kenya the tracers were used in this study. Mt. Kenya is one of the major sources of water in Kenya and therefore important in sustaining underground and river water levels. Its ecosystem is therefore important in sustainable economic growth, food production and poverty eradication. However, Kenya has been experiencing reduction in river water levels and drying of many wetlands resulting in extended arid lands, especially in the neighborhood of semiarid areas. Strong winds and convective systems are known to contribute mineral dust particles in the middle troposphere. This species of aerosol particles have an estimated lifetime of weeks and can be transported for long distances, for example the impact of Saharan dust in the Atlantic Ocean and America. The semiarid lands and increasing anthropogenic activities, especially cultivation, within the fast increasing population in Kenya were suspected of impacting on Mt. Kenya ecosystem. However, tracing the sources that contributed to pollution at that altitude remained inhibited due to scanty measurements in the region. In March 2015, during a period of dry and hot conditions, which preceded the long rains, a measurement campaign was carried out at a site on the south-south eastern slopes of Mt. Kenya. The site location is at the equator, at more than 4.7 km above sea level (a.s.l) and is characterized by tropical alpine highland glacier in the neighborhood of high mountain peaks of heights ranging from 4985 to 5199 m a.s.l and lakes. The campaign mobilized gas and particle monitors, which included a black carbon monitor, and battery powered particle samplers. Gravimetric measurements of collected airborne particles on Teflon filter media; the elemental constituents of those particles, glacier snow, ice and water were used as tracer properties for assessing the source on pollution impacting the site. Water, snow and ice samples were collected into precleaned plastic containers. The filter samples were analyzed using convectional EDXRF spectrometer and the samples of water, snow and ice by TXRF at the Institute of Nuclear Science and Technology, University of Nairobi, Kenya. On filter samples Ca, Ti, Cr, Mn, Fe, Ni, Cu, Zn and Pb; the abundant elements were Ca, Ti, Mn, Fe and Zn and in glacier snow, ice and water it was Mn, Ca, Ti and Fe. These analyzed elements are common tracers of mineral dust thus implicating local and distance arid lands and anthropogenic activities as sources of pollution that contribute to the degradation Mt. Kenya ecosystem. However more comprehensive studies are necessary, despite the difficult terrain and conditions.

$CaSO_4$:Dy and $CaSO_4$:Ce,Eu Intrinsic Efficiencies Dependence on Ionizing Radiation Type and Quality

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The dependence of a thermoluminescent (TL) dosimeter response to the type and quality of radiation is a key issue that is being tackled worldwide by the development of new dosimetric materials associated with this technique. In this context, the aim of the present work is to evaluate the intrinsic efficiency of $CaSO_4$:Dy, considered as the standard material, and $CaSO_4$:Ce,Eu, a newly developed TL material, for different ionizing radiation types and energies. To do so, a batch of 55 dosimeters of each material was selected according to their non-irradiated TL readout and intrinsic efficiency to the ^{60}Co γ-radiation on air and electronic equilibrium conditions and then divided into eleven sets of five dosimeters, one of the sets being kept as the control set to evaluate the non-irradiated TL signal while the ten remaining sets were irradiated, again in air and electronic equilibrium conditions, with doses ranging from 0.1 mGy to 10 Gy in secondary standards ^{60}Co and ^{137}Cs γ-radiation sources, RQR, RQA and RQT ISO/IEC 61267 series and N ISO 4037 series X-ray beams, always including the reference quality for the radiation beam series, and tertiary standard collimated electron beams with effective energies from 4 MeV to 20 MeV. A Thermo (Harshaw) 3500 thermoluminescent reader was used to evaluate TL readouts 24 h after the irradiation and the obtained glow curves were exported in the ASC format through WinREMS TL reader controller associated software. Individual peak intensity, integrated response, peak to peak intensity ratio, calibration curves and intrinsic efficiency, provided that all dosimeters are 0.8 mm thick pellets of 6.0 mm of diameter containing 16.67 mg of TL material, were calculated with the aid of SciLab 5.5.2 software, also used to graphically explore the behaviour of $CaSO_4$:Dy and $CaSO_4$:Ce,Eu intrinsic efficiencies with the radiation type or the radiation quality. As expected from literature, $CaSO_4$:Dy intrinsic efficiency presented a dependence of up to 30% with radiation type or quality while $CaSO_4$:Ce,Eu intrinsic efficiency varied by 200% with radiation quality. Despite this huge dependence, the $CaSO_4$:Ce,Eu peak I to peak II intensity ratio remains stable with the radiation type and varies by 5% from one radiation type to another, so that this newly developed TL material can be used as a dosimeter capable of determining, in non-mixed radiation fields and after an adequate and rigorous calibration, both radiation type and quality besides the dose.

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Evaluation of TL and OSL Response of CaF_2:Tm for Electron Beams Dosimetry in Radiation Processing

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An increasing number of pytosanitary irradiations using electron beams has encouraged the development of surface dosimetry systems to cope with both low and intermediate absorbed doses and dose rates. Besides the well-established reference and routine dosimeters, ranging from alanine to radiochromic films, there is an interest in dosimeters based on thermoluminescence (TL) and optically stimulated luminescence (OSL) effects. In this context, the aim of this paper is to study the TL and infrared stimulated luminescence (IRSL) response of the calcium fluoride dosimeter doped with thulium (CaF_2:Tm) produced via combustion synthesis (CS) by the Nuclear Energy Department of Federal University of Pernambuco, Brazil. The pellets with 6 mm in diameter and 1 mm thickness were obtained by pressing the powder using 10% PTFE as binder material. The individual TL and OSL sensitivities of the dosimeters of the batch were previously evaluated and a group of 50 pellets with a standard deviation of 6.8% was selected to be used in this study. After that, the performance of these dosimeters to electron beams with 1.5 MeV from a DC 1500/25/4 – JOB 188 Accelerator at the Radiation Technology Center at IPEN-CNEN/SP was investigated. For each dose, four pellets of CaF_2:Tm, together with four pellets of alanine were irradiated with doses from 0.5 kGy up to 10 kGy. The TL and OSL readings were carried out after a preheating at 100°C during 15 min using a Riso TL/OSL reader, model DA-20. The TL measurements were taken with a heating rate of 2°C/s, in the range from 50°C to 350°C. The OSL readings were carried out with infrared stimulation with optical power attenuated to 20% during 240 s. These readings were thermally assisted at 150°C. Residual thermoluminescent glow curves for IRSL were recorded after stimulation times.

The reproducibility and stability of the TL and IRSL responses were also evaluated, as well as the dependence with different dose rates.

The results showed that the main TL peak of the glow is in the region of 200°C and it was observed that the IRSL curve of the dosimeters presents a fast and a slow decaying IRSL signals. The TL and OSL dose response curves were fitted by a second order polynomial function with correlation coefficients of 0.97 and 0.99, respectively. The results indicated the possibility of the application of CaF_2:Tm for electron beam dosimetry in radiation processing.

Radiation Shielding Design Assessment of Nucleonic Gauges

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In recent years, several standards have been issued by different international committees specifying requirements for the design of nucleonic gauges taking into account issues related to radiological protection. For this end, agreement with the standards should be included as part of the equipment specification of the licencing process, however, most nucleonic gauges in Brazil were installed in the period prior to the issuance of these international standards. This study will evaluate the shielding performance of different models of nucleonic gauges, installed in Brazilian industrial facilities, during operational and maintenance procedures, taking into account the international standards (ISO/IEC) concerning the constructional requirements and classification of nucleonic gauges. In Brazil, there are several hundred of these apparatus installed in at least 500 industrial facilities. Using the information available from the Brazilian nuclear regulatory body database, it was selected reference industrial facilities that use a wide range of nucleonic gauges with different radioactive sources and manufacturers.

In order to assess the shielding performance of nucleonic gauges, the dose equivalent rate was determined in-loco during operational procedures. The measurement protocol took into account the requirements and procedures proposed by IEC 62598:2011. The maximum dose equivalent rate was determined at different distances from the nearest accessible surface using ionization chambers with different detection volumes.

In view of the specific operational conditions found at reference facilities (not covering all operational situations), the measurements obtained have been used for the validation of a GEANT4-based Monte Carlo code to allow extrapolations for other operational conditions. Initially, different designs of nucleonic gauges developed in Brazil were evaluated. The maximum dose equivalent rate was determined at the reference facility and the designs were modelled and simulated using the MC. With the dose equivalent rate results for each model, the nucleonic gauges should be classified into the seven dose rates classes, as specified in the international standards. It should be noted that, according IEC standard, the equipment in class one are considered non-compliant with constructional requirements, and should be retired. The study is still in progress, in order to include other nucleonic gauge models in use in Brazil. Nucleonic gauges can be subject to extreme environmental conditions such as high temperatures, salinity, humidity and explosive atmospheres. Aspects of the design and manufacture of these devices should be treated as an important feature for a proper approach to radiological protection.

The efficacy of a regulatory system to control radioactive sources is determined by its appropriated implementation considering the resources available, normally limited. Therefore an optimization of resources is needed. The results obtained in this study can enable the establishment of a safety indicator tool to industrial facilities, taking into account different designs of nucleonic gauges, so, this additional parameter can be used to determine and to optimize the frequency of regulatory inspections.

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Axial Computed Tomography Phase-Space Source Model in the PenEasy/PENELOPE Monte Carlo System: Implementation and Validation

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The dosimetric quantities currently adopted by national regulations, or for standardization of dosimetric models adopted by manufacturers of CT equipment are based on a basic metric, introduced about thirty years ago: the computed tomography dose index (CTDI). This quantity, independent of its definition variations, represents the absorbed dose along the longitudinal axis (central and peripheral) of an acrylic phantom with known and well defined dimensions. Since the introduction of CTDI as the appropriate metric for determining the dosimetric characteristics of CT procedures, and its acceptance in the scientific community and between equipment manufacturers, the technology modified significantly the architecture of these systems as well as the clinical procedures for their use. The introduction of CT cone beam systems, with enlargement of the dimensions of the radiation beams to accommodation in a small number of rotations of a larger region of interest, brought significant clinical advantages. However, this expansion of the dimensions of the X-ray beams used in CT scans and the use of helical techniques, started to make improper the use of CTDI. As a consequence, the correct assessment of the CTDI through the measurement of the dose profile along the central and peripheral cylindrical phantom axis has become a work of crucial importance. Several research groups around the world have been developed CT dosimetry tools based on the Monte Carlo method. The ImPACT group provides a CT dosimetry tool based on NRPB SR250 dose distribution data or the use of EGSnrc Monte Carlo system to assess the dose distribution in cylindrical and anthropomorphic phantoms. In this work, it will implement an axial computed tomography phase-space source model in the PenEasy/PENELOPE Monte Carlo system in order to assess the dose spread function along the z-axis and along a peripheral axis of a cylindrical phantom. The X-ray source model has been created for a GE Lightspeed CT family, and it considers the tilted anode, the heel effect and the X-ray spectrum self-attenuation. The phase-space file has been simulated after the CT collimator and the CT setup includes the construction of the shaper filter (bowtie filter). Previous result show the primary dose spread function affected by the tilted anode and by the anode self-attenuation. Finally, the phase-space source model will be used to simulate an axial and helical scan introducing the table displacement (pitch).

Application of Radiation Science and Technology in the Republic of Tajikistan

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One of the IAEA National TC Projects having relation to radiation science and technology which was successfully implemented in Tajikistan was TAD/8/002 "Creating Non-Destructive Testing Capability" initiated in 2009. Tajikistan, situated in the one of the most seismic-affected areas in the world having a number of civil and industrial buildings, bridges, tunnels, pipelines, hydropower structures, dams and other objects, has only a very limited knowledge and application of non-destructive testing (NDT). The main objective of the project TAD/8/002 was to establish facilities for non-destructive testing of industrial equipment and components as well as for civil engineering structures in accordance with international standards. Fact-finding expert mission found out the detailed sectors and industries for the possible use of NDT technique in the country, checked on personnel availabilities, and visited the possible laboratory buildings. Several meetings with senior governmental officials were organized, where lectures on NDT for industries, including civil engineering and special purposes, QA management as well as training and certification were presented. They aimed in creating awareness among future possible alliances and end-users of NDT. Necessary equipment to be provided for the laboratory was discussed and agreed. Echograph with C-software; X-ray generator, both with accessories and software for civil engineering applications; magneto-anisotropic indicator of mechanical stresses, model stress vision-with software for 2D and 3D presentations; ultrasonic testing calibration block with carrying case and certificate; several laboratory equipment, supplies were purchased. Scientific visits were organized to gain knowledge about the NDT applications in industry and civil engineering structures, the new and advanced developments in the field of NDT including the NDT of civil engineering structures. Two group fellowships have been granted to gain some hands-on experience in the use of the above NDT methods in industry, acquire training at levels 1 and 2 in the four basic NDT methods, to familiarize with standards and procedures for carrying out NDT tests in industry and to take certification examinations at levels 1 and 2 in the above methods. During the national seminar, presentations on infrared thermography stress monitor techniques, rebound hammer, carbonation method, ground penetration radar, ultrasonic techniques, ultrasonic pulse velocity testing and electromagnetic method were presented. In addition other methods, e.g., the oldest and most commonly and widest used method visual techniques, was also presented. Training materials on NDT for industrial and civil engineering safety in Russian language have been prepared and reviewed. Experts advised on formation of infrastructure for accreditation and certification of NDT in Tajikistan to meet requirements of international standards. NDT capability in the country has been developed. Non-destructive testing laboratory has been created and equipped, personnel properly trained and non-destructive testing procedures established. Procedures for non-destructive control service have been documented and established. Tajikistan has now complete know-how, through which industrial and ecological safety can be improved, risk and extended lifetimes of critical components in civil engineering, transportation, uranium mining and other industries reduced.

Simulation Studies on the Image Quality of Industrial Film Radiography

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This communication highlights investigations aimed to attain a comprehension about the radiographic non-destructive testing (RT) of water-filled pipes; with the objective of improving the radiographic quality. A radiographic testing computational toolkit was used to simulate film radiography of a water-filled pipe having an outside diameter of 219 mm (8″), using ^{192}Ir. The results showed that water significantly increases the scattered direct ratio (SDR) on the film, which results in a poor sensitivity. An approach to decrease the SDR was examined; and the results indicated prospects to improve the radiographic quality. Simulation results will be used to set up experiments; to further study the proposed approach.

Comparison of Image Reconstructions for γ-Transmission Computed Tomography System by Using MATLAB and i-Gorbit Software

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With wide industrial application, computerized tomography CT is a rapidly developing technique that is especially useful for imaging and measuring multicomponent and multi-phase processes. The most important contribution of CT is to greatly improve abilities to distinguish regions with different γ-ray transmittance and to separate over-lying structures. The CT system of single source and detector γ-transmission tomography GORBIT, designed by CANTI, Viet Nam, was used to analyze the different density materials. Hardware of the GORBIT CT system consists of two servo motors, data logger, computer, a radiation source and a radiation detector. The measurements in GORBIT system were carried out at the CT Laboratory in the Department of Atomic Energy, Yangon. This tomography system operates with a 1.85 GBq (50 mCi) ^{60}Co γ-ray source and a NaI(Tl) scintillation detector. Measured γ-transmitted data were used to reconstruct the cross-sectional images of research samples. These images were reconstructed from the measured transmitted data in different image reconstructions algorithms. Analytical methods of back projection (BP), the filtered back projection method (FBP) and iterative algorithms of algebraic reconstruction method (ART) and estimation maximizations (EM) methods were used in i-GORBIT image reconstruction software. Another image reconstruction programme GCTS was created by using MATLAB package. In this image reconstruction, different algorithms of back projection (BP) and filtered back projection (FBP) were used. In FBP method, different filters of Ram-lack filter, Sheep-Logan, Hamming, Hann and Cosine filter can be chosen and different interpolation methods can be applied to improve the quality of images. The results of different image reconstructions programmes were compared and analyzed for the sample materials. In this research work we will present some results obtained by using tomographic techniques to analyze various samples to check the distribution of various density materials. These samples are made by using different properties of materials with high and low density materials of lead, ion, six holes brick, polymer slab contained in a polymer pipe vessel. These samples are also used to verify the outcome from the CT analysis with different image reconstructions programmes i-GORBIT and MATLAB.

Neutron Radiography Studies for Detection of Hydrogen Distribution in Nuclear Fuel Claddings at Research Centre Řež

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Zirconium (Zr) based nuclear fuel claddings act as a barrier against loss of fuel particles into the coolant water during plant operation, handling and dry storage of the spent fuel rods. The claddings absorb hydrogen produced during reactor operation due to water side corrosion. Increase in the hydrogen (H) concentration limit can lead to hydride precipitation, resulting in the reduction of cladding strength and/or mechanical failure by a process called delayed hydride cracking (DHC). The DHC damage mechanism is related and dependent on the hydrogen concentration, temperature and stress level in the cladding. Therefore, the distribution and quantification of hydrogen in Zr-based fuel claddings is an object of intensive research. The high sensitivity of neutrons for hydrogen and as a non-destructive method, makes neutron radiography a useful technique for detection metal hydrides and their distribution/location in cladding.

Un-irradiated Zr based fuel clads (Zr-1%Nb) have been investigated at the neutron radiography facility of LVR-15 research reactor in Řež, Czech Republic. The samples were investigated in a horizontal channel that offers an intense thermal neutron beam with a 10 cm diameter. The facility is equipped with newest Timepix based detectors, with thin ^{6}LiF converters for neutron detection capable of delivering high resolution. 2D radiography results have been obtained from three fuel cladding sections that differ in their hydrogen content. Qualitative information on hydrogen concentration locations in fuel cladding were identified. The H-distribution was revealed by image processing based on intensity histograms. Based on the neutron radiography results, quantitative evaluation of hydrides distribution was performed by classical metallographic procedure and electron microscopy. Qualitative and quantitative inspection of hydrogen distribution in fuel claddings is reported in this paper.

Adsorption Behaviour of Chloroauric Acid, a Generic Adsorbing Tracer, for Finding Wetting Behaviour of Fluids in Oil and Gas Industry

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Tracers are widely used to study physical phenomena taking place inside reactors like studying the hydrodynamics of the reactor by residence time distribution or characterizing oil reservoirs for heterogeneity and residual oil saturation. Dual tracer method, which uses one adsorbing tracer and one nonadsorbing tracer, is used to characterize the reactors for wetting efficiency of the fluid in gas liquid reactors (trickle bed reactor). Nonadsorbing tracers are well studied in the literature. Chloroauric acid ($HAuCl_4 \bullet 3H_2O$), with ^{198}Au as γ emitter, is a tracer that adsorbs on the solid surface, therefore can be used as an adsorbing tracer. It is adsorbed on the surfaces that are easily protonated like silicates (albite, quartz, feldspar), chitosan, polymers and a wide variety of surfaces. This adsorbing behaviour makes chloroauric acid a potential generic adsorbing tracer for oil and gas industry. Glass beads are used in lab scale reactor experiments to form a porous medium. Therefore, adsorption kinetics and dynamics of chloroauric acid on glass surface will impact the characterization of the reactor using the two tracer technique. In the present work, adsorption isotherms and adsorption kinetics of chloroauric acid on glass surface are studied. The nonradioactive form of chloroauric acid is used for this study which can be translated to radioactive gold chemical for better accuracy at industrial scale.

UV-visible spectrophotometer, at different wavelengths is used for concentration measurement of nonradioactive chloroauric acid in the chloroauric acid solution. In UV-visible spectrophotometer, UV or visible rays are passed through the sample. The absorbance of incident rays of a particular wavelength follows the Beer-Lambert law, and is proportional to the concentration of chloroauric acid in the sample. Batch adsorption studies are carried out using glass beads and change in concentration of the solution is measured with time by UV-Vis spectrophotometer.

The adsorption and desorption behaviour of chloroauric acid on glass beads is obtained for different tracer concentrations. For chloroauric acid, the pH and chloride ion concentration are found to impact the adsorption–desorption behaviour on the glass surface. The results obtained will be used to characterize the lab scale porous medium for wetting efficiency.

Ion Irradiation Effects on the Optical Properties of Quantum Dots for Nano-Dosimetric Systems

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Nowadays it is generally accepted that the radiation damage on cells induced by hadron beams is related to the track structure, i.e., to the spatial distribution of stochastic interactions occurring with nanometric volumes.

Luminescent quantum dots (QD) seem to be promising candidates for the realization of portable systems for the evaluation of the nanodose. Ionization produced in QDs by scattered electrons give rise to quenching or luminescent centres affecting the optical properties of nanocrystals. So, changes of both luminescence features and excited states lifetimes after irradiation can be used for evaluation the damage released by ions in nanometric volumes.

In this work, we studied the optical properties of luminescent QDs irradiated with 2.0 MeV H^+ proton beams at different fluences. Semiconductor QDs are dispersed into polysiloxane films at different concentrations on silicon substrates and their luminescence properties are analyzed before and after the irradiation. During irradiation the light yield is monitored by means of ion beam induced luminescence (IBIL) measurement. The luminescence bands are measured with a spectrofluorimeter Jasco FP6300 by exciting the samples at different wavelength in order to identify possible distribution of emitting centres or size dependent optical properties. Lifetime measurements are performed with different pulsed lasers, at 355, 405 and 450 nm. The lifetime changes after irradiation are correlated with the formation of quenching centres in QDs.

The results are a proof of concept for the realization of a nanodosimeter based on QD luminescence properties.

Results of Radiation Protection in Practices with Sources of Ionizing Radiation in the Petroleum Refining Industry

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Sources of ionizing radiation have wide application in medicine, industry, research, agriculture and education. These sources must be managed in conditions of safety and security. If used incorrectly or in unsafe conditions, radioactive sources can cause death, serious injuries and economic losses, as demonstrated by the experience in many areas of the world.

In the oil industry, specifically the oil refining industry has wide application of ionizing radiation sources in the following fields: 1) Study and control of catalysis. 2) Measure and control fluid flow. 3) Determination of residence times of liquids in closed systems. 4) Location of interfaces or separation zones of petroleum products circulating in the same pipe. 5) Analytical determination of components such as sulfur. 6) Studies on corrosion protection. 7) Fire detection and gas. 8) other

In Cuba three oil refineries are installed in different parts of the country the case in this work is the Cienfuegos refinery located in the south-central Cuba, specifically in the northern margin lobe of the Bay of Cienfuegos region. Its purpose is oil refining and product manufacturing, purchase, storage, processing, distribution and marketing of oil and petroleum products within the Cuban territory and abroad.

In the Cienfuegos oil refinery various types of sources of ionizing radiation, linked to the following practices are used: 1) Location of interfaces or separation zones fixed level nuclear gauges are used with ^{137}Cs, for a total of eight sealed sources, which are used in desalination. 2) Fire detection and gas, ionic smoke detectors used with sources ^{241}Am, for a total of 450 sources, 3) Detection of analytical components, two sulfur analyzers with X-ray tubes.

The above practices have spent more than 8 years in use with very good results. Radiation protection in the exercise of these was based on the demands and requirements established by law and national legislation in line with the basic rules and guidelines proposed by the IAEA internationally.

At the time elapsed they have not reported overdose of occupationally exposed workers, or specialists and workers related to the exercise of practices, nor have reported incidents or radiological events.

The results are based on training and training of occupationally exposed workers and workers linked to practices in the documentation of each and study and exercise plan radiological emergency linked to other key plans like plan emergency in case of fire and disaster reduction plan. Training continuity by simple elements such as lectures, conferences, videos, business web, and internal magazines to the entity raise awareness and training of workers in confronting possible events and the responsible use of the potential of the exercise of these practices.

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Radiation Dosimetry of Laboratory Practices based on Radiotracers Techniques

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Radiotracers techniques have become an important tool for diagnosing industrial reactors and optimizing processes. Recently, many radiotracer laboratories have been established aimed at on-the-job training and R&D in the African region with the aid of IAEA TC projects. This paper shows our efforts in radiation dosimetry, safety, and emergency procedures complying with the regulations of the Sudanese Nuclear and Radiological Regulatory Authority (SNRRA) for the licencing and commissioning of a radiotracer laboratory. Experiments using $^{99m}\mathrm{Tc}$ 15 GBq radionuclide generator have been conducted in the lab in the presence of expert radiation inspectors from SNRRA. Radiation monitoring for the workplace has been done as well as for the surrounding environment. Consequently, personal dosimetry has been recorded for the radiation workers involved in those experiments. The paper shows the results of measurements and discusses how optimizing radiation dosimetry, safety has been achieved during the work.

Application of Complementary Beam Techniques to Study Deformation Mechanisms in Heterogeneous Materials for Automotive Industry

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The increasing demand on power and efficiency in automotive industry increases the thermo-mechanical loads and power densities in combustion engines. New materials are required, which combine light weight with sophisticated high temperature strength and creep resistance to meet the requirements. AlSi and AlCu alloy systems are developed for structural parts to improve long-term stability and reduce thermal fatigue damage. In such alloys a composite-like heterogeneous microstructure is formed during casting. The Al_2Cu phase in AlCu systems and Si phase in AlSi systems acts as reinforcement of a soft α-Al phase. The microstructure morphology (interconnectivity) and the matrix stiffness have significant influence on stress distributions, deformability and crack formation. Therefore, not only composition, but also thermal history (i.e., cooling rates after casting and heat treatments) play an important role for material properties.

Two current projects, the "μ-Fe Sensitivitätsanalyse" and "OptiAlloy" funded by the Bayrischen Forschungsstiftung, deal with non-destructive characterization of heterogeneous cast light alloys by complementary applications of high sophisticated beam techniques. Several diffraction and imaging experiments were performed to measure microstress (neutron diffraction), characterize damage initiation and propagation (synchrotron tomography) and to relate them to the microstructure's morphology (transmission electron microscopy and synchrotron tomography). Photons, electrons and neutrons were used as probe particles according to their interaction with metal and spatial resolution limitations, applicable for the specific problem.

Neutron diffraction (Stress Spec, FRM2, Garching, Germany) results show elastic and plastic deformation between the brittle primary phase (AlSi and Al_2Cu network) and α-Al matrix. Big gauge volume and high penetration depths allow in situ acquisition of strains during high temperature tensile testing. Strain measurements under load and after unloading were performed to distinguish between micro- and macrostress contributions. Synchrotron tomography (parallel beam) with absorption contrast imaging of AlCu alloys and phase contrast imaging of AlSi alloys (low-Z contrast between Al and Si) helps to qualify microcracks within the microstructure in 3D.

Two independent characteristics could be identified as mainly responsible for crack sensitivity of AlSi and AlCu alloys: First the morphology of the brittle reinforcing phase (isolated particles versus interconnected network) as crack inducing parameter and second the ductility of the α-Al matrix (accommodating stresses by plastic deformation) as crack growth inhibitor.

Neutron Activation Installments for Control of Flour Spar Enriching Factory in Mongolia

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Mongolia is rich in fluorite resources and enriched fluorine is one of items of mineral export of Mongolia. Sorting fluorite ore on the input of the enriching factory is an important measure to keep the enrichment process running smoothly. A determination of fluorine content in the enriching pulp allows fast control of the enriching process. Rapid neutron activation technique for fluorine content determination in the pulp takes 15 min against the traditional chemical analysis (one day).

In this paper, devices based on neutron activation technique for fluorine determination in fluorite ore and enriching pulp in the factory are described. The first device (Flourite-1) was developed as a stationary instrument for fluorine content determination in the fluorite ore at mine. The second device (Fluorite-2) was developed to determine fluorine content in ore on the lorry to sort ores in the factory input. Sorting ore on arrival by its content is important for enriching process control, as ore to the factory arrives from different mines. The third device (Fluorite 1M) was developed as stationary (like Fluorite-1) to determine fluorine content in the enriching pulp to control a enriching process.

All devices use fast neutron activation analysis. Neutron sources ^{238}Pu-Be, ^{241}Am-Be, ^{252}Cf were used for nuclear reaction $^{19}\mathrm{F}(n,\alpha)^{16}\mathrm{N}$ with measurements based on detecting the resulting 6.13 MeV γ-ray. Coincident γ-ray of 5.5 MeV and 5.11 Mev are detected which are released from the samples during the measurement. The ^{16}N half-life is 7.35 s and the γ-ray intensity is proportional to the fluorine content (CaF_2) in the ore or enriching pulp. Fluorine content is calculated compared with standard samples. Regular 150×100 mm NaI(Tl) γ-ray detectors collect the data.

Fluorite-1 is single channel spectrometry system, where samples and standards are measured in turn using one counter system. Fluorite-2 is a microprocessor controlled system. Neutron activation of the ore and γ-ray detection is made by a pneumatic system moving source and detector to the lorry. Spectrometry amplifier stabilizer was developed as the detector of device placed outside and amplitude of detector signal was changing depending on temperature change (temperature range is -40°C to $+40^\circ$C). Standard ^{137}Cs sources were used for stabilization, calibration and control of the measuring system. Fluorite-1M has two counters to count pulses from standard and the samples in each counter, which allow to reduce time of measurement.

Fluorite 1M had absolute error less than 1% and it was much needed for Bor-Undur, Fluorite Enriching Factory, Mongolia during the economic crisis years 1990–2000, when there were shortage of chemical components for chemical analysis of the factory. This kind of device can be used for control of fluorine enriching factory for industry process control. Especially this kind of device is needed for purchasing of fluorite ore from individual customers or export in Mongolia.

Synthesis Method of Multimodal Radiotracers for Industrial Processes and Environmental Research

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Radiotracer methodology has been described extensively in the literature. Though radioisotopes have been applied to the solution of problems in industry for over 60 years, research and development of the technology continues unabated. Their role in investigating industrial problems has been expanding both in routine testing and process research and development. Extensive experience has been gathered all over the world in application of radiotracers in industry. There are many reasons for the continuing interest. One of the most important is industry driven. Multimodal radiotracers with other specific properties (fluorescent or magnetic properties) are attractive field of investigation. It can be used for mass transport experiments into copper metallurgy industry. Such studies require the development of representative tracers in order to follow raw material particles along their routes of transfer. Second great area of interesting is using radiotracers into environmental research field. Radiotracers are used primarily to reveal the transport processes, dispersion and settling of industrial waste in the natural environment. With their limited environmental impact, radiotracers have the potential to be used in a variety of new applications to create a wider awareness of the environment and the challenges it faces.

The objective of the work is developing of novel multimodal radiotracers with optical and/or magnetic properties. Basing on our experience, silica crystals SIO_2 have been selected as a radiotracer matrix. This material is easily obtained by an advanced chemical-ceramic method called sol-gel process. Gels in the forms of powders were prepared by hydrolysis and subsequent polycondensation of tetraethoxide/Me nitrate solutions containing ascorbic acid (ASC) as a catalyst, instead of the HCl or NH_4OH routinely used for catalysis in similar synthesis. During the formation of the silica gel, various metals can be immobilized into crystal structure of silica particles. The material is sintered and milled. Finally the metal incorporated into the structure is activated via neutron flux and the radiotracer is ready to use.

Following our method, we obtained several samples of various radiotracers. As a radiotracer ^{192}Ir was selected. Iridium is easy to activate via neutron flux and the half-life of ^{192}Ir seems to be acceptable. For obtaining fluorescence or magnetic properties we can use various additives. The tracer properties were investigated by fluorimeter, magnetic resonance and γ-spectroscopy.

The advanced radiotracers with combined properties are very unique and can be used for wide range of applications. Proposed materials can be used for wide range of industrial and environmental applications. Modified sol-gel process is a suitable and efficient method for synthesis of this kind of radiotracers.

This work is part of the projects: “Nano-radiotracers with magnetic and fluorescence properties for labelling of micro-particles of sand and clay.” co-financed by Polish Ministry of Science and Higher Education and IAEA.

Examination the Performance of the Trayed Ethylen Production Column Using γ-Ray Scan Techique

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The γ-ray scanning technique has been demonstrated to investigate the performance of trayed column in a petrochemical company. The trayed column is a caustic/water tower of having diameter of 4.2 m and 40 m height. The multigrid scanning was performed using 70 mCi of ^{60}Co γ source and a scintillation detector. Ten trays, starting from tray #13 at elevation of 35.050 mm to tray #4 at elevation of 26.950 mm above ground level. Scan data show that all trays were in their positions. Tray #4 to tray #10 were functioned properly then carried approximately the same amount of liquid. Light liquid flooding on tray #11 and heavy flooding on tray #12 were identified. Partial flooding was identified on the tray #13. At the time of shutdown, the scanned data was verified and it was found that the liquid flooding on the tray #12 was caused by presence of a bucket on that tray, covered with solidified mud.

Resident Time Determination of IPAG60 in Order to Increase Efficiency of Drinking Water Treatment Plant for Peatland Area

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The majority of areas in Riau Province and Middle Kalimantan Province have the land with peat surface water. The characteristics of the peat water are: low pH levels (2–4) that is highly acidic; high levels of organics; high levels of iron and manganese; yellow or dark brown. This kind of surface water is basically not suitable as raw water for drinking. Compared with other surface water that is fresh water, the water from the turf needs to be processed specifically by adding stages in the process. In order to improve the efficiency of water treatment plant, it would require a study to determine the resident time of IPAG60. A Li tracer will be used in this study for the reason of availability, accuracy and ease of use. Peat water treatment technology that has been established in previous studies allows the peat areas have peat water treatment facility for drinking water supply. The implementation and testing of the water treatment facility is limited in the area of Katingan District, Central Kalimantan province and Bengkalis district, Riau Province, meanwhile, a lot of territory in some areas in Indonesia, especially Sumatra and Kalimantan, which has a clean water source issues. Implementation of this technology in the wider area is necessary to support the increase in water services in the region. The quality of peat water and clean water (treated by IPAG) indicate that the IPAG can improve peat water quality (class C) into clean water quality (class A).

Terrestrial Background Radiation in Norochcholai in the North Western Coast of Sri Lanka

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Radiation from natural sources are broadly classified into two sources, terrestrial radiation and extraterrestrial radiation. Terrestrial radiation originates from natural radionuclides present in rocks, soils, atmosphere, and the hydrosphere. Extraterrestrial radiation or cosmic radiation having very high energy originates from the sun. In most cases, radiation exposure from natural sources is not harmful to humans but health protection measures need to be considered. The objective of this study was to assess background radiation in soil, water and air in a Sri Lankan population (in Norochcholai) living in close proximity to the nuclear power plant in Kudankulam, India for future monitoring of potential radiation leaks.

Background radiation levels at 1 m height were recorded using a survey meter (automess dose rate meter 6150AD). Superficial soil samples from 23 locations and water samples from 15 locations were analyzed by γ-spectrometry. The activity concentration of natural radionuclides in the soil and water samples were measured by using a HPGe detector having a relative efficiency of 32.6% with G1 geometry (84 mm diameter, 29 mm height) at ISO 17025:2005 accredited γ-spectrometry laboratory of the Sri Lanka Atomic Energy Board. The radioactivity concentrations of ^{232}Th, ^{40}K, ^{226}Ra and ^{210}Pb radionuclides in the soil and water samples were measured.

The median radioactivity concentrations (range) of ^{232}Th, ^{40}K, ^{226}Ra and ^{210}Pb were 56.0 Bq/kg (16–256 Bq/kg), 96 Bq/kg (62.5–294 Bq/kg) 24 Bq/kg (0.7–83 Bq/kg) and 27 Bq/kg (13–81 Bq/kg), respectively. Mean background radiation level was 0.1 μSv/h. The γ-ray absorbed dose rates due to ^{32}Th, ^{40}K and ^{226}Ra in soil samples varied between 13.9 nGy/h and 202.8 nGy/h with an average of 61.0 nGy/h which is higher than the global average of 57 nGy/h. The mean effective dose was 74.9 μSv/y. Radium equivalent activity ranged from 30.3–458.4 Bq/kg and the mean was 136.5 Bq/kg. In one soil sample the radium equivalent activity was above 370 which is the cutoff value set by the NEA group of experts as safe to be used in building materials. The absorbed dose rate did not correlate with the background radiation levels detected ($p = 0.727$). The annual effective dose due to terrestrial radiation (0.074 mSv/y) was less than the worldwide average of annual effective dose from natural background radiation due to terrestrial gamma radiation (0.46 mSv/y). No radioactivity was detected in any of the water samples.

The soil from this study area is safe for use in construction of human dwellings. No radioactivity was detected in water sample.

Indexes

Abstracts by Paper Number

Contributions by Indico Submission Number

Contributor Index

— C —

— D —

— L —

— M —

— N —

— O —

— P —

— Q —

— R —

— S —

— T —

— Z —

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2011 **Radiotracer Applications in Wastewater Treatment Plants**
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2009 **Leak Detection in Heat Exchangers and Underground Pipelines Using Radiotracers**
IAEA Training course series № 38

2008 **Radiotracer Residence Time Distribution Method for Industrial and Environmental Applications**
IAEA Training course series № 31

Participation in an IAEA Scientific Meeting

Governments of Member States and those organizations whose activities are relevant to the meeting subject matter are invited to designate participants in the IAEA scientific conferences and symposia. In addition, the IAEA itself may invite a limited number of scientists as invited speakers. Only participants designated or invited in this way are entitled to present papers and take part in the discussions.

Representatives of the press, radio, television or other information media and members of the public, the latter as "observers", may also be authorized to attend, but without the right to take part in the proceedings.

Scientists interested in participating in any of the IAEA meetings should request information from the Government authorities of their own countries, in most cases the Ministry of Foreign Affairs or national atomic energy authority.

Upcoming IAEA Meetings

For complete information on forthcoming scientific meetings, please consult the IAEA conference web site: `http://www.iaea.org/meetings`.

2017, 22–26 May *Vienna, Austria*	3rd FAO/IAEA International Conference on Area-wide Management of Insect Pests: Integrating the Sterile Insect and Related Nuclear and Other Techniques
2017, 30 May–1 June *Vienna, Austria*	International Conference on the IAEA Technical Cooperation Programme: Sixty Years and Beyond - Contributing to Development
2017, 6–9 June *Vienna, Austria*	International Conference on Topical Issues in Nuclear Installation Safety: Safety Demonstration of Advanced Water Cooled NPPs
2017, 20–23 June *Vienna, Austria*	International Conference on Advances in Radiation Oncology (ICARO2)
2017, 26–29 June *Yekaterinburg, Russian Fed.*	International Conference on Fast Reactors and Related Fuel Cycles (FR17)
2017, 19–20 September *Vienna, Austria*	Scientific Forum: Nuclear Technology for Human Health: Prevention, Diagnosis and Treatment
2017, 23–27 October *Lyon, France*	Fourth International Conference on Nuclear Power Plant Life Management (PLiM)
2017, 30 Oct.– 1 Nov. *Abu Dhabi, UAE*	International Ministerial Conference on Nuclear Power in the 21st Century
2017, 13–17 November *Vienna, Austria*	International Conference on Physical Protection of Nuclear Material and Nuclear Facilities
2017, 11–15 December *Vienna, Austria*	International Conference on Radiation Protection in Medicine: Achieving Change in Practice

2018, 28–31 May *Gyeongju, Rep. of Korea*	Third International Conference on Human Resource Development for Introducing and Expanding Nuclear Power Programmes: Meeting Challenges to Ensure the Future Nuclear Workforce Capability
2018, 25–29 June *Vienna, Austria*	International Symposium on Uranium Raw Material for Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues (URAM-2018)
2018, 6–10 August *Vienna, Austria*	International Symposium on Plant Mutation Breeding and Biotechnology
2018, 1–5 October *Vienna, Austria*	International Symposium on Communicating Nuclear and Radiological Emergencies to the Public
2018, 15–19 October *Brussels, Belgium*	International Conference on Challenges Faced by Technical and Scientific Support Organizations (TSOs) in Enhancing Nuclear Safety and Security
2018, 22–27 October *Ahmedabad, India*	27th IAEA Fusion Energy Conference (FEC–2018)
2018, 5–9 November *Vienna, Austria*	Symposium on International Safeguards
2018, 3–7 December *Vienna, Austria*	International Conference on Global Radioactive Material Security Governance: Prevention and Detection in Action
2018, To be Decided *Vienna, Austria*	Ministerial Conference on Nuclear Science, Technology and Applications for Peaceful Uses
2018, To be Decided *Vienna, Austria*	International Symposium on Understanding the Double Burden of Malnutrition for Effective Interventions
2019, To be Decided *Vienna, Austria*	International Symposium on Trends in Radiopharmaceuticals