INTERNATIONAL CONFERENCE ON

ACCELERATORS FOR RESEARCH AND SUSTAINABLE DEVELOPMENT

From good practices towards socioeconomic impact

Book of Abstracts

23–27 May 2022

IAEA Headquarters, Vienna, Austria

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

CN-301
#Accelerators2022
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From Good Practices Towards Socioeconomic Impact

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BOOK OF ABSTRACTS

Organized by the

International Atomic Energy Agency (IAEA)

Programme Committee:

N. Alamanos, CEA, France
G. Aquilanti, Elettra Sincrotrone Trieste, Italy
C. Brenner, ANSTO, Australia
T. Gutberlet, Forschungszentrum Julich, Germany
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M. Jaksic, Ruđer Bošković Institute (RBI), Croatia
J. Mittendorfer, High Tech Consulting, Austria

IAEA Secretariat:

Scientific Secretaries, NAPC: S. Charisopoulos
V. Starovoitova
D. Ridikas
C. Horak

Event Organizer, MTCD: J. Zellinger
Administrative Support, NAPC: E. Nazarova
T. Kornelyuk
O. Bilous

Location of the Event:

International Atomic Energy Agency
Vienna International Centre (VIC)
Building M, Board Rooms A, B/M1

Wagramer Strasse 5
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Tel.: (+43 1) 2600 21330

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International Conference on Accelerators for Research and Sustainable Development: from Good Practices towards Socioeconomic Impact

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A. Background

The International Atomic Energy Agency (IAEA) is organizing the First International Conference on Accelerators for Research and Development: from good practices towards socioeconomics impact. Such a Conference was long awaited by the Member States to address important needs in our high-tech oriented society, where particle accelerators have become indispensable.

Nowadays, more than 20,000 particle accelerators operating world-wide are used for commercial applications, either in the medical (radiotherapy treatments) or industrial sectors (materials modification). Although only a few hundred accelerators are used for scientific research, the knowledge and technological spin-offs gained from these facilities drive the development of commercial applications and support the research and development needs of a diverse range of fields, including fundamental and applied science. The current trend is to utilize accelerators in a dedicated way to support specific high technology application areas. The main demand from researchers is for high quality X ray, neutron, and ion beams to engage in cutting-edge research in energy, food and agriculture, environment, biology, medicine, forensics, cultural heritage, materials science, and many other areas. Accelerators also play a key role in capacity building, provide education and training both in academia and industry, contributing to the solution of problems of modern society and to increased competitiveness of local economies.

Numerous innovations and accomplishments in the field of accelerator-based research and development as well as diverse applications have been already acknowledged, however it is now time to take a comprehensive look at their socioeconomic impact, assess their sustainability and ability to meet future challenges. The IAEA has been implementing programmatic activities that provide interested Member States with platforms to exchange information on new trends and applications in accelerator-based nuclear science and technology. Indeed, the IAEA successfully implements a few programmes with direct relevance to use of particle accelerators such as Nuclear Science, Radioisotope Production and Radiation Technology, Human Health and Environment. In addition, direct support and assistance to the Member States in the area of accelerator-based research and applications is also provided through the IAEA Technical Cooperation Programme.

B. Purpose and Objectives

The Conference aims primarily to present an international stage for discussing accelerator applications in research and industry, foster exchange of information on best practices in accelerator facility utilization and management, and to provide a showcase how achievements and experience attained with accelerator technologies contribute to a sustainable development. All types of accelerators will be considered: from low-energy ion-beam electrostatic accelerators to cyclotrons, from compact accelerator-based neutron sources to large-scale spallation facilities, from electron-based irradiation facilities to synchrotron light sources, and many others.

Special emphasis will also be given in accelerator applications of large societal impact such as human health, environmental monitoring, cultural heritage, food quality, energy sector, forensics, nuclear security, and others promoting economic development. The Conference will provide a unique opportunity to achieve the following specific objectives:

- To disseminate:
    - New knowledge and technologies developed through accelerator-based research and applications in a wide spectrum of scientific areas.
    - Best practices in establishing new accelerator facilities, and ensuring their effective management and sustainability
- To review:
    - Key developments in particle accelerator technologies, established and emerging ones, and their role in enhancing innovations
    - National, regional and global initiatives for implementing proven accelerator applications that lead to socio-economic benefits and strengthen capacity building in Member States; and
- To serve:
    - As a composite platform through which academia and industry can foster new initiatives for ensuring the success of accelerator applications in addressing the emerging challenges in multiple disciplines.
    - As a bridge to enhance existing and establish new collaborations among scientists and institutions from Member States aiming at benefiting from accelerator technologies to face challenges in a series of problems of modern society.

C. Themes and Topics

The IAEA welcomes high-quality, well structured, abstracts and papers in all fields of accelerator-based research and applications which will be grouped under three main themes/tracks:

A. Cutting-edge scientific results and innovation in applications

B. Success stories and case studies demonstrating socioeconomic impact

C. Best practices in effective management, safe operation, and sustainability of accelerator facilities, including establishment of new facilities

The scope of the conference is meant to cover, but is not limited to, the following topical areas:

- Biology and biophysics
- Cultural heritage
- Engineering applications (including energy sector)
- Environmental applications (including geosciences and climate change)
- Food and agriculture
- Forensics and security applications
- Information and quantum technologies
- Materials research (including materials damage studies)

- Medical applications (including radioisotope production and Boron Neutron Capture Therapy)
- Nuclear data and modelling benchmarks
- Radioactive beam applications
- R&D on new accelerator and alternative technologies (including Compact Accelerator based Neutron Sources)
- Best practices in and lessons learned from
  - Education and training with accelerators
  - Establishment of new facilities
  - Facility management and user programmes
  - Facility operations and maintenance
  - Outreach, knowledge preservation and management
  - User access programmes and regional/interregional networking
  - Strategic considerations for sustainability and self-reliance

D. Structure

The aforementioned topical areas will be discussed under the three main themes outlined in section C. A series of plenary sessions will address the most interesting and crucial topics and the meeting programme will include invited keynote speakers from academia and industry, giving oral presentations and participating in panel discussions and round table sessions. Several poster sessions will be organized to allow ample time for discussion and interaction. In addition, the participants will have an opportunity to interact with conference exhibitors and participate in technical tour(s). Finally, a closing panel session will review the main conclusions drawn in the plenary sessions and will summarize recommendations for the future development of radiation sciences and technologies using particle accelerators.

E. Expected Outcomes

The conference will strengthen contacts and foster cooperation among accelerator-based science and application researchers, accelerator manufacturers, facility operators and the coordinators of academic programmes in the accelerator sciences, leading to a comprehensive review of the status of accelerator-based research and applications. The conference is expected to generate ideas that will form the basis of future IAEA programmes in the area of research and applications using accelerator technologies.

F. Target Audience

This conference will focus on applications of accelerator science and technology, which is a multidisciplinary area covering many different branches from accelerator and nuclear physics, materials science, biology, environment, medicine, cultural heritage to engineering and industrial applications. Accordingly, the target audience for this conference comprises, but is not limited to:

- research scientists engaged in accelerator-based research and applications;
- accelerator operators and users;
- entrepreneurs or stakeholders involved in applications of accelerator technologies;
- policy makers and regulators.

TIMETABLE

Monday, 23 May 2022

Time	Session No.	Session Title / Break	Venue
10:00–10:30		Opening Session	M Plenary
10:30–11:15	PL1	Plenary Session 1: Accelerators for the Environment	M Plenary
11:15–12:45	PL2	Plenary Session 2: Accelerators for Medical Radioisotopes, Energy Production and Nuclear Research	M Plenary
12:45–14:00		*Lunch Break*	
14:00–15:30	PS3.A	Parallel Session 3.A: Advances in Accelerator Technologies	Board Room A
14:00–15:30	PS3.B	Parallel Session 3.B: Accelerators for Medical Applications - 1	M Plenary
15:30–16:00		*Coffee/Tea Break*	
16:00–17:30	PS4.A	Parallel Session 4.A: Accelerators for Environmental Monitoring	Board Room A
16:00–17:30	PS4.B	Parallel Session 4.B: Accelerators for Medical Applications - 2	M Plenary
18:00–20:00		*Welcome Reception*	M-Building – Ground Floor

Tuesday, 24 May 2022

Time	Session No.	Session Title / Break	Venue
09:00–10:30	PL5	Plenary Session 5: Accelerators for Neutron Therapy, Cultural Heritage, Innovation and Education	M Plenary
10:30–11:00		*Coffee/Tea Break*	
11:00–12:30	PS6.A	Parallel Session 6.A: Accelerators for BNCT and Cultural Heritage	Board Room A
11:00–12:30	PS6.B	Parallel Session 6.B: Best Practices in Using Accelerators for R&D, Education, Environmental and Industrial Applications	M Plenary
12:30–14:00		*Lunch Break*	
14:00–15:30	SE 1	Side Event 1: Accelerator-Based Sources of Radiation: Recent Developments	Board Room A
14:00–15:30	PS 1	All posters (see separate page)	M Building
15:30–16:00		*Coffee/Tea Break*	
16:00–17:30	PS7.A	Parallel Session 7.A: IBA Facilities and their R&D Program	Board Room A
16:00–17:30	PS7.B	Parallel Session 7.B: Regulatory Aspects of Accelerator Facilities	M Plenary

Wednesday, 25 May 2022

Time	Session No.	Session Title / Break	Venue
09:00–10:30	PL8	Plenary Session 8: Accelerators for Nuclear Data and Materials Research	M Plenary
10:30–11:00		*Coffee/Tea Break*	
11:00–12:30	PS9.A	Parallel Session 9.A: Accelerators for Nuclear Data	Board Room A
11:00–12:30	PS9.B	Parallel Session 9.B: Radiation Technologies and their Applications	M Plenary
12:30–14:00		*Lunch Break*	
14:00–15:30	SE2	Side Event 2: Collaborating Centers of IAEA	Board Room A
14:00–15:30	SE3	Side Event 3: Women in Accelerator-based Science	M Plenary
15:30–16:00		*Coffee/Tea Break*	
16:00–17:30	PS10.A	Parallel Session 10.A: Applications of Heavy Ion Beams	Board Room A
16:00–17:30	PS10.B	Parallel Session 10.B: Societal Applications of Accelerators and Sustainable Development	M Plenary

Thursday, 26 May 2022

Time	Session No.	Session Title / Break	Venue
09:00–10:30	PL11	Plenary Session 11: Emerging Accelerator Technologies – Accelerator Technologies for Food Safety and Security	M Plenary
10:30–11:00		*Coffee/Tea Break*	
11:00–12:30	PS12.A	Parallel Session 12.A: Future Accelerator-based Neutron Sources	Board Room A
11:00–12:30	PS12.B	Parallel Session 12.B: Electron Beams and Applications	M Plenary
12:30–14:00		*Lunch Break*	
14:00–15:30	SE4	Side Event 4: Promoting Self-Reliance and Sustainability of National Nuclear Institutions Operating Accelerator Facilities	M Plenary
14:00–15:30	PS2	All posters (see separate page)	M Building
15:30–16:00		*Coffee/Tea Break*	
16:00–17:30	PS13.A	Parallel Session 13.A: Selected Applications of Accelerator-based Analytical Techniques	Board Room A
16:00–17:30	PS13.B	Parallel Session 13.B: Accelerators and Interdisciplinary Applications	M Plenary

Friday, 27 May 2022

Time	Session No.	Session Title / Break	Venue
09:00–10:30	PL14	Plenary Session 14: Accelerators and Multidisciplinary Research and Applications	M Plenary
10:30–11:00		*Coffee/Tea Break*	
11:00–11:30	PL15	Plenary Session 15: Conference Summary and Highlights	M Plenary
11:30–12:30	PL16	Plenary Session 16: Conference Closing and Award Ceremony	M Plenary

MONDAY, 23 MAY 2022

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10:00-10:30 OPENING SESSION M Plenary

Time	Name	Affiliation & Designating Member State / Organization	Title
10:00–10:05	**M. Denecke**	Director NAPC, IAEA	Welcome Address
10:05–10:15	**R. M. Grossi**	Director General, IAEA	Opening Statement
10:15–10:25	**N. Mokhtar** **M. Chudakov** **H. Liu**	DDG-NA, IAEA DDG-NE, IAEA DDG-TC, IAEA	Opening Remarks

10:30-11:15 PLENARY SESSION 1: Accelerators for the Environment M Plenary

Chairpersons: D. Ridikas (IAEA)
C. Horak (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
10:30–11:15	224	**D. Cohen**	ANSTO, Australia	Accelerators for Environmental Monitoring and Climate Change Related Studies
	207	**A. Chmielewski**	INCT, Poland	Electron Accelerator-Based Systems for Air, Water and Soil Pollution Control

11:15-12:45 PLENARY SESSION 2: Accelerators for Medical Radioisotopes, Energy Production and Nuclear Research M Plenary

Chairpersons: D. Ridikas (IAEA)
C. Horak (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
11:15–11:45	209	**C. S. Cutler**	BNL, USA	50 Years of Isotope Production via High Energy Accelerators at Brookhaven National Laboratory
11:45–12:15	223	**H. Ait Abderrahim**	SCK CEN, Belgium	Realization of a new Research Infrastructure in Belgium: MYRRHA - Present Status and Focus on Latest Developments of MYRRHA ADS Accelerator
12:15-12:45	208	**B. Sharkov**	JINR, Russian Federation	Large Scale Accelerator Facilities for Nuclear Research and Practical Applications
12:45–14:00		*Lunch Break*		

14:00–15:30 **PARALLEL SESSION 3.A: Advances in Accelerator Technologies** **Board Room A**

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Chairpersons: **N. Alamanos (CEA, France)**
S. Charisopoulos (IAEA)

Time	Paper No.	Name	Affiliation & Designating Member State/ Organization	Title of Paper
14:00–14:15	204	**J. G. Weisend II**	ESS, Sweden	The European Spallation Source Accelerator: Overview and Status
14:15–14:30	49	**B. Hornberger**	Lyncean Technologies, USA	Recent Developments in Compact X-ray and Gamma-ray Sources Based on Inverse Compton Scattering
14:30–14:45	101	**S. Lauber**	GSI, Germany	Alternating Phase Focusing Beam Dynamics for Drift Tube Linacs
14:45–15:00	190	**M. Fedurin**	BNL, USA	Novel Accelerator Concept Utilizing Cyclotron Resonance (eCRA)
15:00–15:15	177	**I. Strydom**	iThemba LABS, South Africa	An Overview of the South African Isotope Facility (SAIF)
15:15–15:30	**Questions and Answers**			
15:30–16:00	*Coffee & Tea break*			

14:00–15:30 **PARALLEL SESSION 3.B: Accelerators for Medical Applications - 1** **M Plenary**

Chairpersons: **C. S. Cutler (BNL, USA)**
V. Starovoitova (IAEA)

14:00–14:15	44	**N. van der Meulen**	PSI, Switzerland	The Use of PSI's High Intensity Proton Accelerator (HIPA) Complex Towards Medical-Radionuclide Development
14:15–14:30	183	**A. Gerbershagen**	University of Groningen, Netherlands	The New Particle Therapy Research Center (PARTREC) at the University Medical Center Groningen
14:30–14:45	73	**G. Pupillo**	INFN-LNL, Italy	Research Activities on the Cyclotron-based Production of Innovative Radionuclides: Experience at the Legnaro National Laboratories of INFN
14:45–15:00	124	**P. Fernandes Costa Jobim**	Federal Univ. Rio Grande do Sul, Brazil	Ion Beam Techniques and Neuroscience: What is Next?
15:00–15:15	136	**C. N. Coleman**	Intern. Cancer Expert Corps, USA	Treatment, not Terror: A Unique Cancer Treatment Paradigm for Developing Novel Linear Accelerators for Resource-limited Settings
15:15–15:30	**Questions and Answers**			
15:30–16:00	*Coffee & Tea break*			

16:00–17:30 **PARALLEL SESSION 4.A: Accelerators for environmental monitoring** **Board Room A**

Chairpersons: **S. Merchel (VERA, Austria)**
R. P. Alvarez (IAEA)

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Time	Paper No.	Name	Affiliation & Designating Member State/ Organization	Title of Paper
16:00–16:15	186	**W. E. Kieser**	University of Ottawa, Canada	Accelerator Mass Spectrometry: An Analytical Tool with Applications for Sustainable Society
16:15–16:30	70	**M. Santoso**	BATAN, Indonesia	Characteristics of Fine Particulates of Two Largest Cities in Indonesia Using Ion Beam Analysis
16:30–16:45	147	**L. Popa-Simil**	LAAS, USA	Ion beam Usage in Environmental Characterization
16:45–17:00	45	**M. Roumie**	LAEC/CNRS, Lebanon	Elemental Characterization of PM2.5 Aerosol Samples in Four Mideastern Cities and Source Apportionment Investigation
17:00–17:15	86	**S. Pollastri**	Elettra, Italy	A Combined XRF and XANES Study on Bottom Ashes from Municipal Solid Waste Incinerator
17:15–17:30	**Questions and Answers**			

16:00–17:30 **PARALLEL SESSION 4.B: Accelerators for Medical Applications - 2** **M Plenary**

Chairpersons: **C. Hoehr (TRIUMF, Canada)**
A. Korde (IAEA)

16:00–16:15	125	**E. Punzón-Quijorna**	JSI, Slovenia	Particle Induced X-ray Emission (PIXE) Reveals Crucial Information in Hip Endoprostheses Failures. MeV Ion Beams for Improving Medical Diagnostics
16:15–16:30	158	**T. Pinheiro**	IST/Univ. de Lisboa, Portugal	Metallacarboranes for Proton Therapy Using Research Accelerators
16:30–16:45	95	**R. Khatun**	BAEC, Bangladesh	Dosimetric Verification of Radiotherapy Treatment Planning System Using Thorax Phantom
16:45–17:00	52	**D. Kottuparamban**	Molecular Cyclotrons, India	Socioeconomic Impact of a Medical Cyclotron in Kerala, India
17:00–17:15	29	**S. M. d. Carvalho**	NCNE, Brazil	Current Status and Perspectives of Cyclotron Facilities in Brazil and the Socioeconomic Impact.
17:15–17:30		**Questions and Answers**		

18:00–20:00 **WELCOME RECEPTION** **M-Building – Ground Floor**

TUESDAY, 24 MAY 2022

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09:00-10:30 **PLENARY SESSION 5: Accelerators for Neutron Therapy, Cultural Heritage, Innovation and Education** **M Plenary**

Chairpersons: **G. Aquilanti (Elettra, Italy)**
I. Swainson (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
09:00–09:30	210	**H. Kumada**	University of Tsukuba, Japan	Current Status of Compact Accelerator-based Neutron Sources for Boron Neutron Capture Therapy in the World
09:30–10:00	212	**L. Beck**	CEA, France	Use of Accelerators to Preserve Cultural Heritage Objects and Detect Forgeries
10:00–10:30	205	**A. Strasser**	Aerial-CRT, France	Best Practices in Establishing and Running Accelerator Facilities to Support Research, Education, and Commercial Uses
10:30–11:00		*Coffee/Tea Break*		

11:00–12:30 **PARALLEL SESSION 6.A: Accelerators for Boron Neutron-Capture Therapy (BNCT) and Cultural Heritage** **Board Room A**

Chairpersons: **G. Aquilanti (Elettra, Italy)**
I. Swainson (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
11:00–11:15	131	**A. Kreiner**	CNEA, Argentina	Review of the Different Accelerator-based BNCT Facilities Worldwide and an Assessment According to the Alara Criterion
11:15–11:30	140	**S. Taskaev**	Budker Institute of Nuclear Physics, Russian Federation	Accelerator-based Neutron Source for Boron Neutron Capture Therapy and other Applications
11:30–11:45	94	**I. Carlomagno**	Elettra, Italy	X-ray Investigations on Ancient Gold Coins: Synchrotron Radiation Contribution to History and Numismatics
11:45–12:00	10	**D. M. Atwa Khalil**	NILES, Egypt	Synchrotron Radiation Based Investigations of Colored Layers, Binding Materials and Resins of the God Ptah-Sokar-Osiris Wooden Statuette and its Mummified Falcon which are Dating Back to 26th Pharaonic Dynasty
12:00–12:15	121	**V. Corregidor**	Univ. de Lisboa, Portugal	Characterization of Cultural Heritage Using a Micro-beam
12:15–12:30		**Questions and Answers**		
12:30–14:00		*Lunch Break*		

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11:00–12:30 **PARALLEL SESSION 6.B: Best Practices in using Accelerators for R&D, Education, Environmental & Industrial Applications** **M Plenary**

Chairpersons: **D. Cohen (ANSTO, Australia)**
N. Skukan (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
11:00–11:15	24	**O. Riabukhin**	Ural Federal University, Russian Federation	The Practice of Electron and Proton Accelerators Utilizing for Industry, Education and Science
11:15–11:30	181	**S. H. Park**	Korea Univ. Sejong, Rep. of Korea	Use of Accelerators for Research and Training in the University Environment
11:30–11:45	60	**P. Foka**	GSI, Greece	Heavy Ion Therapy MasterClass School and Capacity Building for Future Ion Research and Therapy Facilities
11:45–12:00	230	**M. Pivi**	MedAustron, Austria	The MedAustron Particle Therapy Accelerator
12:00–12:15	116	**F. Zanini**	Elettra, Italy	Life Cycle Assessment
12:15–12:30	**Questions and Answers**			
12:30–14:00	*Lunch Break*			

14:00–15:30 **SIDE EVENT 1: Accelerator-Based Sources of Radiation: Recent Developments** **M Plenary**

Chairpersons: **S. Pillai (Texas A&M University, USA)**
V. Starovoitova (IAEA)

14:00–14:10	**S. Norris**	DOE/NNSA, USA	Opening Remarks
14:10–14:30	**J. Schwindling**	CEA, France	Compact Accelerator-based Neutron Sources
14:30–14:50	**A.-L. Lamure**	RadiaBeam Technologies, USA	High Power Electron Beams
14:50–15:10	**A. Pierard**	IBA, Belgium	Electron Accelerators as X-ray Sources
15:10-15:30	**Round table discussion - Questions and Answers**		
15:30-16:00	*Coffee/Tea Break*		

14:00–15:30 **POSTER SESSION 1 (See separate page)** **M Building**

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16:00–17:30 **PARALLEL SESSION 7.A: IBA facilities and their R&D programme** **Board Room A**

Chairpersons: **E. Da Costa Alves (Univ. de Lisboa, Portugal)**
N. Skukan (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
16:00–16:15	108	**V. Rigato**	LNL/INFN, Italy	Multidisciplinary Physics with MeV Ion Beams at the Laboratori Nazionali di Legnaro using the CN and AN2000 Accelerators
16:15–16:30	229	**S. Charisopoulos**	IAEA	The IAEA Ion Beam Facility (IBF) project
16:30–16:45	118	**I. Bogdanovic Radovic**	RBI, Croatia	Development and Applications of the Secondary Ion Mass Spectrometry with MeV Ions (MeV SIMS) Technique at the RBI Accelerator
16:45–17:00	151	**A. Karydas**	NCSR “Demokritos”, Greece	Applications of Proton-induced X-rays at the Tandem Accelerator Laboratory of NCSR “Demokritos”
17:00–17:15	19	**R. O. Barrachina**	CNEA, Argentina	Six Decades of Research and Development with Accelerators in the Dept. of Interaction of Radiation with Matter of the Bariloche Atomic Center
17:15–17:30	**Questions and Answers**			

16:00–17:30 **PARALLEL SESSION 7.B: Regulatory aspects of accelerator facilities** **M Plenary**

Chairpersons: **R. P. Jimenez (IAEA)**
N. Ramamoorthy (Independent consultant, India)

16:00–16:15	47	**M. Heimann**	CNSC-CCSN, Canada	Agile Regulatory Oversight: Adapting Regulations to Accommodate Rapidly Changing Accelerator Technology
16:15–16:30	98	**F. Schmitz**	Bel V, Belgium	Licensing Unconventional Accelerator Projects: A Quest for the Safest Compromise
16:30–16:45	56	**G. Rabi**	Autoridad Regulatoria Nuclear, Argentina	Regulatory Control at the Construction Stage of a Radiopharmaceuticals Production Facility with Cyclotron in the Context of Covid-19 Pandemic
16:45–17:00	78	**G. Garcia Fernandez**	Universidad Politecnica de Madrid, Spain	Commissioning of Operational Radiation Protection in Compact Proton Therapy Centers (CPTC) with Small Accelerators
17:00–17:30	**Questions and Answers**			

WEDNESDAY, 25 MAY 2022

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09:00-10:30 **PLENARY SESSION 8: Accelerators for Nuclear Data and Materials Research** **M Plenary**

Chairpersons: **F. Ott (CEA, France)**
A. Koning (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
09:00–09:30	213	**M. Rubel**	Royal Institute of Technology, Sweden	Accelerator Techniques and Nuclear Data needs for IBA of wall Materials for Fusion reactors
09:30–10:00	218	**Y. Wang**	Los Alamos National Lab, USA	Application of Accelerators in Nanomaterials Research
10:00–10:30	220	**Z. Siketic**	Ruđer Bošković Institute, Croatia	Sustainability of the Tandem Accelerator Facility at the Ruđer Bošković Institute
10:30–11:00		*Coffee/Tea Break*		

11:00–12:30 **PARALLEL SESSION 9.A: Accelerators for Nuclear Data** **Board Room A**

Chairpersons: **M. Rubel (Royal Institute of Technology, Sweden)**
A. Koning (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
11:00–11:15	232	**J.C. Sublet**	IAEA	Radiation Damages Bohr's Metrics: Accelerator & Elemental Landscapes
11:15–11:30	154	**N. Patronis**	University of Ioannina, Greece	Status Report of the N_TOF Facility after the 2nd CERN long Shutdown Period
11:30–11:45	157	**R. Vlastou-Zanni**	National Technical University of Athens, Greece	The Neutron Facility at NCSR "Demokritos" and Neutron Activation Research Activities of NTUA
11:45–12:00	109	**B. P. L. Ström**	Uppsala University, Sweden	Ion Accelerators for Modification and Analysis of Materials: Present Status and an Outlook Towards the Future
12:00–12:15	132	**A. Widdowson**	UKAEA, United Kingdom	Determination of Fuel Retention in Tokamaks by Accelerator-based Methods
12:15–12:30		**Questions and Answers**		
12:30–14:00		*Lunch Break*		

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11:00–12:30 **PARALLEL SESSION 9.B: Radiation Technologies and their Applications** **M Plenary**

Chairpersons: **A. Chmielewski (INCT, Poland)**
V. Starovoitova (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
11:00–11:15	92	**K. Howie**	Texas A&M University, USA	Electron Beam Technology for Preserving Quality Attributes of Mandarins for Enhancing Export Potential
11:15–11:30	159	**D. Kaoumi**	North Carolina State University, USA	The Use of In-situ Transmission Electron Microscopy to Investigate Microstructure Evolution under Ion Irradiation
11:30–11:45	198	**R. Schwarz**	Pacific Northwest National Laboratory, USA	Penelope-based User-Friendly Fast Interface for Calculating Distribution in Irradiated Products
11:45–12:00	32	**D. Chmielewska-Śmietanko**	Institute of Nuclear Chemistry and Technology, Poland	Application of Electron Beam Accelerator for Preservation Biodeteriorated Cultural Heritage Paper-Based Objects: Multiparametric Analysis
12:00–12:15	163	**S. Ramarad**	Heriot-Watt University Malaysia, Putrajaya	Rubber Recycling: Compatibilization of Waste Tire Rubber/Poly(ethylene-co-vinyl acetate) Blends Using Liquid Rubber and Electron Beam Irradiation
12:15–12:30	**Questions and Answers**			
12:30–14:00	*Lunch Break*			

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14:00–15:30 **SIDE EVENT 2: Collaborating Centers of IAEA** **Board Room A**

Chairpersons: **A. Simon (IAEA)**
B. S. Han (IAEA)

Time	Name	Affiliation & Designating Member State / Organization	Title
14:00–14:15	**S. Hollins**	ANSTO, Australia	New and Advanced Techniques and Applications of Nuclear Science and Technology towards a Sustainable Environment
14:15–14:30	**M. Kiskinova**	Elettra, Italy	IAEA-Elettra Collaborating Center
14:30–14:45	**L. Bertrand**	ENS Paris-Saclay, France	Implementation of the IAEA Collaborating Center Atoms for Heritage at Université Paris-Saclay
14:45–15:00	**R. Nchodu**	iThemba LABS, South Africa	iThemba LABS: The IAEA Collab-orating Centre for Accelerator Based Scientific Research & Applications
15:00–15:15	**S. Pillai**	Texas A&M University, USA	The National Center for Electron Beam Research at Texas A&M University - Two Decades of Advancing Electron Beam and X-ray Technologies Around the World
15:15-15:30	**Round table discussion - Questions and Answers**		
15:30-16:00	*Coffee/Tea Break*		

14:00–15:30 **SIDE EVENT 3: Women in Accelerator-based Science** **M Plenary**

Chairpersons: **C. Hoehr (TRIUMF, Canada)**
A. Peeva (IAEA)

Time	Name	Affiliation & Designating Member State / Organization	Title
14:00–14:10	**C. Hoehr**	TRIUMF, Canada	Opening Remarks
14:10–14:20	**J. Donner**	SGIM, IAEA	Overview of IAEA's effort in promoting gender parity
14:20–15:20	**Panel discussion**		**Moderator: A. Peeva (IAEA)** **Participants:** D. Cohen, ANSTO N. Alamanos, CEA S. Carvalho, NCNE, Brazil C. Gutierrez, Elettra (recipient of the Marie Curie Fellowship Programme)
15:20–15:30	**Round table discussion - Questions and Answers**		
15:30-16:00	*Coffee/Tea Break*		

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16:00–17:30 **PARALLEL SESSION 10.A: Applications of heavy ion beams** **Board Room A**

Chairpersons: **B. Sharkov (JINR, Russian Federation)**
R. Padilla Alvarez (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
16:00–16:15	179	**P. Kluth**	Australian National University, Australia	Swift Heavy Ion Modified Materials: Applications and Characterisation Using Synchrotron Small Angle X-ray Scattering
16:15–16:30	69	**M. Wagner**	GSI, Germany	Three Dimensional Nanochannel Networks Fabricated with Ion Track-Etch Technology and Their Applications
16:30–16:45	233	**N. Pessoa Barradas**	IAEA	Specific Considerations and Guidance for the Establishment of Ionizing Radiation Facilities
16:45–17:00	195	**M. Lang**	University of Tennessee, USA	Investigating Radiation Effects in Materials Using State-of-the-Art Particle Accelerators
17:00–17:15	165	**C. Vyas**	Michigan State University, India	Isotope Harvesting Project: from White Paper to Implementation
17:15–17:30	**Questions and Answers**			

16:00–17:30 **PARALLEL SESSION 10.B: Societal Applications of Accelerators and Sustainable Development** **M Plenary**

Chairpersons: **F. Zanini (Elettra, Italy)**
K. Kanaki (IAEA)

16:00–16:15	189	**S. Norris**	DOE/NNSA, USA	How Support for Machine-Based Sources of Radiation Contributes to Sustainable Development
16:15–16:30	58	**B. Nsouli**	LAEC, Lebanon	On the Use of Ion and Cluster Beams Analysis at LAEC for Forensic Sciences: Infrastructure and Applications
16:30–16:45	106	**A. Magazinik**	CERN, Switzerland	Societal Impact of the Compact Linear Collider Study
16:45–17:00	74	**T. Edgecock**	University of Huddersfield, United Kingdom	IFAST Accelerators for Societal Applications
17:00–17:15	54	**B. List**	CERN	Sustainability Studies for Linear Colliders
17:15–17:30	**Questions and Answers**			

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09:00-10:30 **PLENARY SESSION 11: Emerging Accelerator Technologies – Accelerator Technologies for Food Safety and Security** **M Plenary**

Chairpersons: **T. Gutberlet (FZ Julich, Germany)**
S. Charisopoulos (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
09:00–09:30	219	**Y. Otake**	RIKEN, Japan	RIKEN Accelerator-driven Compact Neutron Systems and RANS Project
09:30–10:00	214	**M. Roth**	TU Darmstadt Institute for Nuclear Physics, Germany	Laser-driven Ion Accelerators: Unique Beams and Compact Neutron Sources
10:00–10:30	217	**S. Pillai**	Texas A&M University, USA	Accelerator Technologies for Food Safety and Food quality: Response of Microbial Populations to Ionizing Technologies
10:30–11:00		*Coffee/Tea Break*		

11:00–12:30 **PARALLEL SESSION 12.A: Future Accelerator-based neutron sources** **Board Room A**

Chairpersons: **A. Kreiner (CNEA, Argentina)**
H. Ben Abdelouahed (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
11:00–11:15	129	**N. Mayordomo**	Helmholtz Zentrum Dresden-Rossendorf, Germany	CANS Production of Technetium-99M and Technetium-101
11:15–11:30	27	**R. Frost**	Lund University, Sweden	A Compact Accelerator Driven Neutron Source at the Nuclear-Applications Laboratory, Lund University
11:30–11:45	221	**F. Ott**	CEA, France	The SONATE Project, a New Neutron Scattering Platform for Materials Science Research
11:45–12:00	77	**A. Maffini**	Politecnico di Milano, Italy	Towards Compact Laser-Driven Accelerators: Exploring the Potential of Advanced Double-Layer Targets
12:00–12:15	227	**I. Swainson**	IAEA	IAEA activities in support of Compact Accelerator based Neutron Sources
12:15–12:30		**Questions and Answers**		
12:30–14:00		*Lunch Break*		

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11:00–12:30 **PARALLEL SESSION 12.B: Electron beams and Applications** **M Plenary**

Chairpersons: **S. Pillai (Texas A&M University, USA)**
B. S. Han (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
11:00–11:15	139	**A. Bryazgin**	Budker Institute, Russian Federation	ILU RF Electron Accelerators for E-beam and X-ray Applications
11:15–11:30	174	**W. A. Parejo Calvo**	IPEN / CNEN / SP, Brazil	Electron Beam Processing to Improve Biodegradable Polymers and for Industrial Wastewater Treatment and Recycling
11:30–11:45	15	**S. Jebri**	National Center of Nuclear Sciences and Technologies, Tunisia	Effect of E-beam Irradiation on the Microbial Quality of Minimally Processed Products: a Case of a Commercialized Ready to Eat Salad
11:45–12:00	107	**M. Vorobyov**	Inst. of High Current Electronics SB RAS, Russian Federation	Low-Energy Electron Accelerators and Sources with Plasma Emitters for Scientific and Technological Purposes
12:00–12:15	8	**P. A. Vasquez Salvador**	IPEN / CNEN / SP, Brazil	Preservation of Photographic and Cinematographic Films by Electron-Beam Irradiation
12:15–12:30	**Questions and Answers**			
12:30–14:00	*Lunch Break*			

14:00–15:30 **SIDE EVENT 4: Promoting Self-Reliance and Sustainability of National Nuclear Institutions** **Board Room A**

Chairpersons: **N. Ramamoorthy (Independent Consultant, India)**
N. Pessoa Barradas (IAEA)

14:00–14:10	**N. Pessoa Barradas**	IAEA	Opening Remarks
14:10–14:25	**F. A. Deluchi**	CNEA, Argentina	Research and Industrial Applications Electron Beam Accelerator Project
14:25–14:40	**C. Arcilla**	Philippine Nuclear Research Institute, Philippines	The new Nuclear Medicine Research and Innovation Center
14:40–14:55	**S. A. Hashim**	WiN, Malaysia	Promoting Application of Electron Accelerator and Radiation Processing in Malaysia.
14:55–15:10	**S. Rugmai**	Synchrotron Light Research Institute, Thailand	The synchrotron projects of Thailand
15:10-15:30	**Round table discussion - Questions and Answers**		
15:30–16:00	*Coffee/Tea Break*		

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14:00–15:30 **POSTER SESSION 2 (See separate page)** **M Building**

16:00–17:30 **PARALLEL SESSION 13.A: Selected Applications of Accelerator-Based Analytical Techniques** **Board Room A**

Chairpersons: **M. Jaksic (RBI, Croatia)**
A. Migliori (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
16:00–16:15	191	**M. Chiari**	INFN, Italy	PIGE Analysis of Fluorine in Materials for the Circular Economy
16:15–16:30	115	**C. E. Iochims dos Santos**	Federal Univ. of Rio Grande, Brazil	Study of Silver Nanoparticles Uptake by Helianthus annuus Crop in Salinity Conditions
16:30–16:45	111	**P. Pongrac**	JSI, Slovenia	Using Micro-PIXE to Evaluate Nutritional Value of Edible Parts of Plants
16:45–17:00	104	**S. Möller**	FZ Jülich, Germany	Lithium Depth Profiling in Battery Anodes by Nuclear Reaction Analysis
17:00–17:15	119	**G. Provatas**	RBI, Croatia	Study of charge Transport in Semiconductors by Ion Beam Induced Charge (IBIC) Microscopy
17:15–17:30	**Questions and Answers**			

16:00–17:30 **PARALLEL SESSION 13.B: Accelerators and Interdisciplinary Applications** **M Plenary**

Chairpersons: **L. Beck (CEA, France)**
N. Pessoa Barradas (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
16:00–16:15	231	**K. Hain**	VERA, Austria	Ultra-trace analysis of anthropogenic long-lived radionuclides in the environment with AMS
16:15–16:30	110	**J. M. Lopez-Gutierrez**	Univ. de Sevilla, Spain	Characterization of Nuclear Waste by Accelerator Mass Spectrometry
16:30–16:45	215	**N. Skukan**	IAEA	IAEA Activities in Support of Sustainable Operation of Electrostatic Accelerator Facilities
16:45–17:00	40	**N. Arbor**	Univ. of Strasbourg France	A Monte Carlo and Experimental Tool for Activation Calculations in High Energy X-rays Irradiation Process
17:00–17:15	20	**S. Masic**	Vinca Institute of Nuclear Sciences, Serbia	Surface Treatment of Special High-Protein Products Using Low Energy Beams from Machine Sources
17:15–17:30	**Questions and Answers**			

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09:00-10:30 **PLENARY SESSION 14: Accelerators and emerging applications** **M Plenary**

Chairpersons: **T. Oshima (NIQRST, Japan)**
A. Simon (IAEA)

Time	Paper No	Name	Affiliation & Designating Member State / Organization	Title
09:00–09:30	216	**O. Girshevitz**	BINA, Israel	Implementation of Ion Beam Analysis for Forensic applications: The way to Global Forensic Database through the unification of different analytical techniques
09:30–10:00	206	**A. A. Bettiol**	Nat. Univ. Singapore, Singapore	Accelerators and Ion Beams for Quantum Technologies
10:00–10:30	222	**T. Stora**	CERN, Switzerland	Radioactive Ion Beams: from Large Scale Facilities to Nuclear Medicine Applications
10:30–11:00	*Coffee/Tea Break*			

11:00-12:00 **PLENARY SESSION 15: Conference Summary and Highlights** **M Plenary**

Chairpersons: **D. Ridikas (IAEA)**
C. Horak (IAEA)

Time	Name	Affiliation & Designating Member State / Organization	Title
11:00–12:00	**C. Hoehr**	Univ.Victoria & TRIUMF, Canada	Conference Summary and Highlights
	N. Alamanos	CEA, France	

11:00-12:00 **PLENARY SESSION 16: Conference Closing and Award Ceremony** **M Plenary**

Time	Name	Affiliation & Affiliation & Designating Member State/Organization	
12:00–12:30	**Celina Horak, Valeriia Starovoitova Sotirios Charisopoulos**	Scientific Secretaries, IAEA	Award Ceremony
12:30	**Danas Ridikas**	Scientific Secretary, IAEA	Closing Remarks

12:30-17:00 **Technical tour to VERA and MEDAUSTRON accelerator facilities**

Oral Presentations

— Plenary Invited Talks

— Contributed oral presentations

MEGAVOLT ACCELERATOR SYSTEMS FOR ENVIRONMENTAL MONITORING

David COHEN
Centre for Accelerator Science, Australian Nuclear Science and Technology organisation, New Illawarra Road, Menai, NSW, 2234, Australia

Accelerator based ion beam analysis (IBA) techniques have been applied successfully to environmental studies for decades. These megavolt accelerators are ideally suited as the techniques of Particle Induced X-ray Emission (PIXE), Particle Induced Gamma Ray Emission (PIGE), Rutherford Backscattering (RBS), Elastic Recoil Detection and Accelerator Mass Spectrometry (AMS), most commonly used on these machines, all have several key properties in common. They are very sensitive, capable of individual atom or photon counting and they can analysis very small samples, picograms to microgram in just a few minutes of beam time.

PIXE has been used since the mid 1970's to analysis filters obtained to characterise fine particle air pollution. Tens of thousands of such filters have been analysed to date across the globe in Europe, Africa, South America, Middle East and Asia by dozens of laboratories with megavolt accelerators. To date, these methods have been greatly refined. All four IBA techniques of PIXE, PIGE, RBS and ERDA can be run simultaneously to determine over 30 different elements from hydrogen to uranium at concentrations from ng/m^3 to hundreds of µg/m^3 of air sampled. The elemental outputs from these methods have been use as input for statistical source apportionment methods such as Positive Matrix Factorisation (PMF) to generate elemental source fingerprints and to then determine the contribution of these fingerprints to the total measured mass of fine particles in the air. This is then taken a step further with the application of hourly wind speed and direction data to pinpoint the location and long-range transport of pollution sources often many hundreds of kilometres away.

The IAEA has run a very successful fine particle characterisation research program for decades across more than 15 countries in Asia from Pakistan in the west to the Philippines in east and Mongolia in the north to New Zealand and Australia in the south. This program has helped national programs understand their air pollution issues and also identified long range pollution transport across national borders.

The technique of PIGE is a fast, sensitive and non-destructive method to determine total fluorine It has been used to determine fluorine down to µg/g levels in Australian coals for export. More recently, total fluorine by PIGE has been applied as a cheap, effective and fast screening method for perfluoroalkyl substances (PFAS) in food wraps, cosmetics and even contaminated ground waters. PFAS are very stable manmade chemicals that have properties that allow them to repel both water and oil and can be toxic in the environment and take a long time to degrade.

AMS is an isotopic method that has the potential to determine isotopic ratios down to 1 part in 10^{15} in microgram samples with a precision approaching ±0.5%. It is basically a dating method capable of measuring dates out to around ten half-lives of the isotope being considered. Megavolt accelerators can accelerator almost any isotope in the periodic table. Common isotopes used include ^{14}C (5,730 years), ^{10}Be (1.386M years) and ^{36}Cl (301k years). These three isotopes together span possible dates from the present to over 10M years and have applications in carbon dating for climate change studies, ^{10}Be for soil erosion and formation and ^{36}Cl for ground water studies.

This talk will discuss the application of the IBA methods and show some of the outcomes and success of applying megavolt accelerator systems that use these methods to better understand our environment.

ELECTRON ACCELERATOR BASED SYSTEMS FOR AIR, WATER AND SOIL POLLUTION CONTROL

A. G. CHMIELEWSKI
Institute of Nuclear Chemistry and Technology, Warsaw, Poland

Along with the increase in the population of the Earth and the development of industry, the emergence of large cities the number and quantities of environmental pollutants have increased dramatically. Currently, the so-called Artificial pollution, which, unlike natural ones, is caused by human activity has become a worldwide problem. The introduction of harmful substances into the air, water and soil, in addition to having a negative impact on the condition of nature, ecosystems, and the Earth's climate, is a direct threat to human health. Industry, power stations and transport are responsible for air pollution with particulate and acidic gases or gases causing the greenhouse effect. With the development of cities and industry, the source of pollution has become the growing amount of domestic, industrial and agricultural sewage. The high degree of water pollution with sewage has led to the exhaustion of their self-purification capacity. Industry and economy are responsible for the growing amount of solid waste, which, when deposited in landfills, releases poisonous substances into water and soil. Therefore, new regulations were introduced in the most countries concerning of any type pollutants emissions control and prevention. Important actions taken in order to counteract environmental pollution are recovery and recycling of waste as well.

The research on the possibility of using ionizing radiation in the treatment of the radiation of ionizing radiation has been undertaken a long time ago. However, the first applications, such as the treatment of drinking water from microbial contamination, the hygienization of excess sludge from biological wastewater treatment plants, etc., were based on the use of isotopic gamma sources. The powerful tools of ionizing radiation, electron accelerators, have been used for radiation processing of materials for more than half a century. However, the possibility of radiation applications for environmental pollution control was realized in the 1970s, when environmental protection agencies were established and standards for pollutant emission limits were set. The pioneer in these applications was the Japan Atomic Energy Research Institute, Takasaki [1]. Sueo Machi, past IAEA DDG, has initiated worldwide developments in the accelerator use in the field “Environmental protection by the use of EB accelerators is a new and important field of application. A commercial plant for the cleaning flue gases from a coal-burning power plant is in operation in Poland, employing high power EB accelerators. In Korea, a commercial plant uses EB to clean wastewater from a dye factory.” [2]. This was a breakthrough in a industrial applications of accelerators in worldwide scale [3]. The special input for application of the technology was the development of new high power electron accelerators which can be used for on-line processing of huge flow streams of liquid or gaseous pollutants. The accelerators were employed for off-gas and wastewater treatment and installed in a big throughput installation [4]. The further developments concern marine diesel off gases and ballast water treatment, and excess sludge hygenization [5]. New directions in environmental applications of accelerator-generated electron beams concern degradation of antibiotics and leftover drugs released in liquid effluents and slurry [6]. IAEA plays very important role in the enhancement of accelerator environmental applications [7]. However, the further developments in accelerator technology for these processes application since the machines must have high power, high electricity consumption efficiency, good reliability to work in harsh industrial conditions, in continuous operation for more than 8000 hours annually, and be available at reliable cost to make this technology competitive.

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50 YEARS OF ISOTOPE PRODUCTION VIA HIGH ENERGY ACCELERATORS AT BROOKHAVEN NATIONAL LABORATORY

C. S. CUTLER, D. MEDVEDEV, V. SANDERS, J. HATCHER LAMARRE, D. KIM
Brookhaven National Laboratory, PO Box 5000, Upton, NY 11973-5000, USA

In February 1972 the Brookhaven Linac Isotope Producer (BLIP) came online to accept protons from the 200 MeV Linac that synergistically supports multiple programs including the isotope production program, the Nasa Space Radiation Laboratory (RHIC) as well as the Relativistic Hadron Ion Collider (RHIC). In addition to the BLIP the isotope program operates the Radionuclide Research and Production Laboratory (RRPL) which contains laboratories and hot cells for processing targets irradiated at the BLIP for external customers as well as internal research. New hot cells have been brought online to aid in the processing of Ac-225. The BLIP allows the production of isotopes from 200 MeV and down in energies using stacked target arrays that allows for multiple isotope production. High energy accelerators play a critical role in supplying radionuclides such as Sr-82 used in Sr-82/Rb-82 generators for cardiac imaging. They continue to be upgraded to further production yields by installing beam rastering systems that have allowed higher intensities and thus higher production yields. Demand for isotopes that can be produced by these systems have also increased. Linear accelerators such as the one at Brookhaven National Laboratory when operating at maximum proton energy of 200 MeV can have simultaneous production of several medically relevant isotopes. Among those are Ac-225 ($T_{1/2}$=10.0 d), Cu-67 ($T_{1/2}$=64.83 h), Se-72/As-72 ($T_{1/2}$=26 h), Sr-82/Rb-82 ($T_{1/2}$=1.26 min) and Ti-44/Sc-44 ($T_{1/2}$=3.97 h). Discussion of recent facility enhancements and future upgrades and production of novel radionuclides will be presented.

REALISATION OF A NEW RESEARCH INFRASTRUCTURE IN BELGIUM: MYRRHA
PRESENT STATUS AND FOCUS ON LATEST DEVELOPMENTS OF MYRRHA ADS ACCELERATOR

Hamid AÏT ABDERRAHIM,
SCK CEN / MYRRHA, Boeretang 200, BE-2400, Mol, Belgium

SCK CEN is at the forefront of Heavy Liquid Metal (HLM) nuclear technology worldwide with the development of the MYRRHA accelerator driven system (ADS). MYRRHA is serving since the FP5 EURATOM framework as the backbone of the P&T strategy of the European Commission based on the "4 building Blocks at Engineering level" and fostering the R&D activities in EU related to the ADS and the associated HLM technology developments.

At the same time MYRRHA is conceived as a flexible fast-spectrum pool-type research irradiation facility cooled by Lead Bismuth Eutectic (LBE) and was identified by SNETP (www.snetp.eu) as the European Technology Pilot Plant for the Lead-cooled Fast Reactor. MYRRHA is proposed to the international community of nuclear energy and nuclear physics as a pan-European large research infrastructure to serve as a multipurpose fast spectrum irradiation facility for various fields of research such as transmutation of High-Level Waste (HLW), material and fuel research for Gen. IV reactors, material for fusion energy, innovative radioisotopes development and production and for fundamental physics. As such MYRRHA is since 2010 on the high priority list of the ESFRI roadmap (http://www.esfri.eu/roadmap-2016).

Since 1998 SCK CEN is developing the MYRRHA project as an accelerator driven system based on the lead-bismuth eutectic as a coolant of the reactor and a material for its spallation target. The nominal design power of the MYRRHA reactor is 100 MWth. It is driven in sub-critical mode (keff = 0.95) by a high-power proton accelerator based on LINAC technology delivering a proton beam in Continuous Wave (CW) mode of 600 MeV proton energy and 4 mA intensity. The choice of LINAC technology is dictated by the unprecedented reliability level required by the ADS application. In the MYRRHA requirements the proton beam delivery should be guaranteed with a number of beam trips lasting more than 3 seconds limited to maximum 10 for a period of 3 months corresponding to the operating cycle of the MYRRHA facility. Since 2015, SCK CEN and Belgium government decided to implement the MYRRHA facility in three phases to minimize the technical risks associated to the needed accelerator reliability.

On September 7, 2018, the Belgian federal government decided to build this large research infrastructure. In this lecture we will present the status of the MYRRHA project as a whole and in particular stressing the specific characteristics and requirements needed for ADS accelerators and how are we progressing in meeting them specifically in the development of the accelerator of MYRRHA.

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LARGE SCALE ACCELERATOR FACILITIES FOR NUCLEAR RESEARCH AND PRACTICAL APPLICATIONS

Boris SHARKOV

Joint Institute for Nuclear Research, Dubna, Moscow region, 141980 Russia.

National Research Nuclear University MEPhI, 115409, Moscow, Kashirskoe shosse, 31.

Charged particle accelerators are one of the main tools for basic research into the modern nuclear and elementary particle physics. The vast majority of fundamental results in particle physics and nuclear physics have been obtained in experiments by using accelerator of protons, ions, electrons and positrons. Accelerator technologies are progressing rapidly providing high-brightness beams with unprecedented parameters useful for practical applications.

Applications derived from basic Nuclear Physics Research have a large impact on many aspects of everyday life. Nowadays, it is obvious that society largely benefits from the vast investments done in basic Nuclear Physics research driven by accelerator technologies.

Nuclear Physics is in the forefront of many applications which cover the range of the needs of Humanity in terms of energy, health, food and agriculture, environment, biology, medicine, forensics, stewardship and security, cultural heritage, materials science, and many other areas. This is due to the peculiar properties of nuclear interactions with matter but also to the developments and the expertise developed by Nuclear Physics groups in accelerator technology, radiation detector technologies, high-performance computing, event reconstruction and ‘big data’.

Overview of the rapid progress in development of large-scale accelerator facilities and verity of related practical applications and spinoffs is presented.

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THE EUROPEAN SPALLATION SOURCE ACCELERATOR: OVERVIEW AND STATUS

J. G. WEISEND II, H. DANARED, M. LINDROOS

European Spallation Source, ERIC
Lund, Sweden

The European Spallation Source (ESS) will provide neutrons for a wide range of experiments in fields such as chemistry, physics, materials science, biology and pharmacology. Once completed in 2027, ESS will enable new areas of neutron science due to its brightness and long neutron pulse capability.

Neutrons are produced at ESS via a spallation process driven by a 2 GeV, 2 MW (upgradeable to 5 MW) proton linac. The bulk of the acceleration in the linac is provided by superconducting RF cavities operating at 2 K. This paper gives an overview of ESS, describes the linac design and details the current status of the accelerator. The use of In-kind partners and heat recovery is also discussed.

RECENT DEVELOPMENTS IN COMPACT X-RAY AND GAMMA-RAY SOURCES BASED ON INVERSE COMPTON SCATTERING

B. HORNBERGER
Lyncean Technologies, Inc., Fremont, CA, USA

J. KASAHARA
Lyncean Technologies, Inc., Fremont, CA, USA

Inverse Compton scattering (ICS) can generate high-flux, energy-tunable, narrow-band, collimated beams of X-rays or gamma-rays in a compact setting [1,2]. It works by scattering laser photons off relativistic electrons, whereby the electrons transfer part of their energy to the photons and up-shift their energy to the keV or MeV range. Fig. 1 illustrates the principle of ICS and plots the energy of the X-rays or gamma-rays vs. electron energy for the operating ranges of the CLS and CGS systems described below.

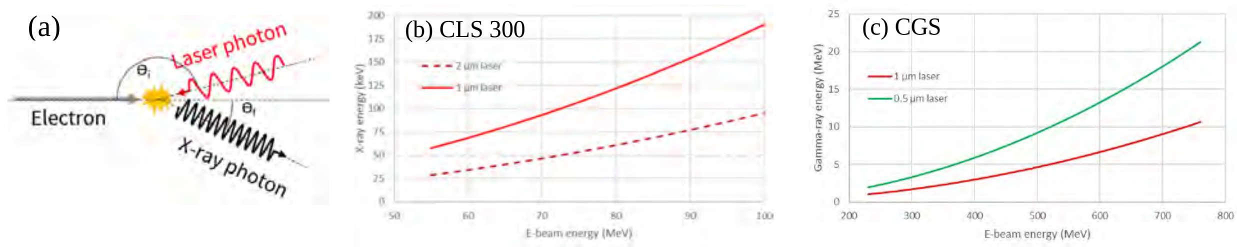

FIG. 1. (a) Principle of inverse Compton scattering. (b) X-ray and (c) gamma-ray energy as a function of electron energy.

The Lyncean Compact Light Source (CLS) [3] bridges the large performance gap between conventional and synchrotron X-ray sources, providing high flux and brightness, collimated, energy-tunable and quasi-monochromatic X-rays in a local laboratory. It enables a variety of techniques such as X-ray imaging, diffraction, spectroscopy and scattering with synchrotron-like capabilities. At the Munich Compact Light Source (MuCLS) [4,5], a Lyncean CLS has been operating in a user facility since 2015, with a research focus on biomedical imaging (see, for example, references in [3,5]). An application example is shown in Fig. 2.

A new design, the CLS 300 [6], is more than two orders of magnitude brighter than the MuCLS. Depending on configuration, it covers an X-ray energy range of about 30-90 keV, or 60-180 keV. It will provide X-ray flux of >4 x 10^{12} photons/s with a beam divergence of 4 mrad and a bandwidth around 10%. This is well-suited for high resolution, micro-CT imaging of millimeter-sized samples at micron resolution, with a flux density similar to some high-energy synchrotron beamlines. The beam properties of the new design are also compatible with focused beam applications such as high-energy diffraction, since using a lower divergence part of the beam with lower bandwidth allows the use of several types of X-ray optics commonly used at synchrotron beamlines. Furthermore, it provides a pathway to clinical implementation of radiotherapy requiring collimated, narrow-bandwidth, energy-tunable beams, such as microbeam radiation therapy (MRT).

FIG. 2. (a) Photograph of the Lyncean Compact Light Source. (b) Example of a dynamic in vivo imaging application from the Munich Compact Light Source, showing delivery of liquid instillations to the nose of a mouse (adapted from [7], Creative Commons License).

Monochromatic, tunable gamma-ray beams with high spectral density (flux/eV) are of interest for many applications [8,9]. Since no monochromators exist for gamma-rays, such beam properties must be generated at the source, and ICS is the only practical method to do so. Lyncean Technologies is currently developing the Compact Gamma-ray Source (CGS). The first CGS will be installed as the Variable Energy Gamma (VEGA) System at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP), a European Center of Excellence for scientific research in high-power lasers and nuclear physics in Romania (http://www.eli-np.ro).

Upon completion, this gamma-ray source will have about an order of magnitude higher flux and a factor of two lower bandwidth than the current state of the art. It will deliver gamma-rays with continuously variable energy from 1 to 19.5 MeV, covering the energy range relevant for low-energy nuclear physics and astrophysics studies, as well as applied research in materials science, management of nuclear materials, and life sciences. The beam will be quasi-monochromatic with a relative bandwidth of <0.5%, high intensity with a spectral density of >5 x 10^3 ph/eV/s and linear polarization of >95%.

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ALTERNATING PHASE FOCUSING BEAM DYNAMICS FOR DRIFT TUBE LINACS

S. LAUBER
HIM, GSI, KPH JGU-Mainz, Darmstadt, Germany

M. BASTEN
HIM, GSI, Darmstadt, Germany

S. YARAMYSHEV
GSI, Darmstadt, Germany

K. AULENBACHER
HIM, GSI, KPH JGU-Mainz, Mainz, Germany

W. BARTH
HIM, GSI, KPH JGU-Mainz, Darmstadt, Germany

F. D. DZIUBA
HIM, GSI, KPH JGU-Mainz, Darmstadt, Germany

M. DROBA
IAP GU Frankfurt, Frankfurt, Germany

H. PODLECH
IAP GU Frankfurt, Frankfurt, Germany

M. MISKI-OGLU
GSI, HIM, Darmstadt, Germany

In contrast to conventional drift tube linac RF-structures (e.g., of ALVAREZ-type) operated in TM-mode, novel H-Mode structures (e.g., Interdigital H-Mode) provide for compact acceleration of ion beams and have been established as highly efficient RF-resonators during the last decades. Thus, H-mode based accelerators are widely applied for heavy-ion acceleration with medium beam energies because of the outstanding capability to provide for high acceleration gradients with relatively low energy consumption.

In order to build upon those advantages, an Alternating Phase Focusing beam dynamics layout has been applied and adapted to provide for a cavity design without internal lenses, which allows for a most compact linac design, eased commissioning, maintenance and potential future upgrades. In order to omit magnetic focusing elements within the cavity, the electric focusing of the RF gaps is used for acceleration and additionally for focusing. But Gauss's law, one of the fundamental Maxwell equations, does not allow simultaneously focusing along all directions in charge free space, $\nabla\vec{E} = 0$. Thus, subsequential longitudinal and transverse electric focusing is necessary to provide for overall beam focusing. Negative, as well as positive synchronous phases, i.e. the RF phase when the accelerated particle beam is centred in the RF gap, are applied alternatingly to provide for the transversal and

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longitudinal focusing. Negative phases are routinely applied for ion acceleration and longitudinal focusing, whereas positive phases found wider application during recent decades, although proposed already in 1953 and refined in following years [1-3]. As predicted by Moore's Law, computational power has increased by several orders since then. It is now possible to provide for a design and detailed analysis of the complex beam transport in Alternating Phase Focusing accelerators. The gradual change from negative to positive synchronous phases is realized by altering the standard βλ/2 resonance acceleration geometry, which usually provides for only longitudinal focusing with -30° synchronous phase. The introduced synchronous phase change Δφ in between two neighbouring RF gaps leads to a change of the resonator geometry:

$$L_{\text{cell}} = \beta\lambda\frac{\Delta\phi}{2\pi} + \frac{\beta\lambda}{2} \quad (1)$$

A dedicated software has been developed to identify the change of gap phases along an accelerator for efficient beam transport and high beam quality. The features of such channel are demonstrated on the example of two IH-cavities, separated by an external quadrupole triplet. This setup provides for heavy ion (mass-to-charge < 7) acceleration from 300 to 1400 keV/u and will be used as injector part of the superconducting continuous wave accelerator HElmholtz LInear ACcelerator HELIAC [4, 5]. This superconducting accelerator, based also on H-mode cavities (Crossbar H-mode) offers for advanced features as a very low energy spread, a variable output energy and continuous wave operation especially designed for beam delivery to the GSI Super Heavy Element research program, contributing to advance the understanding of fundamental nuclear interactions. Hence, this promising approach generally enables safe routine operation for various applications as super heavy ion research, material science and radiobiological applications and heavy-ion tumour therapy. APF in general is an extremely interesting and attractive option for very different applications, such as LINAC concepts for accelerating electrons or hadrons of different mass.

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NOVEL ACCELERATOR CONCEPT UTILIZING CYCLOTRON RESONANCE (ECRA)

M. FEDURIN
Brookhaven National Laboratory, Upton, USA

J. HIRSHFIELD, X. CHANG, S. SHCHELKUNOV,
Yale University, New Haven, USA

K. AMM, P. THIEBERGER, W. STERN, M. PALMER
Brookhaven National Laboratory, Upton, USA

We will present progress in our effort to design and develop a new type of compact accelerator that can help to solve some flux and energy limit challenges associated with the current generation of accelerators. This accelerator concept utilizes cyclotron resonance in a TE rotating-mode microwave cavity. In this electron Cyclotron Resonance Accelerator (eCRA), particles gyrate along axial field lines and are accelerated by the transverse RF fields generated by a TE RF cavity. In this configuration, an initially non-relativistic electron beam will become relativistic after only a few gyrations in the magnetic field and energy gains of order 10 MeV can be readily achieved for a range of applications. A key feature of the proposed accelerator configuration is that the beam remains un-bunched, in contrast to beams generated with conventional acceleration schemes using a linac or RFQ. This results in reduced space charge fields and enables acceleration of high current beams in a compact accelerating structure.

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AN OVERVIEW OF THE SOUTH AFRICAN ISOTOPE FACILITY (SAIF) PROJECT

F. AZAIEZ
iThemba LABS, Somerset-West, South Africa

I.L. STRYDOM
iThemba LABS, Somerset-West, South Africa

The South African Isotope Facility (SAIF) is a new radioisotope production facility currently under construction at iThemba LABS in Cape Town and scheduled for completion in 2022.

A commercial 70 MeV proton cyclotron from IBA with a number of beam lines equipped with isotope production stations, are being installed in retrofitted concrete vaults. The facility will be supported by new infrastructure and services which are being constructed. The completion of SAIF will greatly increase the radioisotope production capability of iThemba LABS and enable the existing Separated Sector Cyclotron to be dedicated to nuclear research activities.

An overview of the SAIF project from the inception phase through to the construction phase is provided here, discussing all related workstreams and progress made to date. A more detailed discussion of some specific systems is given, including the design of the isotope production stations, target handling system, and a new radioactive waste management facility.

THE USE OF PSI'S HIGH INTENSITY PROTON ACCELERATOR (HIPA) COMPLEX TOWARDS MEDICAL-RADIONUCLIDE DEVELOPMENT

N. P. VAN DER MEULEN
Paul Scherrer Institute, Villigen-PSI, Switzerland

Paul Scherrer Institute (PSI) runs a High Intensity Proton Accelerator (HIPA) facility, with three accelerators run in tandem to increase proton beam energy. Initially, a Cockroft-Walton accelerator accelerates protons at 870 keV that are fed into a separated-sector cyclotron, known as Injector II. There, the protons are accelerated to 72 MeV, at a beam intensity of up to 2.5 mA, en route to a larger cyclotron, referred to as the 'Ring' cyclotron. The Ring cyclotron accelerates the protons further to 590 MeV, which is then sent down the beamline to various experimental vaults for physics research. The remainder of the beam is collected in a Pb target, which serves as a neutron spallation source for the Swiss Neutron Source (SINQ). The proton beam is split not far from the exit of Injector II, where a maximum of 100 µA protons is gleaned from high intensity 72 MeV protons into the IP2 target station. These protons irradiate various targets towards the production of exotic radionuclides intended for medical purposes [1].

Many radiometals in use today, as radiopharmaceuticals, are for the diagnosis and treatment of disease, with the most popular means of detection being Positron Emission Tomography. These positron emitters are easily produced at low-proton energies using medical cyclotrons, however, developments at these facilities are lacking, as many such cyclotrons situated at clinics do not perform research and development with them. The fixed 72 MeV proton beam from Injector II is degraded at IP2 to provide the desired energy to irradiate targets to produce the likes of ^{44}Sc, ^{43}Sc, ^{64}Cu and ^{68}Ga as a proof of principle, which are of interest to the nuclear medicine community. Other radionuclides developed at this facility include ^{165}Er and ^{155}Tb, for use in Single Photon Emission Tomography and potential Auger therapy. The results from this development work in the form of target preparation and design, chemical separation systems and methods can then be implemented at facilities containing medical cyclotrons [2].

The use of SINQ towards neutron irradiation of enriched Gd targets led to the development of ^{161}Tb, a therapeutic radionuclide which can possibly be the paradigm shift in radionuclide therapy. The production of the nuclide has since been scaled up to the use of research reactors with higher neutron fluxes, with therapeutic activities envisaged for the near future [1].

The HIPA facility at PSI provides the means to produce radionuclide developmental research, as a proof of concept. Once perfected, the conceptual design can be transferred to collaborative partners. It is aimed to develop the nuclides in question such that they can be part of the radiopharmaceutical manufacturing process under Good Manufacturing Practice (GMP), such that they can be administered to patients.

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THE NEW PARTICLE THERAPY RESEARCH CENTER (PARTREC) AT THE UNIVERSITY MEDICAL CENTER GRONINGEN

A. GERBERSHAGEN[1,2], L. BARAZZUOL[1,2,3], S. BOTH[1,2], S. BRANDENBURG[1,2], R.P. COPPES[1,2,3], P. DENDOOVEN[1,2], M.-J. VAN GOETHEM[1,2], E.R. VAN DER GRAAF[1,2], B.N. JONES[1,3], P. VAN LUIJK[1,2,3]

[1] *Particle Therapy Research Center (PARTREC). University Medical Center Groningen, University of Groningen, Groningen, The Netherlands*
[2] *Department of Radiation Oncology, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands.*
[3] *Department of Biomedical Sciences of Cells and Systems, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands.*

PARTREC facility

The PARticle Therapy REsearch Center (PARTREC) is a newly established research facility at the University Medical Center Groningen (UMCG). Built on the success of the KVI-CART research center, it utilizes the superconducting cyclotron AGOR for experimental research, mainly in radiation physics and biology. Working in close collaboration with the UMCG Groningen Proton Therapy Center (GPTC), PARTREC uniquely combines radiation physics, medical physics, biology and radiotherapy research with an R&D program to continuously improve hadron therapy technology and advance radiation treatment for cancer patients. In addition, it provides opportunities for experiments in the domain of radiation hardness, for both the scientific and commercial communities, and nuclear science, in collaboration with the Faculty of Science and Engineering of the University of Groningen.

Accelerator Capabilities

AGOR delivers ion beams of all stable elements with an energy dependent on the charge-to-mass ratio of the ions. Proton beams with clinically relevant energies (range up to 230 mm) are used for preclinical radiation biology research and proton therapy related physics since twenty-five years.
For radiation hardness tests, the facility provides beams of protons at different primary energies and various ions (from He to Xe) at 30 MeV/amu. Experiments can also be performed with C and O ions at 90 MeV/amu. Extension of the palette of beams towards heavier ions and lower energies is under development.

Image guided preclinical research

Modern image-guidance is an essential element for the realization of the next generation of preclinical experiments to further develop clinical particle therapy. Novel orthotopic tumour models, display anatomical variation that requires not only individually image-guided irradiation planning, but also pencil beam scanning to create highly conformal dose distributions. Image-guided Monte Carlo irradiation planning reduces dose variation between animals reducing the number of animals needed to detect significant differences.

To facilitate this development a new research infrastructure for image guided preclinical research is currently under development and is expected to be available in 2023. With the new infrastructure also helium (range in water up to 60 mm) beam will become available for preclinical research. A wide range of irradiation modalities based on both scattering and pencil beam scanning will be available, including shoot-through with high energy protons as well as Spread-Out Bragg Peak for protons and helium. Additionally, the adaptation of the facility for the delivery of spatial fractionation (GRID) and high dose rates in excess of 300 Gy/s (FLASH) is maturing.

Research plans with the new infrastructure

PARTREC will provide users a one stop facility to address various research questions such as:

— Studies of radiation sensitivity variations within normal tissue and tumour.
— Mechanistic studies using various tumour and normal tissue *in vitro* and *in vivo* models to investigate interaction between radiation and systemic treatments, such as chemotherapy, immunotherapy and DNA damage response (DDR) modulators.
— LET and RBE studies for biological treatment planning.
— Advanced radiotherapy dose delivery techniques, such as GRID and FLASH.
— Therapeutic window optimization and translation to the clinic.
— Biological and physical radiation effects in space.

Conclusion

The new PARTREC facility will provide the radiation biology, physics and radiotherapy community with a state-of-the-art, open access research infrastructure for cell/tissue culture and small animal research. The upgrades to the infrastructure will become available from 2023.

Acknowledgement

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RESEARCH ACTIVITIES ON THE CYCLOTRON-BASED PRODUCTION OF INNOVATIVE RADIONUCLIDES: THE EXPERIENCE AT THE LEGNARO NATIONAL LABORATORIES OF INFN

G. PUPILLO[1], A. ANDRIGHETTO[1], M. BALLAN[1], S. CISTERNINO[1,2], S. CORRADETTI[1], L. DE DOMINICIS[1,2], J. ESPOSITO[1], M. MANZOLARO[1], P. MARTINI[3,4], A. MONETTI[1], L. MORSELLI[1,3], L. MOU[1,3], D. SCARPA[1], G. SCIACCA[1,2]

[1] *Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro (INFN-LNL)*
[2] *Università di Padova, Padova (PD), Italy*
[3] *Università di Ferrara, Ferrara (FE), Italy*
[4] *INFN-FE, Ferrara (FE), Italy*

The cyclotron-based production of radionuclides for medicine is one of the research activities carried out in the framework of the SPES (Selective Production of Exotic Species) project at the Legnaro National Laboratories of the National Institute for Nuclear Physics (INFN-LNL). The heart of SPES is the 70 MeV proton-cyclotron with a dual-beam extraction, installed in 2015 in a new building equipped with ancillary laboratories currently under completion. The project aims at the construction of an advanced ISOL (Isotope Separation On-Line) facility for the production of re-accelerated exotic ion beams for nuclear physics studies. The double-beam extraction of the cyclotron also allows to perform multidisciplinary activities, such as radionuclides production for medical applications and neutron-based research. This work will mainly present the results obtained with the interdisciplinary projects LARAMED (LAboratory of RAdionuclides for MEDicine) and ISOLPHARM (ISOL technique for radioPHARMaceuticals). The first one is based on the direct-activation method, and it includes the proton-based production of ^{99m}Tc, ^{67}Cu, $^{52/51}$Mn, ^{47}Sc and recently Tb-isotopes, from the nuclear cross section measurements to the preclinical studies. ISOLPHARM uses the ISOL technique for the development and the production of radioisotopes with high-specific activity, such as ^{111}Ag, going beyond the state-of-art in the field. A consolidated network of collaborations with national and international facilities, including universities and hospitals, characterizes the research activities on radionuclides production at the INFN-LNL.

ION BEAM TECHNIQUES AND NEUROSCIENCE: WHAT IS NEXT?

P. FERNANDES COSTA JOBIM
Federal University of Rio Grande do Sul, Porto Alegre, Brazil

C. E. IOCHIMS DOS SANTOS
Federal University of Rio Grande Santo Antônio da Patrulha, Brazil

A. RASIA-FILHO
Federal University of Health Science of Porto Alegre Porto Alegre, Brazil

J. FERRAZ DIAS
Federal University of Rio Grande do Sul Porto Alegre, Brazil

Particle accelerator based techniques, including PIXE and STIM, have been used to address biological questions. On the other hand, cognitive neuroscience research has used high- resolution techniques to understand the neural mechanism behind cognitive processes. It is well established that humans are among the species with higher mental capacities, such as mind theory, self-transcendence, and spirituality. The human brain is considered the most complex natural system in structural and functional terms. We have tried to define with precision the brain cytoarchitecture, however histological techniques traditionally used for this purpose have some limitations. In principle, none of them provides the unambiguous and non-subjective definition of the edges of the studied structures. The design of different brain structures commonly done by the Nissl technique has the disadvantage that the intensity of the staining depends on the level of protein synthesis of each cell. Because of this, there is an inherent degree of subjectivity when the researcher uses it to make the definitions of the edges of the studied structures. Our goal was to analyze the brain structure that makes us humans, the neocortex. The neocortex has a cytoarchitecture composed of a *continuum* of six cellular layers, some with varied features and/or subdivisions that serve to characterize adjacent areas along different lobes. Brain samples were obtained from two males aged 51 and 83 years who died of non-violent causes and with no previous neurological or psychiatric diseases. Tissue blocks were fixed by immersion in 10% non-buffered formaldehyde and stored at room temperature until experimental processing. Samples were coronally sectioned into 40 μm thick slices using a cryostat, with the cutting chamber at -15°C, prior to being dehydrated using a freeze-drier. The elemental concentrations of gray matter (GM) and white matter (WM) obtained by PIXE were compared under the same sample preparation and acquisition data conditions. The concentrations of Mg, S, Ca, Fe, Cu and Zn were higher in the GM when compared to the results obtained from the adjacent WM ($p< 0.05$). From these elements, the GM layers II and V showed higher values of Zn. STIM results from the cerebral cortex revealed different areal densities for the human cerebral cortex sampled: WM denser than GM, which might be related to the higher amount and packaging pattern of the myelinated axons in the WM. In addition, detailed STIM scans were performed on the cortical GM, looking for the possibility of distinction of the six cellular layers based on their areal density characteristics. Our data showed an areal density that decreases from layer I towards layer II. This pattern reduced even more from the middle of layer III towards layer IV. The areal density increases in layer V, presenting a similar level as observed in layers II and III, and a higher value in layer VI. These results presented potential new approaches that could add to the study of human neocortical layers with high precision data from ion beam techniques.

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TREATMENT, NOT TERROR. A UNIQUE CANCER TREATMENT PARADIGM FOR DEVELOPING NOVEL LINEAR ACCELERATORS FOR RESOURCE- LIMITED SETTINGS.

Miles A. POMPER[1], Graeme CAMPBELL BURT[1,2], Suzie SHEEY[1,3], Deepa ANGAL-KALLININ[1,4], Taofeeq IGE[5], C NORMAN COLEMAN[1], Eugenia WENDLING[1], Manjit DOSANJH[1,6].

[1]*International Cancer Expert Corps*
[2] *Cockroft*
[3] *University of Oxford*
[4] *STFC Daresbury Laboratory, Warrington, UK*
[5] *National Hospital Abuja, Abuja, Nigeria, University of Abuja, Abuja, Nigeria*
[6] *CERN, Geneva, Switzerland*

Introduction: **The confluence of problems being addressed:** Over the last decade, two major socioeconomic challenges have been recognized that led to the development of a novel linear accelerator (LINAC) as a solution. With data over decades indicating the rising burden of noncommunicable diseases (NCDs) [predominantly cardiovascular, oncologic, respiratory and metabolic diseases] the United Nations General Assembly formally recognized this as a global problem in 2011. The terrorism concerns from the Office of Radiological Security, US Department of Energy, National Nuclear Security Agency from poorly controlled high-activity resources led to initiatives to develop "Alternative Technology" (Alt Tech).[1] Resulting from an international meeting on these topics that recognized the importance of Cobalt-60 for cancer care particularly in poor-security regions, Pomper and Delnoki-Veress created the paradigm of "Treatment, not Terror" for simultaneously addressing cancer and security. The International Cancer Expert Corps (ICEC) [3], a global NGO, recognized the need for novel technology for challenging environments [4] and the essential requirement for expertise to manage the patients and facilities. ICEC has since entered into partnership with LINAC experts to develop a novel LINAC with progress as follows.

Building Collaborations and taking action: ICEC set out to define, understand and address the challenges faced by the health professionals at the grass-roots in low- middle income countries (LMICs) who treat cancer patients with radiotherapy (RT). A number of workshops were held from 2016 - 2020 involving medical and technical experts from CERN, the ICEC and its global membership and, since 2017, the UK Science and Technology Facilities Council (STFC). ICEC especially involded representatives from LMICs and Official Development Assistance (ODA) countries to understand the challenges and develop effective, innovative solutions, especially for our partners across Africa.

Technology challenges: Current RT LINAC technology requires a large number of expert professional staff (including radiation oncologists, medical physicists, dosimetrists, service engineers and radiation therapy technologists) to treat patients and to maintain the equipment. In most LMICs there is both a shortage of machines and frequent breakdowns and too few engineers to keep the machines working.

Data: Obtaining RT data from the ODA countries was an essential step thus we obtained specific information from grass-roots practitioners from workshops and from a specific questionaire from all 28 African countries that offer LINAC treatment. From our analysis (data to be presented) technology development is needed to produce a modular, robust machine suited for the challenging environmental conditions and poorer infrastructures while requiring fewer qualified experts. The RT system should be user- and patient-centered and incorporate artificial intelligence (AI) and machine learning (ML)

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throughout all processes to help reduce both clinician effort and the need for costly and scarce technical support personnel. The use of modular design in conjunction with remote monitoring and fault analysis, will expedite maintenance and repairs, lessening the need for specialized personnel and shortening down times.

Expertise-healthcare: The essence of the ICEC solution for global cancer care is a sustained mentorship program having the necessary, sustainable onsite expertise built from local champions and local and/or country-based investment.[5] The expertise includes medical care delivery, oncologic science, and supporting care. Critical are proper education and training and the ability to remain up to date in a world of rapidly advancing science.[6]

Socioeconomic impact: That having RT as an essential component of effective cancer care will have a broad impact on a country. The enabling LINAC technology - that encompasses the machine, the AI/ML assistance in machine capability and enhancing medical expertise - can through a global trusted network fill the current shortfall of >5,000 LINACs worldwide. An innovative healthcare system model has the potential for the necessary exponential growth in cancer care capacity.

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ACCELERATOR MASS SPECTROMETRY: AN ANALYTICAL TOOL WITH APPLICATIONS FOR A SUSTAINABLE SOCIETY

WILIAM E. KIESER
A. E. Lalonde AMS Laboratory, University of Ottawa
Ottawa K1N 6N5 Canada

Accelerator Mass Spectrometry (AMS) adds the techniques of charged particle acceleration to the basic principles of Isotope Ratio Mass Spectrometry (IRMS) to provide extremely low detection capability (below 1 femtogram) of rare isotopes in in samples of natural materials as small as 1 mg. Depending on the element selected and the configuration of the equipment, sensitivities can reach one part in 10^{15}. The advantages of this small sample size and high sensitivity include the economic benefit of collecting, shipping and preparing much smaller samples, and also the ability to analyse specific chemical compounds within the sample, so that the pathway taken by that compound through complex systems can be more precisely traced or, in the case of radioactive isotopes, more precise chronological information can be provided.

There are currently approximately 160 AMS systems in operation throughout the world, ranging in acceleration voltage from 200 kV to 15 MV, a number which has doubled in the past 10 years. While many which operate at the lowest of these voltages are specifically designed for one element (typically carbon isotopes), there are a number of multi-element machines coming online which operate at 300 kV. Many of these systems can be equipped with integrated sample preparation equipment, such as elemental analyzers, carbonate analysis systems or even IRMS systems for abundant stable isotope analyses of the same sample.

In the over 40 years of the availability or AMS analyses, many applications in Earth, environmental, planetary, biomedical and cultural sciences have been developed. Of particular interest to sustainability are the contributions made to climate change research using ^{14}C and more recently ^{26}Al, ^{36}Cl and ^{10}Be, to provide details about previous climate change events and to monitor the specific events associated with current changes, such as permafrost thawing, sources of atmospheric methane, or carbon cycling in the oceans. For the energy sector, atmospheric measurements of ^{14}C are used to assess the efficacy of bio-remediation programs for fossil fuel spills and the actinides and fission fragments are analysed to monitor the production, use and disposal of nuclear fuel. Cultural applications include collaborations with indigenous communities to provide chronologies for events chronicled in oral histories, some of which include their adaptation to earlier environmental changes.

This presentation will provide a basic overview of AMS technology and follow with examples of some of the applications outlined above.

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CHARACTERISTICS OF FINE PARTICULATES OF TWO LARGEST CITIES IN INDONESIA USING ION BEAM ANALYSIS

M. SANTOSO
Center for Applied Nuclear Research and Technology – National Nuclear Energy Agency (BATAN), Bandung Indonesia

D.D. LESTIANI[1], A. ATANACIO[2], S. KURNIAWATI[1], E. DAMASTUTI[1]
[1]Center for Applied Nuclear Research and Technology – National Nuclear Energy Agency Bandung, Indonesia
[2]ANSTO Centre for Accelerator Science, Lucas Heights, NSW 2234, Australia

Urban air pollution is a major problem in Indonesia and has growing recognition of the health effect problems resulting from airborne particles. Even some cities have been identified for their high levels of air pollution. Therefore, characterization of the chemical composition of air particulates is a fundamental step for identification of pollutant sources. These chemical compositions are generally at trace levels thus require an accurate and suitable analytical method such as Ion Beam Analysis (IBA) which is fast, effective and has high sensitivity. In this study, a non-destructive IBA method was applied to characterize $PM_{2.5}$ of ambient air samples in the two largest cities in Indonesia, namely Jakarta and Surabaya which have different characteristic as urban cities. There are two sampling sites in Surabaya; East-South Surabaya is an area where a lot of industries are located, and West Surabaya which is close to port but no metal industries, while Jakarta has been identified as Mega City with the most populous city in Indonesia. The locations of the sampling were present in Fig.1. The $PM_{2.5}$ air particulate samples were collected for 24-hours using GENT sampler from 2019 – 2020. As much as 105 samples; 32 samples from Jakarta, 35 samples from East-South Surabaya and 38 samples form West Surabaya, have been collected and analyzed. Several elemental compositions i.e., F, Na, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Br, Rb, Sr, Y, Zr and Pb, have been well quantified. Figure 2 showed the ratio of elemental concentration between East-South Surabaya and West Surabaya to Jakarta as comparison.

a b

Figure 1. The sampling locations in Jakarta (a) and Surabaya (b)

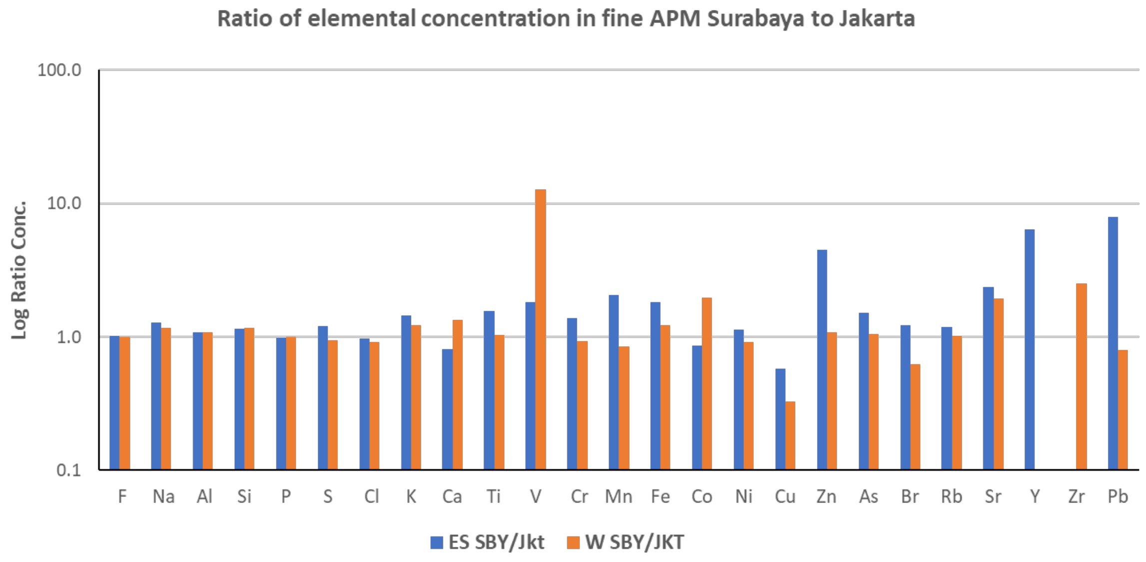

Figure 2. The elemental ratio concentration of ambient air $PM_{2.5}$ between East-South Surabaya to Jakarta (ES SBY/Jkt) and West Surabaya to Jakarta (W SBY/Jkt)

From Fig 2, it can be seen that Potassium in Surabaya at 2 sites were higher than in Jakarta that may related to biomass burning. In West Surabaya, Vanadium was found significantly higher than in Jakarta as showed in Fig.2. This may be due to the location that close to the port since Vanadium is one of key elements to the emission of refinery oil. Several metals such as Cr, Mn, and Fe were found higher in East-South Surabaya which may related to the metal and steel smelter industries. Significant high concentration of Zn and Pb were also found in East and South Surabaya, reached 4.5 and 7.8 times respectively, which are due to Lead and Zinc smelter in the area. While in Jakarta, Cu concentration was 2-3 times higher than it's found in East-South Surabaya and West Surabaya as well, describing the possibility of the sources from non-ferrous industries.

The results of elemental composition in ambient air $PM_{2.5}$ using IBA technique analysis is able to provide good and comprehensive results in term of urban air characterization. Three sampling locations from Jakarta and Surabaya gave different results according to the characteristics of the area. The multi-element identification from the IBA analysis is also able to provide an overview of the contribution of emissions from industry to air quality in the surrounding environment.

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ION BEAM USAGE IN ENVIRONMENTAL CHARACTERIZATION

L. POPA_SIMIL
LAAS - Los Alamos Academy of Sciences, Los Alamos, USA

There are many circumstances we were interested in getting more knowledge on environmental atomic and molecular composition, as monitoring pollution, identifying pollution sources, looking for air, water and soil on surface and underground composition. Accelerator based techniques offer a large palette of measurement capabilities, with high sensibility and accuracy, requiring small samples but they are expensive and time consuming, and need to be organized in such a manner to get a holistic characterization of an array of interest in a single sampling, or repetitive for trend identification.

Starting in 1980 in Romania, I have started measuring environment as related to singular events, to industrial pollution and general environment research using nuclear technologies. First sets of measurements were using gamma-spectroscopy associated to geodesic studies or singular events forensics. Samples from environment were taken and measured for elemental and molecular composition using, PIXE, PIGE, CPAA and NAA. Chernobyl accident found us so unprepared to reliably characterize the impact in air and on ground and water, and we used a combination of measurements, trying to identify the contamination not only with radioactive material, but with stable elements also. The interest was to correlate various contaminants in air bound to various size aerosols, and we started developing our multi-stage stacked filter unit, that was applied successfully to water, lubricant and wine filtration, using tangential filtering units for large filtered volumes. Atmospheric pollution, and atmospheric corrosion, became important, and we have used TLA method to characterize the material corrosion in air, and simultaneously measure the acidity in air using special filtration unit in parallel, and taking precipitation samples. The need for measuring bio-samples which are evaporating in vacuum and under beam's energy deposition led us to the development of methods with beam extracted in air, or controlled atmosphere, generically called bio-PIXE.

During 1990s we were interested in tracking pollution, and we used the protocols developed by Nagoya Technical Univ., Prof. Susumu Amemyia, which was based on mobile air samplers with 0.4µ and 5µ pores, tuned for industrial pollution, and the IMPROVE protocol, developed with Prof. Thomas Cahill at UC Davis, CA participation, using 0.8 µ and 8 µ filters, simulating better human buccopharyngeal cavity, augmented with nearby soil, vegetation and water samples. Starting from mid 1980s we have added remote sensing capabilities using thermos and multi-spectral vision for characterizing short range transportation, where the data were correlated with elemental analyses of samples from the area in order to produce signature patterns for image automatic identification. Measurements across US, Europe and Romania were made, mainly measured by PIXE and XRF, while stoichiometry was used to identify substances.

After year 2000, soil and vegetables samples were taken to scale the impact in the area of the so called "nuclear legacy", on local environment and looked to more evolved AMS methods using RGAs in order to better identify the molecular compositions and develop accelerator based forensic installation, using both the analytical and radiolysis capabilities, in an effort to extract maximum information from the measurements, sometimes performed in real-time.

These experiments drive us to the conclusion that for best accurate and complete results one has to use a plurality of methods applied quasi-simultaneously on the same sample.

In most of the cases was difficult to say which was the real contribution of a singular event on the composition of elements and molecules in an area, and most often we used in volume sampling to obtain the densities of each component, and from those variation to estimate the single event's contribution. In this case accelerators have to cooperate doing simultaneously elemental analysis and atomic mass spectroscopy, to identify all molecular species, and to corroborate these results with CPAA, NAA and RBS for solid samples. Radioactivity is also an important feature and makes a more complex image. In some cases, using radiolysis and sequential measurements allows obtaining more complete information about volatile substances, which may be detected with Residual gases analysers online with the beam, is sample temperature is also considered by using IR imager.

It has been detected an affinity between some substances and elements to associate with certain particulates and aerosols, as in the case of wine clearing by ultrafiltration, where wen removing a class of particulates was changing the wine scent and aromas, and a study in depth was required to better understanding these manifestations.

Using the lessons learned, in order to get competitive, fast and useful data, there is the need to consolidate the accelerators in clusters application ready, with some process automation, able to process many samples a day under quality assurance standards. Another direction is to develop mobile equipment for on-site measurements that will deliver the primary data collected during the sampling time, covering all aspects of the studied area. That will represent virtual centres of excellence, assuring accelerators an important role in environmental and micro-particle knowledge progress.

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ELEMENTAL CHARACTERIZATION OF $PM_{2.5}$ AEROSOL SAMPLES IN FOUR MIDEASTERN CITIES AND SOURCE APPORTIONMENT INVESTIGATION

M. ROUMIE
Lebanese Atomic Energy Commission Beirut, Lebanon

A. ABA
Kuwait Institute for Scientific Research Kuwait City, Kuwait

L. AL-SAADI
Ministry of Environment Doha, Qatar

M. SULTAN
Ministry of Science and Technology Baghdad, Iraq

M. CHIARI
INFN Florence, Italy

This work is a part of a study conducted among several Arab countries in West Asia, under an IAEA regional technical cooperation project, dealing with air pollution in ARASIA region (Arab countries in Asia). Since atmospheric particulate matter PM10 and PM2.5 are trans-boundary and can effectively contribute to air pollution in certain localized areas, it was proposed to investigate and evaluate atmospheric particulate matter APM, in particular PM2.5, in a regional context. In a first phase, some preliminary results were obtained based only on a moderate number of samples from few participating countries [1]. In the second phase of the project, a large sampling campaign was performed, more countries were involved and, consequently, many samples are collected for a better investigation of PM2.5 aerosol samples in the region (elemental composition, total mass, black carbon and consequent pollution sources). Particle Induced X-ray Emission PIXE technique was performed, using 3 MeV proton beam, to determine the elemental composition of the $PM_{2.5}$ particulate matter (from Na to Pb) that are collected for 24 hours on Teflon filters at the rate of twice per week, during the period 2018-2020. It concerns samples from Baghdad, Beirut, Doha and Kuwait City, where the different characteristics of their $PM_{2.5}$ will be compared and discussed, highlighting their source apportionment.

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A COMBINED XRF AND XANES STUDY ON BOTTOM ASHES FROM MUNICIPAL SOLID WASTE INCINERATOR

SIMONE POLLASTRI

Elettra - Sincrotrone Trieste S.C.p.A., 34149, Basovizza, Trieste, Italy

CHIARA DE MATTEIS, LUCIANA MANTOVANI, MARIO TRIBAUDINO

Università di Parma, Dipartimento di Scienze Chimiche, della Vita e Sostenibilità Ambientale 43124, Parma, Italy.

The correct management of waste is a key aspect of the transition of our society to become as environmentally neutral as possible. Only in Italy, each year about 30 million tons of urban waste are produced, of which 5.3 million are disposed in incinerators; the incineration process then produces about one million tons of ashes [ISPRA, 2018].

In general, ashes from municipal solid waste incinerators (MSWI) are made by bottom ashes (BA), and fly ashes (FA), which corresponds to about 20% and 4% by weight of the original waste, respectively [Baalbaki et al., 2019]. Whereas FA are classified as dangerous waste, BA can be recycled and are the main secondary raw material from incinerators. Recycling BA as a secondary raw material represent an interesting, environmentally friendly, alternative solution to landfill disposal; indeed, several processes have been proposed, like inclusion in ceramics or in concrete [Bertolini et al., 2004].

Nevertheless, any form of recycling requires an assessment of the potential pollution for environment and health risk. This can be achieved through a detailed study of the chemical and mineralogical composition of BA and with specific tests to determine their eventual evolution following ageing, leaching and weathering [Alam et al., 2019]. BA are made by crystalline phases, i.e. silicate, carbonate, oxides, sulphates, amorphous glass and metallic inclusion. They are mainly composed by Si, Al, Fe, Ca, Mg, K, Na, S, Cl. However, they also contain potentially dangerous elements (PTE) such as Zn, Pb, Cu, Cr and Ni. The actual danger depends on the mineralogical environment in which they are found, which controls the potential release in the environment, so for any potential reuse it’s important to determine their speciation.

For this reason, on few grains (sized 0.5 - 1 mm) of BA from a waste-to-energy plant, SEM-EDS, XRF mapping and XANES measurements were performed. The sample was embedded in epoxy resin and one side was polished. Then, XRF maps with a resolution of 50x50 μm^2 and an incident beam energy of 14 keV were collected in various areas.

Orienting on the basis of the elemental distribution, XANES spectra from different elements (Zn, Cu, Cr, Ni and Pb) were then collected on selected clasts.

XRF maps evidenced that PTE are present with different oxidation states and structures, like in metallic form, amorphous phases, silicates and carbonates. A preliminary look to the XANES data collected at the Cr K-edge permits to exclude the presence of Cr^{6+}, as all the collected spectra have features resembling that of Chromite (Cr^{3+}).

Also, all the XANES data collected at Pb L_3-edge on various clasts are almost identical, and from the comparison with Pb metal foil and PbO standard compound spectra, we can qualitatively derive that Pb is oxidized in all the clasts. Cu appears to be present both in metal and oxidized form. The precise oxidation state and coordination geometry of all the investigated chemical elements will be determined through linear combination fit (LCF) analyses.

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PARTICLE INDUCED X-RAY EMISSION (PIXE) REVEALS CRUCIAL INFORMATION IN HIP ENDOPROSTHESES FAILURES. MEV ION BEAMS FOR IMPROVING MEDICAL DIAGNOSTICS

Esther PUNZÓN-QUIJORNA[1], Mitja KELEMEN[1], Primož VAVPETIČ[1], Samo K. FOKTER[2], Peter WAHL[3], Iztok ARČON[1], Primož PELICON[1]

[1]*Jožef Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia*
[2]*University Medical Center Maribor (UKC MB), Ljubljanska ulica 5, SI-2000 Maribor, Slovenia*
[3]*Kantonsspital Winterthur, Brauerstrasse 15, Postfach 834, 8401 Winterthur, Switzerland*

Worldwide, approximately one million hip replacements take place every year. This number is expected to grow, due to increased life expectancy and ageing population. Despite the rapid development of cutting-edge materials, there is an increased number of injuries linked to prosthesis failure during recent years. In response to this, the European Commission is working on a database, EUDAMED[1], to monitor the safety and performance of medical devices.

The insufficient understanding of physiological processes leading to prosthesis failure call for the use of complementary tools. Diagnostic techniques currently applied in hospitals, such as X-ray scans or optical tissue microscopies, are able to distinguish metal particles, but they are not able to identify their specific metallic origin (Ti, V, Al, etc.) and concentration.

Aiming to achieve better diagnostic tools to identify causes of hip prosthesis failure, TissueMaps[2] project was launched. The project was a multidisciplinary project of Jožef Stefan Institute and University Medical Centre Maribor, both in Slovenia, and it counted with the financial support of Marie Skłodowska-Curie Actions. The research has recently continued thanks to the RADIATE Transnational Access[3] by including new clinical cases from Switzerland.

Micro-PIXE has proved to be a valuable tool for mapping the distribution and quantification of metallic particles released from degraded prostheses, helping identify which prosthesis component is causing the failure, and to what extent.

The Micro-beam end station available at Jožef Stefan Institute 2MV tandetrom accelerator is especially suited for this type of research. With a high-brightness (14 A m^{-2} rad^{-2} eV^{-1}) focused proton beam, it allows the reduction of the object-slit aperture and acceptance angle, resulting in a reduced beam size. In addition, its high elemental sensitivity, with a detection limit down to 0.1 µg/g, and a lateral resolution down to 600 nm, makes it especially suited for this type of experiments.

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[1] https://ec.europa.eu/tools/eudamed/#/screen/home

[2] This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 799182.

[3] https://www.ionbeamcenters.eu/radiate/radiate-transnational-access/

METALLACARBORANES FOR PROTON THERAPY USING RESEARCH ACCELERATORS

T. PINHEIRO[1,2], **L.C. ALVES**[1,3], **V. CORREGIDOR**[1,3], **F. MARQUES**[1,3], **F. TEIXIDOR**[4], **C. VINÃS**[4]

[1]*DECN, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*
[2]*Centro de Ciências e Tecnologias Nucleares*
[3]*IBB, Instituto de Bioengenharia e Biociências*
[4]*Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Campus UAB, 08193 Bellaterra, Barcelona, Spain.*

The use of energetic proton beams offers advantages in cancer treatment including tumor confinement, higher LET (linear energy transfer), and higher RBE (relative biological effectiveness). Recently, new drugs with greater selectivity for tumor cells that enable increasing the RBE for protons have been investigated. These new drugs are constituted by carborane boron clusters [1] coordinated by a central metal ion. The presence of B may increase the effect of protons on cell death, due to the $p + {}^{11}B \rightarrow 3\alpha$ nuclear fusion reaction, with a resonance at 675 keV and a high cross section (1.2 barn). The emitted α-particles have a broad spectrum with a predominant energy of 4 MeV. Due to these characteristics, the reaction has become very attractive in the context of medical applications of proton therapy as emitted α- particles range in water is of the order of a cell dimension.

Herein we report on the impact in the viability of U87 glioblastoma cells treated with Fe carborane (FeC) and its iodinated analogue (I_2FeC) compounds after proton irradiation, as a function of deposited dose. The nuclear microprobe external beam facility at the Van de Graaff accelerator at CTN/IST was used to perform the U87 cell's irradiations. The focused proton beam was scanned over a monolayer of U87 cells seeded in 96-well plates. The energy deposited in cells was tuned to reach the resonance energy of the B nuclear fusion reaction in the cell layer (SRIM simulation: for 30 µm cell layer thickness, medium transmitted energy=470 keV and LET=26 keV/µm [2]).

As the therapeutic effectiveness relies on the cellular amount and distribution of compounds, we have evaluated quantitatively the net Fe uptake in U87 cells. PIXE results showed that the Fe uptake in U87 treated cells were 5-fold higher than the control (non-treated cells).

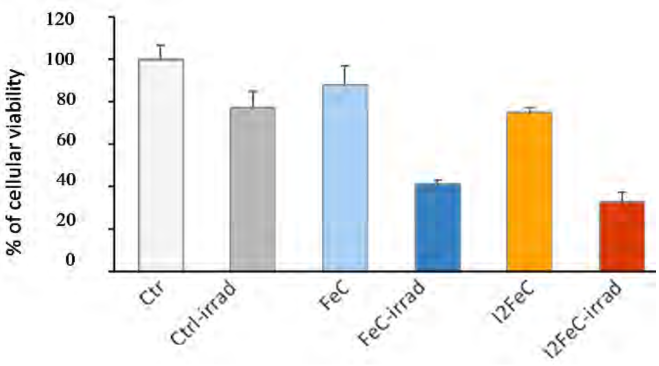

Fig. 1 – Viability of U87 cells under control (Ctr) and treated conditions and their response to proton irradiation for 10s with a dose of 3.7 kGy.

In non-irradiated U87 cells the treatment with FeC and I_2FeC caused a small decrease in viability relative to controls as measured by MTT assay. However, after proton irradiation U87 cells exposed to FeC and I_2FeC compounds showed a 50% increase in lethality contrasting with a 16% increase in irradiated controls as can be depicted in Fig. 1. The magnitude of lethality achieved evidenced the potential of FeC and I2FeC compounds to increase cellular killing following proton irradiation.

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DOSIMETRIC VERIFICATION OF RADIOTHERAPY TREATMENT PLANNING SYSTEM USING THORAX PHANTOM

R. KHATUN
Medical Physics Division, Atomic Energy Centre, Dhaka, Bangladesh

S. AKTER
Medical Physics Division, Atomic Energy Centre, Dhaka, Bangladesh

S. M. E. KABIR
Delta Hospital Ltd, Tolarbag, Mirpur, Dhaka, Bangladesh

A. N. Monika
Institute of Nuclear Medical Physics, Dhaka, Bangladesh

M. M. Rahman
Accelerator Facilities Division, Atomic Energy Centre, Dhaka, Bangladesh

M. M. Ahasan
Bangladesh Atomic Energy Commission, Dhaka, Bangladesh

Background: Quality Assurance (QA) in radiotherapy treatment planning process is essential to ensure that the dose calculation is performed correctly and to minimize the possibility of accidental exposure. Reduction of errors and uncertainties plays an important role in the outcome of radiotherapy treatment. Based on clinical dose-response curves, the overall accuracy of the dose delivery should be less than 5% [1–3]. In order to achieve that goal a number of task groups over the past several years have developed guidelines and protocols for systematic QA of radiotherapy treatment planning systems (TPSs) [4,5]. The purpose of this study is to verify the Treatment Planning System (TPS) i.e. to verify the Hounsfield units (HU) to relative electron density (RED) conversion curve stored in the TPSs and hence to observe the range of deviations between planned and delivered doses.

Materials and Methods: The study was conducted in the radiotherapy departments of Delta Hospital Ltd., using Linac (True Beam, Varian). An anthropomorphic phantom (CIRS Thorax, Model 002LFC) was scanned twice with a computed tomography unit (SIEMENS, Somatom) and treatment plans for seven different test cases involving various beam configurations suggested by the IAEA TECDOC 1583 were prepared on local treatment planning systems (TPSs). The phantom was irradiated following the treatment plans for these test cases and doses in specific points were measured with an ionization chamber (FC-65P) and and DOSE 1 Reference Class Electrometer (IBA). The differences between the measured and calculated doses were reported.

Results: The deviation between the measured and calculated values for all test cases were made with advanced algorithms within the agreement criteria, while the larger deviations have been observed for simpler algorithms. All systems reviewed in this study had generic or TPS manufacturer supplied CT to RED conversion curves. Based on the measurements, we concluded that there were differences of 6-12% in the region of higher electron densities. The acceptance criteria for the difference between the stored and measured values of CT numbers for the same RED were ±20HU. However, it was estimated that this difference in relative electron density affects dose calculation accuracy ~3% (2-3%).

Conclusion: This research helped the users to better understand the operational features and limitations of their TPSs and resulted in increased confidence in dose calculation accuracy using TPSs.

Future Plan: To verify the TPS and to observe the range of deviations between planned and delivered doses of all radiotherapy centers in Bangladesh and hence to make an inter-comparison between them.

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SOCIOECONOMIC IMPACT OF A MEDICAL CYCLOTRON IN KERALA, INDIA

DILSHAD KOTTUPARAMBAN,
ANEES MUHAMMED, RAVITEJA NANABALA, M.R.A. PILLAI,
K.N. SUDHAKARAN NAIR, AJITH JOY

Molecular Cyclotrons Pvt. Ltd., Kochi, India

Positron Emission Tomography (PET) has applications in oncology, cardiology, and neurology. As per the IAEA data (IMAGINE), the number of PET scanners available per million is more than three in higher income countries, however, in India it is presently less than one. Local availability of radiopharmaceuticals is the key factor in promoting the investment on PET-CT machines. In this study we analyse the role of proximity of a medical cyclotron in the growth of PET-CT centres in the state of Kerala, India.

The first PET-CT machine in Kerala was installed in 2008 which functioned using radiopharmaceuticals procured from Mumbai and then from Bangalore, both transported by flight. The installation of an 11 MeV Siemens HP cyclotron was initiated in Kochi, Kerala in 2015 and by the same time another four PET-CT machines were installed in Kerala anticipating local supply. The cyclotron was licensed for operation in 2017 and within four years the number of PET scanners in the state increased to 16 including a PET-MR (Fig.1). The location of the PET scanners in Kerala is given in Fig. 2.

As per a recent report, approximately 23,000 new cancer cases are registering every year in Kerala [1]. The total number of living cancer cases in the state could be over 150,000. These patients will need at least one PET-CT scanning per year as part of staging, therapy evaluation, restaging and recurrence evaluation. However, the present number is about 40,000 as deduced from the supply of radiopharmaceuticals. Hence, there exists a large gap even today with the current availability of PET-CT scanners in the state.

As per the records of Atomic Energy Regulatory Board (AERB) there are 297 PET-CT scanners in India (0.22 scanner per million population). Kerala is in the second position regarding the availability of PET-CT scanners (0.45 scanner per million population) and is far above the national average when union territories are excluded.

The radiopharmaceuticals from the Molecular cyclotron facility are transported to hospitals within 250 km by road which takes a maximum of 4 hours at a cost which is about 40-50% of what was prevailing when the medicine was brought from other states. Local and reliable availability of FDG had a big impact in the cost of PET-CT scan which almost halved. While ten years back most patients from the state were going to Bangalore or Mumbai for PET-CT scan, a hospital facility offering this service is available within 50 km from the residence for all patients resulting in enormous cost reduction in travel, stay and cost of PET-CT. The real impact was that the oncologists started relying more on PET-CT for patient management thereby percolating the benefits of PET-CT scan to more needy patients.

Establishment of the cyclotron in the state of Kerala brought significant growth in practice of nuclear medicine in Kerala. As per IMAGINE, Kerala requires at least 35 PET-CTs to reduce inequities in access to diagnostic nuclear medicine. This number is expected to be achieved within three years in Kerala and will grow further. A second cyclotron facility is under planning to cater to the enhanced demand of radiopharmaceuticals.

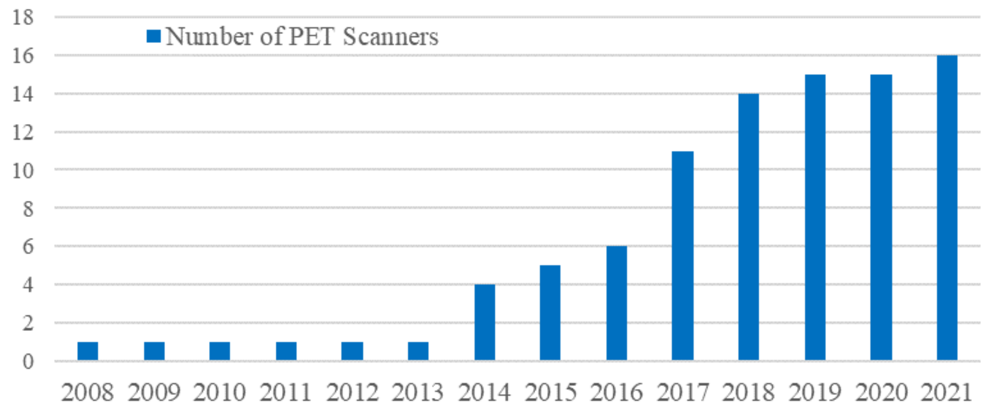

FIG. 1. Year-wise gradual increase in the number of PET scanners in the state of Kerala

FIG. 2. Location of PET scanners and cyclotron facility in the state of Kerala

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CURRENT STATUS AND PERSPECTIVES OF CYCLOTRONS FACILITIES IN BRAZIL AND THE SOCIOECONOMIC IMPACT

CARVALHO, SAMIRA
Brazilian Commission of Nuclear Energy, Rio de Janeiro / Brazil

In Brazil, as has been occurring worldwide, the number of procedures using radiopharmaceuticals is increasing. The production and selling of short half-life radioisotopes used to be a monopoly of the Brazilian Government. In 2006, a Constitutional Amendment revoked the state monopoly due to the need for the use of short half-life radioisotopes in nuclear medicine centers very far from the government production facilities. This study aims to describe the current status and perspectives of cyclotron facilities in Brazil and discuss the socioeconomic impact.

Currently, there are 17 cyclotrons facilities for medical radioisotope production in Brazil. Of which 13 are operating, 3 are under construction, 1 started the decommissioning process. There is a lot of equipment concentrated in the Southeast and no cyclotrons operating in the Northern part of the country. The other socioeconomic impact is the same concentrations of nuclear medicine centers in the Southeast, which hinders the access of the population from more distant regions to the treatments available in the nuclear medicine centers.

There are 4 cyclotrons located inside the university's campuses with a focus on research and development, but also to meet the demand for nuclear medicine in the region. Due to the high cost of these installations, the hybrid model, with research development and commercial focus, has been applied in Brazil.

Most cyclotrons facilities are dedicated to 18F-FDG or 18F-PSMA production, but a few facilities are producing other radioisotopes such as 11C, 68Ga, and 123I. The facilities are investing in moderns equipment and approaches looking to improve the development of new radiopharmaceuticals in Brazil. With this objective, many facilities maintain research agreements with universities with a focus on training new professionals and developing new molecules.

The perspective for the future is the increase in the number of cyclotrons aiming to serve the most distant regions and expanding the nuclear medicine in the country through the development of new radiopharmaceuticals.

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CURRENT STATUS OF THE DEVELOPMENT OF COMPACT ACCELERATOR-BASED NEUTRON SOURCE DEVICES FOR BORON NEUTRON CAPTURE THERAPY IN THE WORLD

Hiroaki KUMADA,

1 Tsukuba University, 1-1-1, Tennodai, Tsukuba, Ibaraki, 305-8575, Japan

Boron neutron capture therapy (BNCT) has attracted attention in recent years as a treatment for intractable cancers. To perform this therapy, a high-intensity neutron source is required. Hence, clinical trials of BNCT have been conducted using research reactors so far. The recent remarkable advances in technology for the compact accelerator-based neutron source enabled us to realize the "accelerator-based BNCT" instead of the "reactor-based BNCT". When the accelerator based BNCT is realized, patients become to be able to receive the therapy in hospitals in the world. In addition, the device can be regulatory approved, allowing BNCT to change from the clinical study stage to the insurance treatment stage.

At present, many development projects for the accelerator based BNCT are in progress worldwide. However, the major specifications of the device, such as the type of accelerator, the energy of charged particles, and the neutron target material, have not yet been optimized. Thus, various approaches for the accelerator-based neutron source are being carried because the combination of several devices constructing an accelerator-based neutron source has not been optimized. For the type of the accelerator, cyclotron, linac, and electrostatic accelerator have been adopted. Regarding target material, beryllium or lithium are being combined. Fig.1 shows a schema of accelerator based BNCT device.

Japan is ahead in this field of R&D, commercial-based treatment devices are being produced. The top runner of the development is Sumitomo Heavy Industry Co. They have succeeded to manufacture a cyclotron-based epithermal neutron source for BNCT named "Neu-Cure". The device adopted beryllium as a target material. Three devices had been installed in hospitals and institutes in Japan, clinical studies for head-and-neck cancer and malignant brain tumor had been implemented. The first clinical study for head-and-neck cancer had been conducted at Kyoto University by using a Neu-Cure in 2012. The clinical study of Phase 1 and Phase 2 had been conducted until 2019, and finally, the device had been regulatory approved in 2020. At present BNCT against recurrent head-and-neck cancer became to be received with the insurance medical care system in Japan. It is expected that the device will be approved for recurrent malignant brain tumor and malignant meningioma also in the near future. In National Cancer Center Hospital in Tokyo, a clinical study for superficial cancer including malignant melanoma is being currently performed by using a linac-based neutron source manufactured by CICS Co. a venture company for BNCT. This device combines lithium as a neutron target material and is the only device that combines a linac as a proton accelerator in the lithium target devices. iBNCT project team headed by University of Tsukuba has been developed a demonstration device of a linac-based BNCT device named "iBNCT001". For accelerator of iBNCT001, a linac consists of an RFQ and a DLT has been adopted. The device accelerators protons of average current of 2 mA to 8 MeV and generate neutrons by irradiating the protons to a thin beryllium target. The results of several characteristic measurements indicated that the device has generated currently the highest intensity neutrons in the accelerator based BNCT device. Non-clinical test just began to perform using the device in the Autumn of 2021. The project team plan to conduct clinical study with actual patient as soon as possible based on the results of the non-clinical test. Nagoya University is also developing an electrostatic accelerator-based neutron source.

Outside Japan also, many developments for the accelerator based BNCT device are being carried out. Neutron Therapeutic Inc. as a venture company in the USA has been developed an electrostatic accelerator based BNCT device, and the first device has been installed in Helsinki University hospital in Finland and clinical study by using the device is planned. The second device of the company is being installed currently to a private hospital in Japan. TAE life science, a venture company in the USA is also developed an electrostatic accelerator-based neutron source for BNCT. They have a very international activity. In the development of the device, they have employed basic technology of an accelerator in Russia. And the first treatment device is being installed in China. The clinical study using this device is expected to begin in the near future. The second device of TAE has been announced to be installed in an institute in Italy. In addition, unique devices for accelerator based BNCT device is also being developed in Argentina, South Korea, and Chine, respectively.

In this presentation, an overview of BNCT and its history will be given briefly, and the developments for the accelerator based BNCT device that are currently being implemented around the world and the future prospects of the field will be introduced.

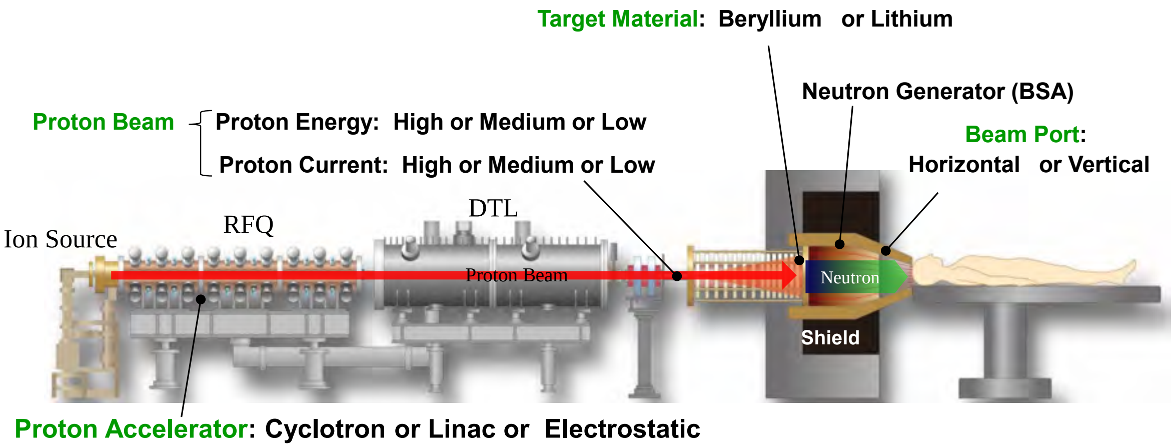

Fig.1 Shema of accelerator-based neutron source device for BNCT

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USE OF ACCELERATORS TO PRESERVE CULTURAL HERITAGE OBJECTS AND DETECT FORGERIES.

Lucile Beck

LMC14, LSCE/IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay - Gif Sur Yvette, France

In the last decades, technological developments of the Ion beam Analysis (IBA) and Accelerator Mass Spectrometry (AMS) techniques have expanded the field of applications allowing to contribute to the preservation of cultural heritage objects as well as the detection of art forgeries.

In this talk, examples of the use of the nuclear and isotopic techniques for the preservation of museum objects and the attribution of artworks will be presented.

In an extensive study of ancient Egyptian musical instruments, AMS ^{14}C was used not only to date them, but also to document their history from their discovery at the beginning of the 19^{th} century to their present preservation conditions in the museums (*Quiles et al., Radiocarbon 63, 2021*). It was thus possible to distinguish original pieces from later restorations for a better knowledge of their production as well as for their presentation in an exhibition on ancient music.

For the restoration of a Japanese folding screen composed of metal plates, IBA determined the composition of multiple complex copper alloys used for the colored decoration. The analysis results helped the curator and restorer to determine the appropriate and safe cleaning procedures (Pacheco et al., in preparation).

IBA and AMS also contribute to detect forgeries (*Calligaro et al., Appl. Phys.A 94, 2009*; *Xihuitl, le bleu éternel, catalogue, 2011*; *Caforio et al., Eur. Phys. J. Plus 129, 2014*; *Hendricks et al., PNAS 116, 2019*). AMS radiocarbon dating was applied to Impressionist paintings of the beginning of 20th century, in the context of a police investigation. ^{14}C measurements show that the plants used to make the canvas were harvested after 1955, that is to say at least 10 years after the death in the 40s of the alleged artists, revealing that the paintings are recent forgeries (*Beck et al., accepted in FSI*).

Finally, ^{14}C AMS demonstrated the misattribution of the Flora bust of the Bode-Museum (Berlin) to Leonardo da Vinci (*Reiche et al., Scientific Reports, 2021*).

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BEST PRACTICES IN ESTABLISHING AND RUNNING ACCELERATOR FACILITIES TO SUPPORT RESEARCH, EDUCATION, AND COMMERCIAL USES

AERIAL: AN EXAMPLE OF A JOURNEY TOWARDS INNOVATION IN THE RADIATION PROCESSING INDUSTRY

Florent Kuntz and Alain Strasser

Aerial, 250 Rue Laurent Fries, 67400 ILLKIRCH GRAFFENSTADEN (France)

The radiation processing industry has changed over the past 35 years of Aerial's existence. In order to be better, more efficient, faster, healthier, more environmentally friendly, innovation and education are clearly needed.

Moreover, to cope with the growing market, especially for the sterilization of medical devices and food irradiation including phytosanitary application, even if all irradiation modalities are still needed today, there is currently a clear trend to evolve from industrial irradiators based on radioactive sources (60Co) to X-ray and electron beam irradiators using accelerators.

The relevance of Aerial's model to implement a specific facility dedicated to innovation in the field of radiation processing was confirmed by a feasibility study conducted by international experts. The needs were assessed through audits of radiation processing companies, users of the technology, laboratories and universities on a local, regional, national and international level.

It was concluded that high energy / high power electron beam and X ray flexible and "industrial– like" irradiation facility would contribute to answer the main requirements. This is where the journey began.

After the encouraging results of the feasibility study, the equipment and the building (an investment of about 10 M€) were co-financed within the framework of an international attractiveness program of the city of Strasbourg - France. Numerous meetings were necessary to convince and collect funds from the European Union, the French State, the Grand-East Region, the City of Strasbourg as well as from our industrial partner IBA.

The success of this project is based on 4 inseparable and complementary pillars:

- the originality and success of Aerial, a French model of Technology Resource Center, an independent structure with a dual research-enterprise culture (private non-profit research organization), with a clearly stated vocation of research and development and training and not aiming at industrial processing.
- the experience of more than 35 years of the Aerial team, its multidisciplinarity and the interdisciplinarity necessary to approach the various subjects concerning the industrial applications of radiation treatment with a special focus on dosimetry and process control.
- A very good timing for the project in accordance with a major international event in the field: the organization of the IMRP19 conference in Strasbourg-France.
- The reinforced international recognition of Aerial by its designation since 2016 as an IAEA collaborating center.

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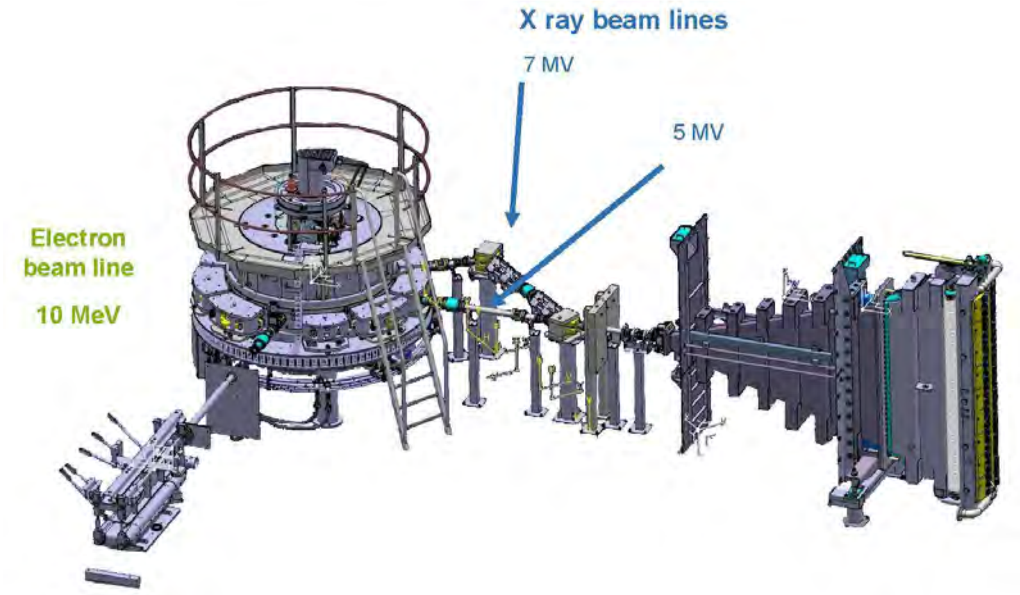
The "feerix" facility, setup in 2019, is an industrial like, novel and unique high energy and high-power irradiation plant with its multiple beam lines producing 10 MeV electrons and 5 and 7 MV X-rays.

It is a complementary tool to Aerial's existing laboratories and platform of irradiation facilities based on electron accelerators for tests, R&D and training purposes on radiation applications, innovative approaches of irradiation process control and on high dose dosimetry.



The first two years of operation of the facility have confirmed its relevance for innovative projects in the field of industrial radiation processing: the good idea quickly turned into a "real good idea".

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REVIEW OF THE DIFFERENT ACCELERATOR BASED-BNCT FACILITIES WORLDWIDE AND AN ASSESSMENT ACCORDING TO THE ALARA CRITERION.

M.E. CAPOULAT and A.J. KREINER
CNEA-CONICET, San Martín, Argentina

Presently, there are a number of different facilities for Accelerator-Based BNCT (AB-BNCT) worldwide, some already working and even treating patients and some under development and construction. They range from high-energy 30 MeV cyclotrons (using the ^{9}Be(p,n) reaction), medium-energy RFQ-DTL accelerators (at 8 and 10 MeV using likewise the ^{9}Be(p,n) reaction), low-energy electrostatic, both Tandem and single-ended, and RFQ machines (working on ^{7}Li(p,n) at about 2.5 MeV), to a very low-energy electrostatic quadrupole accelerator (working on ^{9}Be(d,n) or ^{13}C(d,n) at 1.45 MeV). We shall briefly describe this last accelerator which is being developed at the National Atomic Energy Commission of Argentina.

In this presentation we will analyze and discuss these installations from the point of view of activation, both at the target and beamline (by the primary beam + neutrons) and also at the level of the Beam Shaping Assembly and other exposed materials in surrounding areas (by neutrons). Since these facilities are intended to work in hospital environments one of the guiding criteria should be the ALARA (As Low As Reasonably Achievable) one. We have followed the IAEA RS-G 1.7 Safety Guide, Application of the Concepts of Exclusion, Exemption and Clearance**,** which recommends limits on the specific activities produced (in Bq/g), to assess the long-term operation sustainability from the point of view of activation.

A thorough analysis using MCNP simulations on the basis of the existing data bases is made evaluating the residual radioactivity produced both by the primary beam and induced nuclear reactions at the target and beam line, and also by the generated neutrons in the surrounding areas like Beam Shaping Assembly, shielding materials and patient treatment room.

We have analyzed the production of residual radioactivity in a representative group of AB-BNCT facilities, mainly for two subsystems: 1. Activation of the target due to the primary beam (p or d). 2. Activation of the Beam Shaping Assembly (BSA).
In particular we present in Table 1 results for the induced target activity (accumulated over 1 year operation) due to primary nuclear reactions at the target.

TABLE 1. INDUCED RADIOACTIVITY IN THE RESPECTIVE TARGETS FOR THE LISTED REACTIONS AT INDICATED BEAM ENERGY AND CURRENT

^{7}Li+p 2.3MeV 30mA	^{9}Be+p 8MeV 10mA	^{9}Be+p 30MeV 1mA	^{9}Be+d 1.45MeV 30mA	^{13}C+d 1.45MeV 30mA
5.7TBq/y (7Be)	Only prompt radiation	1.2TBq/y(7Be) 51GBq/y (tritium)	54GBq/y (tritium)	9.3GBq/y (tritium) 8GBq/y (^{14}C)

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There are other sources of residual radioactivity that have been analyzed here:

(a) Target Backing materials & target assembly: e.g., Copper. Several exothermic and low-threshold neutron-induced reactions generate intermediate and long-lived radionuclides (e.g., ^{64}Cu: $T_{½}$ =12.701 h, ^{63}Ni: T ½ =101.2 y, ^{60}Co: T ½ =5.272 y, etc.).

(b) Beamline and accelerator parts (especially for intermediate and high energy beams): Proton scattering on the residual gas. Beam energies are higher than Coulomb Barriers of several elements of the beamline leading to activation (e.g., Copper: ^{65}Cu(p,n)^{65}Zn, T ½ =243.93 d).

This paper contributes to an optimization and assessment of the sustainability of different facilities, particularly considering that they are intended to work in hospital environments.

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ACCELERATOR BASED NEUTRON SOURCE FOR BORON NEUTRON CAPTURE THERAPY AND OTHER APPLICATIONS

S.Yu. TASKAEV

Budker Institute of Nuclear Physics, Novosibirsk State University
Novosibirsk, Russian Federation

A neutron source comprises an original design tandem accelerator, solid lithium target, a neutron beam shaping assembly, and is placed in two bunkers as shown in Fig. 1. The facility has the ability to place a lithium neutron producing target in 5 positions; in Fig. 1, they are marked as positions *A*, *B*, *C*, *D*, *E*.

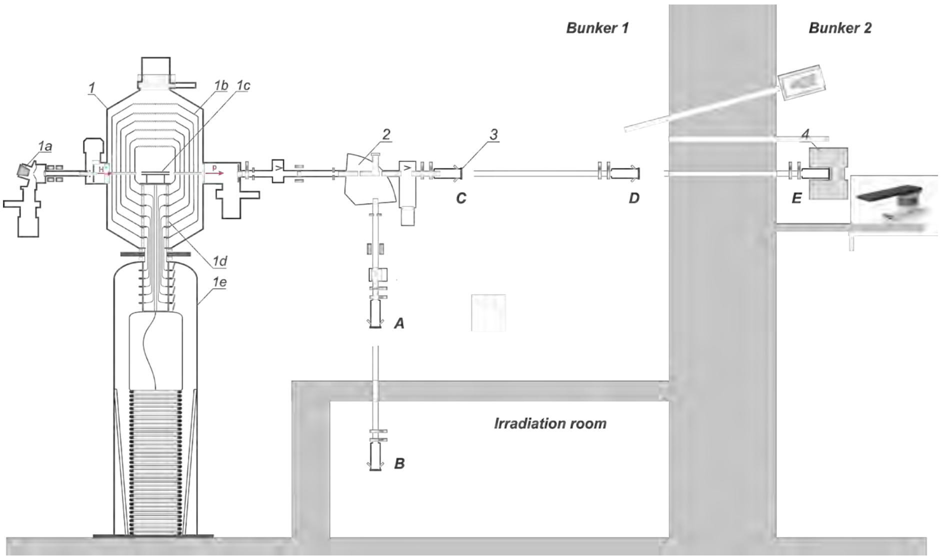

FIG. 1. Layout of the experimental facility: 1 – vacuum-insulated tandem accelerator (1a – negative ion source, 1b – intermediate- and high-voltage electrodes, 1c – gas stripper, 1d – feedthrough insulator, 1e – high-voltage power supply), 2 – bending magnet, 3 – lithium target, 4 – beam-shaping assembly. A, B, C, D, E – lithium target placement positions.

In order to generate a high-current, low-energy proton beam, a DC tandem accelerator is used. The BINP tandem accelerator, which was named as Vacuum-Insulated Tandem Accelerator (VITA), has a specific design that does not involve accelerating tubes, unlike conventional tandem accelerators. Instead of those, the nested intermediate electrodes (*1b*) fixed at a feedthrough insulator (*1d*) is used, as shown in Fig. 1. The advantage of such an arrangement is moving ceramic parts of the feedthrough insulator far enough from the ion beam, thus increasing the high-voltage strength of the accelerating gaps given high ion beam current. A consequence of this design was also a fast rate of ion acceleration – up to 25 keV/cm. The proton beam energy can be varied within a range of 0.6–2.3 MeV, keeping a high-energy stability of 0.1%. The beam current can also be varied in a wide range (from 1 pA to 10 mA) with high current stability (0.4%). The tandem accelerator is also capable of generating a deuteron beam with similar characteristics. The proton beam was used to study the radiation blistering of metals [1], to study the effect of blistering on the neutron yield from a lithium layer deposited on a metal [2], and is planned to be used for in-depth investigation of the promising $^{11}B(p,\alpha)\alpha\alpha$ neutronless fusion reaction.

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Lithium target 10 cm in diameter has three layers: a thin layer of pure lithium to generate neutrons in ^{7}Li(p,n)^{7}Be or ^{7}Li(d,n) reactions; a thin layer of material totally resistant to radiation blistering; and a thin copper substrate for efficient heat removal. This target provides a stable neutron yield for a long time with an acceptably low level of contamination of the beam transport path by the inevitably formed radioactive isotope beryllium-7.

The facility is capable of producing:

— epithermal neutrons for boron neutron capture therapy (BNCT) [3] using magnesium fluoride moderator
— cold neutrons for neutron diffraction using heavy water ice;
— thermal neutrons for BNCT developing [4] and for measuring hazardous impurities in ITER materials [5] using plexiglas moderator
— monoenergetic neutrons for calibrating a dark matter detector and for boron imaging by prompt γ-ray spectroscopy using kinematic collimation
— fast neutrons in ^{7}Li(d,n) reaction [6] for radiation testing of materials developed for ITER and CERN
— 478 keV photons in ^{7}Li(p,p'γ)^{7}Li reaction [7] and 511 keV photons in ^{19}F(p,αe^+e^-)^{16}O reaction for *in situ* measuring the lithium layer thickness [8] and for determining the doses of high-LET radiation [9]
— α-particles in ^{7}Li(p,α)α and ^{11}B(p,α)αα reactions
— positrons in ^{19}F(p,αe^+e^-)^{16}O reaction.

This neutron source is considered as one of the most attractive sources of neutrons for BNCT in an oncological clinic. The first facility was installed in a clinic in Xiamen (China), in one of the first six BNCT clinics in the world. The manufacture of two more neutron sources began this year: for National Oncological Hadron Therapy Center (CNAO) in Pavia, Italy, and for National Medical Research Center of Oncology in Moscow, Russia.

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X-RAY INVESTIGATIONS ON ANCIENT GOLD COINS: SYNCHROTRON RADIATION CONTRIBUTION TO HISTORY AND NUMISMATICS

I. CARLOMAGNO, M. AMATI, P. ZELLER, G. AQUILANTI

Elettra Sincrotrone Trieste, Trieste, Italy

G. MARUSSI, M. CROSERA, B. CALLEGHER

Università di Trieste, Trieste, Italy

E. PRENESTI

Università di Torino, Torino, Italy

G. ADAMI

Università di Trieste, Trieste, Italy

X-rays are an excellent investigation tool in the field of cultural heritage, this is mainly due to their capability of yielding fine details about chemical and structural information of a sample without damaging its integrity [1-4]. Synchrotron Radiation (SR) sources offer additional advantages to the X-ray techniques carried out with laboratory sources: the tuneable photon energy and the high photon flux provided by synchrotrons allow one to optimise the sensitivity to a given element while pushing the detection limits down to the ppm range. These characteristics enable to detect and quantify trace elements in artefacts. From such quantification, insightful details on the materials employed in the fabrication and on the fabrication process itself can be obtained.

In this work, four gold coins dated back to the Roman Empire (IV - V century) were studied with X-Ray Fluorescence (XRF) and X-ray Absorption Near Edge Spectroscopy (XANES), both carried out at XRF beamline, at Elettra Sincrotrone Trieste.

XRF was used to investigate the elemental distribution on the surface of each coin, discriminating between the composition of the metallic alloy and that of successive deposits due to the burial period. A fine analysis of the SR-XRF spectra was performed to assess the small variation in Au purity among the four coins. Such variation, analysed as a function of the time of coinage, provides insight on the inflation or devaluation dynamics in the ancient coinage. Additional details were then gained from the study of the contaminants. Indeed, indications about the Au purification processes and the geographical location of the Au mine are enclosed in the chemical composition and in the relative abundance of such elements. Thanks to the high sensitivity of SR-XRF, a precise quantification of trace elements like Pt, Pd, Ag, Hg, Cu, and Zn could be carried out, enabling historians and numismatics to reconstruct not only the methodologies employed in ancient metallurgy, but also to gain details about the geographical location of the mines, coinage processes, and gold purification methods.

XANES was employed to assess and quantify the phases of Fe, Zn, and Cu present on the coin surface. In the case of Fe, once identified the different oxides present in the sample, their relative abundance can be used to evaluate the geographical provenance of the burial soil. Indeed, the formation of the Fe phases is regulated by temperature and water activity, both indications of geographical areas [5].

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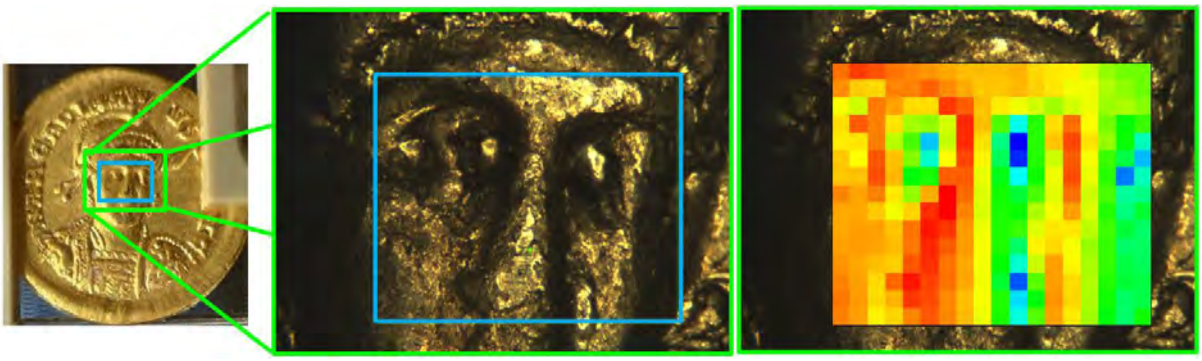

FIG. 1. (left) Recto of one of the four samples investigated, (center) magnified area of the coin surface: the blue square marks the region where XRF maps have been carried out, (right) SR-XRF map of the selected area is superimposed to the optical image.

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SYNCHROTRON RADIATION BASED INVESTIGATIONS OF COLORED LAYERS , BINDING MATERIALS AND RESINS OF THE GOD PTAH-SOKAR-OSIRIS WOODEN STATUETTE AND ITS MUMMIFIED FALCON WHICH ARE DATING BACK TO 26TH PHARAONIC DYNASTY.

Dina Mohamed ATWA KHALIL

The Grand Egyptian Museum – Conservation Center, Giza, Egypt

Abstract:
The main goal of this work was to study the colour palette of a polychrome wooden statuette of the God Ptah –Sokr- Osiris from 26th dynasty of ancient Egypt. Analysis of painted layered materials, preparation layers, resins and linen rolls samples have been performed using synchrotron radiation based μ (FT-IR) and (XRD) techniques. The application of SR techniques provided new and valuable information about the chemical nature of pigments, adhesives and binding materials that used by the ancient maker over other conventional spectroscopic techniques. In an attempt to evaluate the degree of statuette wood degradation, the wood sample was identified using the thin sections with SEM. SEM micrographs of wood allow identifying it as a (*Ficus sycamores*). The preparation layer was proved to be a mixture of calcite and quartz. The chromatic palette used in the statuette was identified as hematite, Egyptian blue, arsenic sulphides, possibly malachite and carbon from charred animal origin. The crystallinity of cellulose has been measured using Segal formula which indicates extreme degradation of the statuette wood. Such study was mandatory in order to set the best strategies for preserving the statuette.

Introduction:
Ancient Egyptian polychrome wooden artifacts have gained much interest in the last decades not only to identity the original materials used by the ancient makers, explain the deterioration processes and establish the strategy of conservation, but also for correlating these results with the archaeological and anthropological studies. The God Path – Sokar – Osiris models appeared at the end of the New Kingdom and became a very common feature of elites' burials through late period until the roman one. (1). Our wooden statuette is composed by two parts, the first part is the body of statuette and its base that have wonderful coloured decorations of gold and colored oxides as we concluded from X- ray fluorescence results (XRF). The second part is the mummified falcon that was decorated with a layer of gold (much of which had fallen) and was preserved in a rectangular cavity covered by a lid, in the base of the statuette. The dimensions of the statuette are 85 cm length and 23 cm shoulder width; it was based on a rectangular wooden base (77 cm, 27 cm, 10 cm). The wooden statuette was carved from a single piece of wood, in the form of God Ptah-Sokar-Osiris with a human face, probably representing the face of the deceased (Figure 1a and 1b).

Figure 2, a,b and c showed the patterns of SR-XRD analysis of our minute samples. Despite of small samples size, we could identify the colored layers clearly. The crystallinity index of cellulose measured to be 66.6 % while the value of standard *Ficus sycamores* is 76.0%.

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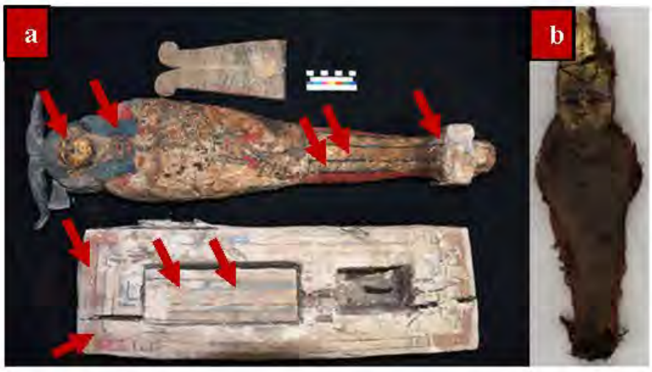


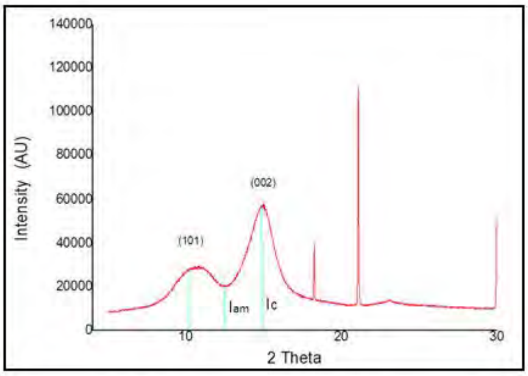
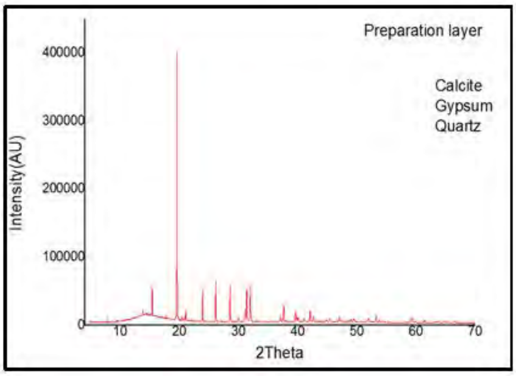
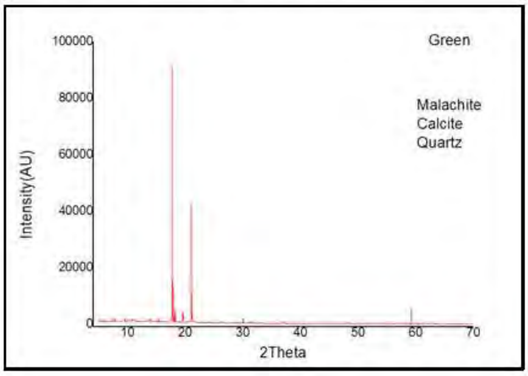


Figure 1a and b represents the images of the object including the positions of the samples.

Figure 2 a,b,c, represents XRD patterns for the sample of wood, preparation layer and green color respectively.





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CHARACTERIZATION OF CULTURAL HERITAGE USING A MICRO-BEAM

V. CORREGIDOR, L.C. ALVES
DECN, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

The use of micro-beams and ion beam analytical techniques to study cultural heritage materials is becoming usual among the scientists. When the proper experimental conditions (for example energy, current or acquisition times) are used, these beams do not induce any radiation damage and, when the measurements are done in open air, the need of sampling can be avoided. The possibility to obtain compositional distributions with high accuracy and without, or minimal, sample surface preparation make them very suitable for the characterization of a wide range of materials.

In the nuclear microprobe available in Lisbon the analyses can be performed in vacuum or in open-air conditions using alpha or proton beams with energies up to ~2.3 MeV [1]. Examples of results obtained in different type of materials such as paper, tiles, paintings or metals will be given (see Fig. 1) and the safe experimental conditions will be discussed.

FIG. 1. Different type of materials (paper with iron-gall ink and metallic object) during the measurements in open-air conditions.

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THE PRACTICE OF ELECTRON AND PROTON ACCELERATORS UTILIZING FOR INDUSTRY, EDUCATION AND SCIENCE

O. V. RIABUKHIN, V. Y. IVANOV, S. S. ZYRIANOV, T. A. MAKSIMOVA

Ural Federal University, Ekaterinburg, Russia

Since 2015 in Ural Federal University the linear electron beam accelerator is functioning for the purposes of radiation sterilization and modification materials, scientific researchers and education. On the base of accelerator, the Radiation Sterilization Center (RSC) was organized with main industry activity in a field of medical devise sterilization. On the present day five main customers are realized procedure of radiation sterilization of single used medical clothes, surgery sets, blood test tubes and other goods at RSC. After six years of activity in this field we can define some critical points for successful operation of facility for radiation technology and where our efforts were made. Regular maintenance and modernization of all installation’s modules (vacuum, high voltage equipment, ventilation, conveyor system and others) needed to be done for reliability providing. Quality management system according to standards of technology should be organized for documenting of radiation sterilization procedure. Dose measurement should be traceable for primary standards of absorbed doses. Regular work with customers for the explaining of radiation sterilization procedure validation should be carried out. In principle that is well known steps but in the specific of countries and used facilities can be realized in different ways.

The scientific and education activities are realized in parallel with industrial work. The construction of RSC allows to irradiate different materials by electrons directly under the beam and with step-by-step accumulation of absorbed dose with using of a conveyor. Moreover, irradiation could be done simultaneously with the main process of radiation sterilization. So, scientific research includes studying in areas of radiation physics, chemistry, biology and focused on condensed matter and biological objects properties changing investigation under the action of E-beam in different modes, determining of velocity and time characteristics of surface and volume modifications. Through the water-cooling system, it is possible irradiate samples without essential increasing of its temperature under the direct electron beam.

Education process at E-beam accelerator realized in two ways. The first one is work with students of bachelor and muster programs. RSC facility is included in regular laboratory works in nuclear physics, applied nuclear physics, Metrology of ionizing radiation, nuclear physics installations and other courses, used for preparation of student’s diploma and scientific research works. The second way is training courses performing. From the 2015 RSC took active part in regional projects of IAEA Technical cooperation projects area of non-power radiation technologies implementation. From 2017 E-beam accelerator with equipment for radiation sterilization became a place for IAEA Regional training courses in a topic of dosimetry measurements. Two courses were carried out in 2017 and 2019, next one is planned in 2023. Besides facility takes part in regular IAEA intercomparison program that allow to estimate the quality of absorbed dose measurements on international level. From 2019 additional training program “Multipurpose irradiation centre as a component in Centre of nuclear science and technologies” started at RSC under Rosatom corporation support. The second one courses will be held in October 2021. The program of courses includes questions of dosimetry basics, measurements of absorbed and equivalent doses and practice on RSC facility.

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The latest activity concern with commissioning of TR-24 cyclotron for the purposes of F-18 and FDG production for supplies to PET centers of Ural region. The same way, as for E-beam accelerator, cyclotron is planned for scientific research, education and training courses realizing. At the present time documentation for GMP – standard providing is actively prepared.

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USE OF ACCELERATORS FOR RESEARCH AND TRAINING IN THE UNIVERSITY ENVIRONMENT

S.H. PARK[1], J. BAHNG[1], B.S. LEE[2], C.S. PARK[1], E.-S. KIM[1]

[1] *Korea University Sejong campus, Sejong, Korea*
[2] *Korea Basic Science Institute, Daejeon, Korea*

Department of Accelerator Science in Korea University Sejong is dedicated to Graduate school curriculum including research and development in the field of accelerator science. Since 2017, compact accelerators are under construction or commissioning for the test and training. First, ECR ion source operating at ~2.45 GHz has been reconstructed for ion mass spectroscopy and/or accelerator-based neutron source. 2 mA of Ar ion at 30 kV of extracting voltage was generated with 0.1% stability for more than 1 hour. Ion beam deflected 90° at an analysing magnet will be accelerated higher energy by an accelerating tube, followed by the second analysing magnet for ion mass spectroscopy. The second beamline deflected 45° at the analysing magnet will be placed with a RFQ, a beam optics for expanding beam size, a Be converter, and a Moderator. The RFQ system is designed for 2.5 MeV deutron or ~3 MeV proton [1] and the design of the target for neutron generation is under way. Main purpose is to develop the more compact and effective neutron source for medical applications.

Secondly, an electrostatic ion accelerator for ion implantation is operational. It consists of a Duoplasmatron for high-current ion beam, an accelerating tube for 150 keV of proton, a diagnostic box, a gate valve and a sample chamber. The doublet optics should be installed next to the gating valve for beam focusing and/or shaping at the sample stage.

The third one is high-power THz free electron laser (FEL) system based on microtron [2], which is in preparation for commissioning. The electron beam can be accelerated from 4 MeV to 7 MeV by adjusting the number of turns before extracted to straight beamline. The extracted electron beam is deflected 90° using three dipoles and the beam optics is optimized to minimize the dispersion effect at the entrance of undulator for FEL. The hybrid-type helical undulator is tuned the deflection parameter K using biased current source instead of changing the gap. The resonator is waveguide mode in vertical direction and free propagating mode in horizontal direction. High power THz is outcoupled in transmissive way. To suppress the diffractive effect a Quartz crystal lens is used for vacuum window. The macro-pulse duration is about 4 μsec having lots of 30 ps micro-pulses separated by 356 ps High power. The macro-pulse is typically operated at 1~3 Hz repetition rate. THz light source is good for R&Ds on a single-shot imaging, a security inspection, THz resonance spectroscopy, and so on. Due to intrinsic property of FEL lasing scheme, the linewidth of THz is less than 10^{-3}. To improve the spectral resolution for fingering of a rotational or vibrational mode of a certain atom or molecule, the linewidth should be reduced further. The Michelson interferometric mode selection system combined the parallel plate waveguide is a candidate in THz spectral range. These compact accelerators are good for training and useful for related applications.

We also have plans to reassemble 50 MeV microtron used as an injector in BESSY and install 50 MeV, sub-ps pulsed electron linac transferred from Pohang Accelerator Laboratory (PAL, Pohang). Fs electron linac is consisted of a photocathode gun, two S-band NC RF accelerators, two chicanes for the pulse compression and the coherent transition radiation (CTR) in THz range. This system will be used for the performance proof-testing of developed equipment and instruments for 4GSR. In near future the central control system will be built for operation and user service.

As for education and training, there is a prototype of RF coupler pair at 325 MHz which was designed, manufactured, and tested [3]. A longitudinal gradient bending magnet in hybrid type and its precise magnetic measurement system is under development. All systems and R&D activities in Department of Accelerator Science will be great resources for the education and training in the world. Beside the regular curriculum in Graduate school, the intensive education and training program has been routinely held for beginners, graduate-level, or personnel in research institutes and/or industries. Asian school for SC RF cavity and Cryogenic system is scheduled if Corvid-19 situation is even out.

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HEAVY ION THERAPY MASTERCLASS SCHOOL AND CAPACITY BUILDING FOR FUTURE ION RESEARCH AND THERAPY FACILITIES

Panagiota FOKA
GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany
CERN, Geneva, Switzerland

Aristeidis MAMARAS
Aristotle University of Thessaloniki Thessaloniki, Greece

The Heavy-Ion Therapy MasterClass School took place, online, between 17th and 22nd of May 2021, for first time (HITM https://indico.cern.ch/event/1019104/), attracting over a thousand participants, from undergraduate students to practitioners. The unexpected and unprecedented high number of participants shows an increasing interest in heavy-ion therapy research and related training. It also demonstrates the enormous potential of the next generation, represented by the young students and early-stage researchers. The main emphasis was on the use of accelerators for the treatment of cancer tumours, highlighting the role of research centres, such as the GSI heavy-ion research centre, where carbon-ion therapy was pioneered in early 90s in Europe.

The main feature of the HITM School was the multidisciplinary approach which stimulated participants, despite the online format. Overview lectures provided the necessary panorama, while focus lectures presented details on medical accelerators and accelerator physics including: Ion sources, Beam optics, Beam delivery systems, Controls, as well as Linear accelerators for isotope production. The scientific programme was shaped to target topics in emerging fields, highlighting the importance of fundamental research in developing new applications in medicine, particularly cancer diagnostics and treatment. The participants feedback clearly demonstrated their appreciation, including the inventive format of the school which is also described in this presentation.

The programme enriched with hands-on sessions focusing on treatment planning, which is the prescription of the therapeutic dose, and related tools. Those were based on the matRad open-source professional toolkit, developed by the DKFZ German cancer research center in Heidelberg, specifically for training and research. Participants, guided by the tutors, used photons, protons or carbon ions to optimise their treatment plans for specific cases. During a video-conference with experts from the CNAO ion therapy centre in Italy, they had the chance to discuss their results, ask questions and enjoy a virtual visit of the accelerator complex and therapy rooms. This was complemented by a virtual visit at the GSI room where some 500 patients were treated with 95% success before the carbon therapy was introduced in the clinics of Heidelberg and Marburg in Germany.

These virtual visits, “from physics to clinics”, clearly highlighted the relevance of fundamental research and its applications for cancer treatment. Participants realised that challenges set by the research projects’ ambitions push high-tech technology which ultimately translates to benefits for society.

The HITM School programme was complemented by social events in the evenings that made a strong impression employing an interactive platform, with different themes every day, spanning from pyjama party and games to a career fair. They provided the feel of real-life interactions while at the same time brought to participants valuable information where institutes such as CERN, CNAO, DKFZ, Cosylab, GSI/FAIR, MedAUSTRON and ENLIGHT presented career opportunities in emerging fields where there is often a lack of specialised personnel. Overall, despite the online format, various interactive methodologies stimulated the typical exchanges in both the lectures and the social events.

The HITM School was organised in the framework of the HITRIplus EU funded project, that received funds from the European Commission's Horizon 2020 Research and Innovation programme under Grant Agreement No 101008548, and is a collaboration between research infrastructures, universities, industry, the four existing European heavy-ion therapy centres, and SEEIIST, the South East European Institute for Sustainable Technologies.

Motivated by the positive response the organisers plan the next one, the HITM School 2022 in the summer 2022, in Thessaloniki, Greece, in person, but also foreseen online participation, through live streaming. Such HITM Schools are expected to support capacity building in preparation for the future ion research and therapy facility planned by SEEIIST, where Greece also actively participates as a full member.

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THE MEDAUSTRON PARTICLE THERAPY ACCELERATOR

Mauro PIVI, Laurids ADLER, Dale PROKOPOVICH, Nadia GAMBINO, Greta GUIDOBONI, Florian KÜHTEUBL, Christoph KURFÜRST, Clemens MADERBÖCK, Szymon MYALSKI, Fabien PLASSARD, Valeria RIZZOGLIO, Claus SCHMITZER, Thomas SCHREINER, Ivan STRASIK, Alexander WASTL, Markus WOLF

MedAustron, Marie Curie Straße 5,2700, Wiener Neustadt, Austria

The MedAustron Particle Therapy Accelerator located in Austria, delivers proton beams in the energy range 60-250 MeV/n and carbon ions 120-400 MeV/n for medical treatment in three irradiation rooms, clinically used for tumour therapy. Proton beams up to 800 MeV/n are also provided to a room dedicated to scientific research. Following beam generation at the ion sources and pre-acceleration, the beam is injected into a 77 m long synchrotron, that accelerates particles up to the required energy for clinical treatment. A 3rd-order resonance slow extraction is used to extract particles from the synchrotron in a controlled process and transfer the beam to 4 irradiation rooms with a spill length 1÷10 seconds, to facilitate the control of the delivered dose to the patient.

Over the last two years, in parallel to clinical operations, we have completed the installation and commissioning of the proton gantry beamline in a dedicated room, with the first patient just recently treated in May 2022. In this manuscript, we provide an overview of the MedAustron gantry beam commissioning including the world-wide first “Rotator” system, a rotating beamline located upstream of the gantry and used to match the slowly extracted non-symmetric beams into the coordinate system of the gantry.

With the recent addition of the Gantry, the MedAustron facility is now fully operational and providing beams in all rooms to patients and to research teams. A review of the facility and future performance and improvement projects is given.

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LIFE CYCLE ASSESSMENT (LCA)

F. ZANINI

Elettra – Sincrotrone Trieste, Basovizza – Trieste, Italy

It is an old motto that 'You cannot manage what you cannot measure', and it is therefore important that we have tools for assessing the sustainability of our choices when we develop solutions or systems that shall help us determine the needs of the present generations without compromising the ability of our descendants to meet their needs in the next future.

As scientists, we must take a life cycle perspective when we want to assess the sustainability of the technologies that lie in front of us. Very often we face problem shifting where solutions that improve or solve a targeted problem unintentionally create new problems of environmental, economic or social nature somewhere else in the systems affected by our choice.

Life Cycle Assessment (LCA) shows all the potential impact of our choices, through the analysis of the whole life cycle of the system or product that is the object of the study and it covers a broad range of potential impacts for which it attempts to perform a quantitative assessment.

Scientists or science managers who develop decision support, or make decisions where sustainability is a concern, should understand the need to view the solutions in a life cycle perspective and to consider possible trade-offs between environmental impacts and between the three sustainability dimensions.

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MULTI-DISCIPLINARY PHYSICS WITH MEV ION BEAMS AT THE LABORATORI NAZIONALI DI LEGNARO USING THE CN AND AN2000 ACCELERATORS

V. RIGATO
INFN-LNL, Legnaro, ITALY

The Laboratori Nazionali di Legnaro is an International Ion Beam Centre with many research programs in fundamental and applied nuclear physics. The laboratory has a pretty large interdisciplinary research equipment inventory developed in the last 6 decades including the two Van de Graaff accelerators dedicated to multi-disciplinary studies with MeV ion beams: the AN2000 (2.2MV) and the CN (6.0MV). The research programs performed with these two accelerators are reviewed and perspectives are presented.

THE IAEA ION BEAM FACILITY (IBF) PROJECT

S. CHARISOPOULOS, N. SKUKAN, A. SIMON, I. P. SWAINSON, R. PADILLA ALVAREZ, A. MIGLIORI, N. PESSOA BARRADAS, K. KANAKI, D. RIDIKAS

Physics Section, Division of Physical and Chemical Sciences,
Department of Nuclear Sciences and Applications, International Atomic Energy Agency,
Vienna International Centre, PO Box 100, A-1400 Vienna, Austria

Due to their unique analytical and irradiation capabilities, ion beam accelerators play a major role in solving problems of modern society related to environmental pollution and monitoring, climate change, water and air quality, forensics, cultural heritage, agriculture, development of advanced materials for energy production via fission or fusion, and many other fields.

In order to assess actual needs and potential impact accelerator technologies could make, a feasibility study for an ion beam accelerator facility at the IAEA laboratories in Seibersdorf was performed. Forty Member States took part in questionnaire and quantified their needs. Their evaluation showed high demand in training in accelerator technologies and associated Ion Beam Analysis (IBA) techniques, as well as in analytical services in almost all areas of IBA applications. An appropriate accelerator design, matching the IAEA's programme for capacity building and provision of products and services across many fields of interest for the Member States, was identified.

The main objective of the Ion-Beam Facility (IBF) project is to establish a state-of-the-art accelerator facility at the IAEA laboratories in Seibersdorf to cover the identified Member States' needs for training scientists and engineers in operating and applying ion beam accelerator technologies and to provide a range of associated services. The expected outcome of the project is to enhance the capacity and capability of the IAEA to address the rising demand of Member States to provide assistance in promotion of applied research using accelerator technologies for a large variety of medical and industrial applications.

Details on the feasibility study, the instruments, and facilities to become available through the IBF project, including preliminary estimates of the resources, will be presented.

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DEVELOPMENT AND APPLICATIONS OF THE SECONDARY ION MASS SPECTROMETRY WITH MEV IONS (MEV SIMS) TECHNIQUE AT THE RBI ACCELERATOR

I. BOGDANOVIĆ RADOVIĆ, M. BARAC, M. BRAJKOVIĆ, D. COSIC, M. JAKŠIĆ, M. KRMPOTIĆ, Z. SIKETIĆ, T. TADIĆ

Ruđer Bošković Institute, Division of Experimental Physics, Bijenička 54, 10000 Zagreb, Croatia

In 2013, the first experimental setup for the Secondary Ion Mass Spectrometry with MeV ions was installed at the RBI heavy ion microprobe [1]. The setup is based on a linear TOF spectrometer and a pulsed ion beam. It is the first accelerator based IBA technique at the RBI that can provide information about molecular composition of the analysed samples.

MeV SIMS is a surface sensitive technique where molecules are desorbed only from the uppermost layers. Use of MeV instead of keV ions ensures less fragmentation and detection of intact molecules, which facilitates the interpretation of the obtained mass spectra. So far, we have successfully applied MeV SIMS in biology for the molecular imaging of liver tissue and single cells at the submicron level [2], in cultural heritage for the identification and 2D imaging of synthetic organic pigments [3], and in forensics for the determination of the deposition order of different writing tools [4].

To overcome some of the limitations related with ion beam handling, as well as with the maximal sample sizes, a capillary microprobe was recently built at the zero-degree beam line [5] where heavy ions are collimated to the micron dimensions with a conical glass capillary. Also, a reflectron type TOF spectrometer was used, allowing for much better mass resolution than a linear TOF. As the secondary molecular ion yield strongly depends on the electronic stopping power, it is clear that the use of heavier ions, such as I or Au, with energies up to 30 MeV will make the technique more sensitive. The most important results obtained by both TOF setups will be presented and discussed.

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APPLICATIONS OF PROTON INDUCED X-RAYS AT THE TANDEM ACCELERATOR LABORATORY OF NCSR "DEMOKRITOS"

A.G. KARYDAS, M. AXIOTIS, A. LAGOYANNIS, S. HARISSOPULOS

Inst. of Nuclear & Particle Physics, NCSR Demokritos, 153.10 Aghia Paraskevi, Athens, Greece

At the Tandem accelerator laboratory of the National Centre for Scientific Research (NCSR) "Demokritos", energetic (1-3 MeV) proton beams have been used for elemental analysis (Particle Induced X-ray Emission-PIXE), and to generate quasi monochromatic X-rays through the irradiation of pure targets with high beam current (≈few hundreds of nA) and the use of appropriate filters [1].

The standard PIXE analysis with ≈1 mm^2 beam size was employed mainly in the external ion-beam set-up by analyzing ancient/historical materials and artifacts such as glass beads, glazed ceramics, historical icons and contemporary paintings [2, 3]. From a different angle and analytical objectives, the quasi-monochromatic X-rays induced by protons have been exploited towards their use for selective XRF analysis and for the experimental study of atomic processes and X-ray interactions with matter [4, 5]. The paper presents an overview of X-ray spectrometry applications using proton induced X-rays at NCSR 'Demokritos" Tandem accelerator laboratory and discusses future perspectives in view of the upgrade instrumentation program currently in progress [6].

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SIX DECADES OF RESEARCH AND DEVELOPMENT WITH ACCELERATORS IN THE DEPARTMENT OF INTERACTION OF RADIATION WITH MATTER OF THE BARILOCHE ATOMIC CENTER

R. O. BARRACHINA

Bariloche Atomic Centre, National Atomic Energy Commission Bariloche, Argentina

In 1960, Prof. Wolfgang Meckbach (1919 – 1998), together with an enthusiastic group of young researchers, technicians, and advanced students, created the first "Ion Beam Laboratory" of Argentina at the Bariloche Atomic Center, dependent on the National Atomic Energy Commission. In this communication we will describe the rich history of scientific research, applications and education and training of human resources, that occurred during the last sixty years of existence of the "Department of Interaction of Radiation with Matter" (DIRM), such is its current name. A special chapter of this story relates to its links with other laboratories, especially in Chile and Brazil at a regional level, and in Germany, Hungary, and the USA, among others. We will also describe the continuous and sustained incorporation of new facilities both for basic research in Atomic, Molecular, and Surface Physics, and for the compositional and structural characterization of samples, with applications in branches such as archaeology, biology, environment, forensic science, analysis of materials for nuclear and non-nuclear use, medicine, nanotechnology, and others. Currently, the DIRM laboratory counts with two electrostatic accelerators of 100 and 300 keV, and a 1.7 MeV tandem accelerator with PIXE, RBS, ERDA, NRA and channelling capabilities, and a chamber for COLTRIMS reaction microscopy. One of its beam lines is dedicated to the analysis of materials and the implantation of ions, with micro beam capacity, with prospects of incorporating a WDS installation. There is also a time-of-flight system for ISS spectroscopy, surface analysis facilities with AES, UPS, XPS, EELS, ISS, DRS, LEED and GIFAD capabilities, and STM and AFM microscopes. Finally, it should be mentioned that DIRM is a member of the Global Network for the Atomic and Molecular Physics of Plasmas (GNAMPP) and the Coordinated Research Project G42008 for "Facilitating Experiments with Ion Beam Accelerators" of the International Atomic Energy Agency.

AGILE REGULATORY OVERSIGHT: ADAPTING REGULATIONS TO ACCOMMODATE RAPIDLY CHANGING ACCELERATOR TECHNOLOGY

M. HEIMANN
Canadian Nuclear Safety Commission, Ottawa, Canada

Canadian nuclear facilities of all types are migrating from nuclear substances to accelerator-based facilities, mirroring the trend first observed in the medical sector in the 1980's and 90's. This shift has been motivated by the need for more flexible and higher throughput facilities, as well as a desire to move away from nuclear-substance-based facilities that require more onerous security requirements. In order to meet this demand, accelerator manufacturers are devising increasingly novel designs and applications, sometimes testing the limits of the current regulatory system.

The Canadian Nuclear Safety Commission (CNSC) is currently in the process of proposing amendments to the regulations which govern the use of particle accelerators in Canada. The intent is to provide modernized and flexible regulations, which will not unnecessarily restrict or hinder innovation in the nuclear industry, while still ensuring that these facilities continue to operate in a safe and secure manner.

This presentation will describe some of the novel new applications of accelerators in Canada, and provide a high level description of the proposed new methods the CNSC is considering in the regulation of these facilities.

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LICENSING UNCONVENTIONAL ACCELERATOR PROJECTS: A QUEST FOR THE SAFEST COMPROMISE

F. SCHMITZ, S. VERMOTE, N. NOTERMAN, C. KENNES

Bel V, Brussel, Belgium

This In recent years, technical exchanges have taken place between operators and the Belgian regulator, FANC[1] (Federal Agency for Nuclear Control) and its technical subsidiary Bel V[2], concerning unusual applications of accelerators[3],[4],[5]. These projects imply the use of an accelerator as alternative to classical radioisotopes production routes, or the use of an accelerator as a way to control the amount of the neutrons produced by nuclear fission. They have been designed for various reasons, including an insufficient production capacity for critical radioisotopes used in medicine for the therapy or an alternative production of well-established radioisotopes used for diagnostic in aging installations.

These special projects represent a challenge for the regulator who must find in the existing legislative corpus the best way to license them[6]. This is particularly important on hybrid systems like Accelerator Driven Systems (ADS).

From a purely technical point of view, the regulator also has to overcome several issues.

The concepts and designs presented to the regulator are new and essentially based on small-scale research and development (R&D) projects. The scaling up of the results from this research has been done with calculation codes and models sometimes poorly benchmarked. Hence, the validation and verification of these models, sometimes developed internally by the operator, is a challenge. On the other hand, since the project is still in the design phase when the first discussions with the regulator take place, it is not uncommon that as the project evolves, major revisions of the basic design are proposed by the operator, rendering obsolete the safety analyses already performed.

There are also many questions, for instance about the definition of reference accidents. Again, this is particularly the case with ADS, where accidents considered minor on an accelerator alone can become major once this accelerator is coupled to a reactor.

The intensive irradiation of targets of unusual design also raised many questions regarding their cooling and the final management of the radioactive waste that will be generated. A thorough characterization of the irradiation parameters as well as the introduction of appropriate interlocks in the machine control system must be evaluated. In terms of decommissioning, the legislator wants these unusual accelerator applications to incorporate, wherever possible, the improvements that have been made by "traditional" industrial accelerators suppliers to reduce facility activation.

Finally, the external feedback (return of experience = REX) from accelerators similar to the project that has to be licensed is often weak and poorly documented. It may be useful to establish relations with regulators in foreign countries that have already licensed similar facilities.

Because of the above issues and the uncertainties that characterize such type of project, the regulator needs to develop a flexible and graded approach to licensing. This approach implies making trade-offs with the licensee in which operational and nuclear safety always remain the priority.

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REGULATORY CONTROL AT THE CONSTRUCTION STAGE OF A RADIOPHARMACEUTICALS PRODUCTION FACILITY WITH CYCLOTRON IN THE CONTEXT OF COVID-19 PANDEMIC

RABI Germán, MAGGIOLO Ayelén, ESPÓSITO Mauro
Autoridad Regulatoria Nuclear, Buenos Aires, Argentina

Inspections and regulatory processes at the construction stage of a radiopharmaceuticals production facility with cyclotron have certain particularities that distinguish them from the processes related to other stages of the life of a facility.

There are a series of considerations that have to be taken into account in order to assure the conditions stipulated during the design phase, concerning radiation protection of workers, the public and the environment.

Particularly, the construction of a bunker of great thickness, such as a non-self-shielded cyclotron bunker, requires a set of specific controls by the regulatory body for the purpose of avoiding construction failures that could ultimately affect the safety conditions during the operational phase.

Furthermore, since March 2020, the Government of Argentina has stablished restrictions to the circulation due to the sanitary emergency that was declared in view of the new coronavirus COVID-19, which affected the development of on-site regulatory tasks.

The Nuclear Regulatory Authority, through the "Class I Particle Accelerators Control Department", describes in the present paper its regulatory action in the context of the construction process of the facility denominated "Cyclotron- Radiopharmacy Laboratory" from Oulton Institute located in Córdoba City, Province of Córdoba, Argentina, during COVID-19 pandemic; and addresses the difficulties that had to be overcome, the technical solutions and the work methodology that were successfully implemented.

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COMMISSIONING OF OPERATIONAL RADIATION PROTECCIÓN IN COMPACT PROTON THERAPY CENTERS (CPTC) WITH SMALL ACELERATORS

GARCÍA FERNÁNDEZ, GONZALO FELIPE
Universidad Politécnica de Madrid (UPM), Madrid, Spain

GALLEGO, EDUARDO
Universidad Politécnica de Madrid (UPM), Madrid, Spain

GÓMEZ-ROS, JOSÉ MARÍA
Ciemat, Madrid, Spain

CARABE-FERNÁNDEZ, ALEJANDRO
Hampton University Proton Therapy Institute (HUPTI), Hampton, United States

BERTOLET-REINA, ALEJANDRO
Massachusetts General Hospital (MFG), Boston, United States

VEGA-CARRILLO, HECTOR RENÉ
Universidad Autónoma de Zacatecas (UAZ), Zacatecas, Mexico

SERANO OGANDO, MARISA
Bioterra, SL, Madrid, Spain

GUZMÁN-GARCÍA, KAREN ARLET
Universidad Autónoma de Zacatecas (UAZ), Zacatecas, Mexico

CEVALLOS-ROBALINO, LENIN ESTUARDO
Universidad Politécnica Salesiana (UPS), Guayaquil, Ecuador

<u>Important and preliminary note:</u>
The main author and other contributors of the work are members of the SEPR (Spanish Society for Radiation Protection), an institution that is part of the IRPA. In this way, membership of the IRPA is fulfilled by membership of the SEPR. (The author GARCÍA FERNÁNDEZ, GONZALO FELIPE is the member number 1292 of SEPR).

Proton therapy is in continuous ever evolving to improve its performance in cancer treatments. Some prominent current trends involve small accelerators, cutting-edge delivery methods, or building compact proton centers. New developments have a direct impact in radiation protection of proton facilities and actions should be developed continuously with the aim that new centers meet all the requirements. The study of radiation protection in multi-room centers has been widely studied elsewhere, however, Compact Proton Therapy Centers (CPTC) have specific features that pose a challenge in radiation protection, and the present work suggest different contributions to the body of knowledge in these compact facilities: Their main element are small and medium-sized accelerators, they usually have one single room, small footprint and a standard configuration, higher radiation density (Sv/m^2), using the most advanced equipment and machinery to reduce their size, the delivery mode of protons is Pencil Beam Scanning (PBS), and there is a mix of professional exposed workers (clinical and technical staff) in these centers.

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The present work is framed into the multinational project *Contributions to operational radiation protection and neutron dosimetry in compact proton therapy centers* (CPTC), developed by nine researchers from seven institutions in five different countries, which is focused on assessing the impact of these innovations on the operational radiation protection and commissioning of these compact facilities. Thus, several tasks have been carried from 2108, as comparing ambient dose equivalent of compact proton centers using different small accelerators (superconductor synchrocyclotron, conventional compact synchrotron and superconductor isocyclotron), checking and evaluation of shielding, comparing ambient dose equivalent of several CPTC, analysing activation with different types of concrete, and activation in accelerators, beamline, air and water of the facility, characterizing wide range rem-meters and neutron area monitors to measure neutron fields, studying new proton delivery techniques and their neutron fields, or assessing personal dosemeters, among others. The aim of this work was to present a commissioning process of the operational radiation protection of Compact Proton Centers, summarized in ten main recommendations, achieved in the activities mentioned, and lined up with the requirements of the Nuclear Authority:

(1) Select a suitable site and location for facility
(2) Design barriers and shielding against neutron and gamma radiation
(3) Use Monte Carlo simulations and check with analytical methods
(4) Choose appropriate materials in barriers
(5) Review the impact of radiation on environment
(6) Anticipate changes in assumptions and future developments
(7) Place the right radiation monitor in the right place of the facility
(8) Pick suitable personal dosemeters
(9) Assume uncertainties
(10) Carry out experimental measurements

Finally, the development of more efficient radiation protection measures could significantly reduce the thickness of the barriers, reducing the cost and size required to implement a proton therapy center. Considering topics as new methods of application of dose in development (proton arc therapy, flash-therapy with protons), new materials for barriers and shielding or recent radiation monitoring equipment, future works must be carried out to study their impact on operational radiation protection and recommendations such as, IAEA Technical Report series 283 *Radiological safety aspects of the Operation of Proton Accelerators*, or ICRP Publication 127, *Radiological Protection in Ion Beam Radiotherapy*, should be updated periodically taking into account the new methods and technologies developed.

ACCELERATOR TECHNIQUES AND NUCLEAR DATA NEEDS FOR ION BEAM ANALYSIS OF WALL MATERIALS FOR CONTROLLED FUSION REACTORS

MAREK RUBEL, PER PETERSSON
KTH Royal Institute of Technology, Department of Fusion Plasma Physics, 100 44 Stockholm, Sweden

DANIEL PRIMETZHOFER
Uppsala University, Department of Physics and Astronomy, 751 20 Uppsala, Sweden

JET Contributors
See the list of authors J. Mailloux, Nucl. Fusion 62 (2022) https://doi.org/10.1088/1741-4326/ac47b4

Integrated science and technology efforts in the field of controlled thermonuclear fusion are directed towards the construction and operation of a rector-class machine for electricity production. In the interdisciplinary world of fusion research, the role of particle accelerators is at least five-fold: (i) provision of nuclear data for ion-material interactions; (ii) ion beam analysis (IBA) of plasma-facing materials and components (PFMC); (iii) ion-induced neutron generation for the material irradiation facility; (iv) ion-induced simulation of neutron radiation effects in surfaces of solids; (v) high current units in the neutral beam injection system for plasma (deuterium and tritium: D and T) heating.

This contribution is concentrated on the role of accelerator techniques in the examination and testing of materials for fusion applications. Quantitative results can only be obtained based on robust nuclear data sets, i.e., stopping powers and reaction cross-sections. Therefore, the work has three equally important strands: (i) determination of nuclear data for selected ion-target combinations; (ii) assessment of fuel inventory and modification of PFMC by erosion and deposition processes; (iii) equipment development to perform cutting-edge research.

Under terrestrial conditions, fusion plasma must be confined by strong magnetic fields and surrounded by walls of a vacuum vessel. Plasma – wall interaction (PWI) processes related to the exposure of PFMC to electromagnetic radiation and particle fluxes modify both plasma and wall materials. Atoms eroded from the wall are ionised, transported along the magnetic field lines and re-deposited together with fuel atoms thus changing the composition and properties of the wall and crucial tools for plasma diagnosis (mirrors, windows). This has an impact on the PFMC lifetime and fuel inventory, i.e., decisive factors for the safety and economy of reactor operation. These are the driving forces for comprehensive analyses and testing of in-vessel components from tokamaks, stellarators, linear PWI simulators and fusion-related material research laboratories. The major materials of interest are beryllium (Be), tungsten (W), molybdenum (Mo). The discrepancies in the existing data base calls for measurements of stopping powers and reaction cross-sections of H and He with these metals.

Over the years, more than fifty different material characterisation techniques have been used in the PFMC research: ion, electron, neutron, optical, magnetic, sound, mechanical, thermal and their combinations. Compositional analyses must cover a broad range of species which are used in a reactor as fuel, gases injected for auxiliary plasma heating or edge cooling, transport markers, wall and diagnostic components and, those for wall conditioning. As a result, the list extends from H, D, T, ^{3}He, ^{4}He, other noble gases (Ne – Xe), isotopes of Li, Be, B, C, N, O, F, via Al, Si to Cr, Fe, Ni and then to W, Re, and even to Au. Such challenge can be met only by accelerator-based ion beam analysis methods (IBA): RBS, NRA, PIXE, ERDA, MEISS, AMS. Taking into account a range of ion beams, spot size, broad energy spectrum, tens of nuclear reactions and data processing software, the “toolbox” offers a huge number of options.

IBA plays a prominent role in the ex-situ examination of materials retrieved from the vacuum vessel: wall tiles and erosion-deposition probes [1-3], diagnostic components [4] and also dust [5]. The above listed IBA methods are complementary to each other. They are quantitative, sensitive and selective. In many cases allow for depth profiling. The information depth in deuterium retention studies with a ^{3}He beam exceeds 20 µm in low-Z targets. The methods facilitate effective elemental mapping over large surfaces without the need of special sample preparation. Using analysis stations with large-volume chambers, long travel distance (15-25 cm) manipulators and loading ports of 150-250 mm in diameter, no sectioning is required even in the case of big PFC blocks: e.g., 4x16x24 cm and mass of 2 kg. Results from several tokamaks will be shown and explained. Analyses of low-Z isotopes are mostly carried out by means of ^{3}He-based NRA. This situation calls for validation of the existing cross-sections, especially for Li, Be, B, C, N and O isotopes for ^{3}He beams.in the 1-6 MeV energy range.

The other role of accelerators in fusion research is in the ion-induced simulation of neutron damage of materials [6-8]. Ion irradiation modifies the surface structure. It has a major impact on fuel retention in PFC and also on optical performance of crucial diagnostic components like so-called first mirrors, i.e., metal mirrors acting as PFMC in all optical plasma diagnosis systems (spectroscopy and imaging) in ITER; the reactor-class machine under construction. The impact of irradiation with H, He (transmutation simulation) and Mo, Zr, Nb (n-induced damage simulation) on the optically active layer of Mo mirrors will be addressed.

The accelerator-based analysis and modification of materials is not an isolated or a passive strand of fusion research. The results directly contribute to decisions regarding the wall composition and diagnostic planning in ITER. This imposes a quest for improvements and developments of analytical capabilities (nuclear data sets, detectors, chambers etc) to ensure cutting edge research. A brief review of IBA facilities in the fusion research will be presented.

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APPLICATION OF ACCELERATORS IN NANOMATERIALS RESEARCH

Y.Q. WANG

Los Alamos National Laboratory, Los Alamos, NM, USA

To streamline the US government support in advancing nanoscience research, Department of Energy's Office of Science established five Nanoscale Science Research Centers (NSRCs) in 2006 at DOE's six national laboratories: Center for Nanoscale Materials (CNM) at Argonne National Laboratory (ANL); Center for Functional Nanomaterials (CFN) at Brookhaven National Laboratory (BNL); Molecular Foundry (The Foundry) at Lawrence Berkeley National Laboratory (LBNL); Center for Nanophase Materials Science (CNMS) at Oak Ridge National Laboratory (ORNL); and Center for Integrated Nanotechnologies (CINT) jointly operated by Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL). While all NSRCs have common capabilities such as electron microscopy to support users, each NSRC also has its distinctive capabilities and uniquely focused research areas. One of the unique research areas at CINT is its ion beam materials research leveraging two accelerator laboratories: Ion Beam Materials Laboratory (IBML) at LANL and Ion Beam Laboratory (IBL) at SNL. The CINT ion beam capabilities cover broad beam energies ranging from tens of eV to over 100 MeV using 11 accelerators/implanters equipped with a variety of ion sources and 25 beamlines/endstations. The beam size can be focused as small as 10 nm on 35 kV Raith Velion Nanoimplanter or rastered as large as 200 mm wafer size on 200 kV Danfysik Research Implanter. Besides traditional single ion beam research such as ion beam analysis, ion beam modification, and radiation effects, coupled beamlines are developed to simulate reactor extremes and support actinide research. In addition, transmission electron microscopy (TEM) and positron annihilation spectroscopy (PAS) are coupled to ion irradiation beamlines to perform in situ defect characterizations. This talk will highlight recent advances in ion beam nanomaterials research ranging from layer-tuneable graphene synthesis, controlled helium confinement through novel metal nanolayers, to new in-situ corrosion monitoring during irradiation based on particle induced X-ray emission (PIXE).

This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science. Los Alamos National Laboratory, an affirmative action equal opportunity employer, is managed by Triad National Security, LLC for the U.S. Department of Energy's NNSA, under contract 89233218CNA000001.

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SUSTAINABILITY OF THE TANDEM ACCELERATOR FACILITY AT THE RUĐER BOŠKOVIĆ INSTITUTE

ZDRAVKO SIKETIĆ and MILKO JAKŠIĆ
Ruđer Bošković Institute, Bijenička c. 54, 10000 Zagreb, Croatia

The Laboratory for Ion Beam Interactions (LIBI) at the Ruđer Bošković Institute (RBI) began with operation in 1987, when the first ion beam was obtained from a 6 MV tandem Van de Graaff accelerator donated by the University of Houston (Texas). The first beam lines were installed for Rutherford Backscattering (RBS) and Particle Induced X-ray Emission (PIXE) experiments mainly done by proton beams. To extend the applications to lower MeV ion energy range and to increase the number of beamlines, an additional 1 MV Tandetron accelerator was installed in 2005 in collaboration with the IAEA under the TC project. The main sources of funding for the operating costs of the laboratory at that time were secured through the Croatian Ministry of Science and a beamline agreement with the IAEA.

In the following period of ten years (2008 - 2017), the LIBI equipment was further upgraded through the numerous projects from various sources (EU, IAEA, national funds, etc.). The acquisition of new ion sources opened the possibility to use different ions in the broad mass range, the modernization of the vacuum system resulted in better transmission of the ion beam, and the computerised accelerator control built in house enabled remote control of the accelerator. Funds from the international and national projects also provided the opportunity to employ young researchers (PhD students and postdoctoral fellows) boosting development of existing and new unique IBA techniques such as dual beam irradiation, heavy ion microbeam, IBIC, HR-PIXE, TOF-ERDA, MeV SIMS, etc. These new emerging techniques as well as other traditional IBA techniques have been successfully applied for applied research in the fields of materials science, detector physics, biology, forensics, cultural heritage, etc., thus opening a large space for the interdisciplinary collaboration between scientists from Croatia and abroad. By mastering new and unique techniques for ion beam analysis and modification, LIBI has gained international recognition and become involved in large international projects such as SPIRIT, RADIATE, AIDA2020, EUROfusion and CERIC-ERIC consortium which allow researchers (and industry) to use accelerator beamtime at LIBI through the transnational access.

The growth of the laboratory over the past 20 years, both in terms of staff and expertise offered in accelerator-based techniques, entails operating costs that cannot be covered by limited government base funding alone. Therefore, to maintain normal operation and further developments, accelerator facilities such as ours must constantly compete for the international funds through the EU projects and collaboration with industry. To further develop the laboratory and open up new research areas (such as quantum sensing and computing and neutron physics), construction of a new accelerator hall, followed by the purchase of a new 6 MV accelerator, will begin in 2022 as a part of the RBI's EU structural project O-ZIP. In addition, a new low-energy implanter (200 kV) will be built by own funds and knowledge, opening the possibility to explore new techniques with low-energy ions. All of this together opens up a space for new projects that will further fund the development of the laboratory, ensuring that LIBI remains one of the world's leading laboratories in the field of ion beam analysis and materials modification, reaching self-sustainability in terms of manpower, education of young researchers and facility operating costs.

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RADIATION DAMAGES BOHR' S METRICS: ACCELERATOR & ELEMENTAL LANDSCAPES

J.-C. SUBLET

*NUCLEAR Data Section, Division of Physical and Chemical Sciences,
Department of Nuclear Sciences and Applications, International Atomic Energy Agency,
Vienna International Centre, PO Box 100, A-1400 Vienna, Austria*

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STATUS REPORT OF THE N_TOF FACILITY AFTER THE 2ND CERN LONG SHUTDOWN PERIOD

N. PATRONIS
Department of Physics – University of Ioannina, Ioannina, Greece

During the 2nd long shutdown period of CERN (2018-2020) important upgrade activities were realized at the n_TOF facility at CERN. The most important one is the replacement of the lead spallation target, that served the facility for more than 10 years, with a new sliced and liquid-nitrogen-cooled lead target [1]. Additionally, by taking the advantage of the enhanced neutron flux at close distances with respect to the lead target, a new experimental area (NEAR) was established. In parallel new detection systems were developed towards to more efficient data taking.

Within the present contribution the n_TOF facility will be presented. First results with respect the neutron flux at the horizontal (EAR-1) and vertical (EAR-2) experimental areas will be given along with characterisation of the newly built NEAR station. The existing and recently developed instrumentation will be described by presenting selected physics cases of previous and future measurements [2, 3].

After its major upgrade during CERN's 2nd Long Shutdown, the n_TOF facility's unique characteristics were further improved and enhanced. As will be presented n_TOF can serve high precision cross-section measurements, in a wide energy range for a large variety of neutron induced reactions with stable or highly radioactive samples (e.g. [4]).

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THE NEUTRON FACILITY AT NCSR "DEMOKRITOS" AND NEUTRON ACTIVATION RESEARCH ACTIVITIES OF NTUA

R. VLASTOU
National Technical University of Athens (NTUA), Athens, Greece

Studies of neutron induced reactions are of considerable interest, not only for their importance to fundamental research in Nuclear Physics and Astrophysics, but also for practical applications in nuclear technology, dosimetry, medicine and industry. These tasks require improved nuclear data and higher precision cross sections for neutron induced reactions on various isotopes.

At the 5.5 MV Tandem T11/25 Accelerator Laboratory of NCSR "Demokritos" quasi-monoenergetic neutron beams can be produced in the energy ranges ~ 15-21 MeV by means of the ^{3}H(d,n)^{4}He reaction, ~ 4-11 MeV via the ^{2}H(d,n)^{3}He reaction and ~ 2.0-5.3 MeV using the ^{3}H(p,n) reaction. The maximum flux has been determined to be of the order of 10^5-10^6 n/cm^{2}s, implementing reference reactions (such as ^{27}Al(n,α)^{24}Na, ^{197}Au(n,2n)^{196}Au and ^{93}Nb(n,2n)^{92m}Nb), while the flux variation of the neutron beam is monitored by using a BF_3 detector. The neutron beam has been characterized using the multiple foil activation technique as well as extensive simulations [1,2].

The neutron beam has been extensively used over the past 15 years by the NTUA group, for the measurement of (n,2n) and occasionally (n,3n), (n,p), (n,α) reaction cross sections on several isotopes of Am, Hf, Ir, Ge and Au, with the activation technique [3-14]. All these isotopes are important for several medical and industrial applications, including reactor technology, cancer treatment, radiochemical detectors etc. After the end of the irradiation the induced γ-ray activity of the samples and the reference targets are measured off- line by HPGe detectors of 100%, 80% and 16% relative efficiency. The absolute efficiency of the detectors is obtained using a calibrated ^{152}Eu source, placed at the same distance as that of the sample. Additionally, the experimental set up is always simulated with the use of the MCNP (Monte Carlo N-Particle) code, for the estimation of the neutron flux, the self-absorption of the γ-rays in the sample, the effect of parasitic neutrons which accompany the beam etc.

Furthermore, statistical model calculations using the codes EMPIRE and TALYS are usually performed on a wide energy range for the measured data measured as well as for the data reported in literature.

An overview of the neutron activation campaign at this facility will be presented.

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ION ACCELERATORS FOR MODIFICATION AND ANALYSIS OF MATERIALS: PRESENT STATUS AND AN OUTLOOK TOWARDS THE FUTURE

P. STRÖM, D. PRIMETZHOFER

Uppsala University, Department of Physics and Astronomy, Uppsala, Sweden

The use of ion beams for analysis of materials has a history dating back to 1909, when Geiger and Marsden observed large angle scattering of alpha particles in an experiment which subsequently motivated Rutherford to propose the existence of atomic nuclei. From the 1950s, we've been able to use the energy spectra of scattered ions, nuclear reaction products as well as characteristic x-rays and gammas to draw conclusions about the composition of a sample [1,2]. Starting in the 1970s, with the invention of solid state silicon diode detectors, techniques like Rutherford Backscattering Spectrometry (RBS) and Elastic Recoil Detection (ERD) have become routine tools for thin film analysis. With improvements of both accelerators and data analysis equipment (computers and associated software), we can nowadays use ion scattering at energies from a few keV up to tens of MeV to measure atomic composition depth profiles with monolayer resolution near the surface of a sample and with information depth down to several micrometres. When combining the available techniques, ion beam measurements are sensitive to all elements in the periodic table at levels of a fraction of a monolayer on a surface, or ppm bulk concentrations of trace components. The modification of materials by ion irradiation and dopant introduction through implantation constitute additional important roles of ion accelerators. Since the 1970s, ion implantation has been instrumental for the manufacturing of integrated circuits, and it continues to fill this role today [3-5]. Finally, accelerator mass spectrometry (AMS) and particle induced X-ray emission (PIXE) have been established as standard methods for dating and tracing the origin of a wide variety of samples, from historical artefacts to food items.

Thanks to the unique applications stated above, we identify ion accelerators as key medium sized research infrastructures, along large-scale installations such as synchrotrons and neutron research facilities. In this contribution, we present highlights of the modern applications of ion accelerators with a focus on materials research. The availability of methods for in-situ and in-operando characterization of material systems relevant for sustainable development is discussed. We further investigate the present lack of visibility for, and knowledge about, ion beam methods in the material science community, which relies heavily on neutron- and photon-based techniques. In order to help mitigate this perceived problem we go through the research questions that are best answered by methods available at ion accelerator facilities and motivate the need for maintaining such facilities as materials research infrastructures. We outline the future use of these accelerator infrastructures as specialized low-threshold user facilities where material scientists can perform tailored measurements in a manner similar to how synchrotrons are often employed today.

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DETERMINATION OF FUEL RETENTION IN TOKAMAKS BY ACCELERATOR-BASED METHODS

A. WIDDOWSON and JET Contributors#
United Kingdom Atomic Energy Authority, Culham Centre for Fusion Energy, Culham Science Centre, Abingdon, OXON, OX14 3DB, UK

M. RUBEL
Royal Institute of Technology (KTH), Association EURATOM-VR, 100 44 Stockholm, Sweden

Nuclear fusion offers a potential future energy supply and is an area of worldwide research with this aim in mind. One such research effort is at the world's largest operating tokamak device based in UK, known as JET – Joint European Torus. JET consists of a 6 m diameter torus (doughnut) shaped vacuum vessel in which high temperature hydrogen plasma is confined by magnetic field to facilitate fusion of hydrogen isotopes, deuterium (D) and tritium (T), to release high energy 14 MeV neutrons.

The inside of the JET vacuum vessel is protected by wall tiles. In the extreme conditions the plasma interacts with the wall components and as a result components undergo erosion, material migration and deposition. This plasma wall interaction has an impact on operational lifetime of components and has the potential to generate dust which poses a safety risk in the event of accident scenarios. Plasma interaction with the wall materials also results in the retention of the hydrogen fuel, including the radionuclide tritium, which is regulated to ensure safe operation of fusion facilities. For these reasons an extensive programme to study materials removed from JET has been ongoing for more than three decades and have influenced decisions on upgrades to JET and the choice of wall materials for ITER, under construction in France. The use of accelerator-based techniques has played a major role in the materials analysis programme and results have advanced the understanding of erosion, material migration, deposition and fuel retention in tokomaks and provided benchmarking for modelling. To facilitate the analysis programme, regular retrieval of plasma-facing components (PFC) and erosion-deposition probes (EDP) is performed during in-vessel maintenance periods in JET. In the current configuration of JET, known as JET ITER-like Wall (JET-ILW) [1], three sets of PFCs and EDP have been removed in the period 2011-2016 following three experimental campaigns lasting 1 – 1.5 years each. The components removed have provided a representative set of specimens for ex-situ studies and – as a consequence – have allowed for a deep insight into material migration including fuel retention and dust generation. This comprised research on PFCs from the poloidal (upper to lower) cross-section of the machine; tungsten PFCs in the bottom of the machine (known as the divertor) and beryllium PFCs in the main chamber of the vessel. The overall aims were: (i) to obtain a comprehensive erosion-deposition pattern and fuel retention assessment before the planned D-T experimental campaigns in 2021 and 2023; (ii) to provide basis for the best-possible predictions for ITER regarding the melt damage of bulk Be and W tiles, tritium inventory and the modification of diagnostic test components. In this programme ion beam analysis facilities with capability for handling components containing tritium and beryllium were crucial in all these studies. Using IBA techniques, the retention of the predominant deuterium fuel and deposition of beryllium and carbon has been extensively studied using nuclear reaction analysis (NRA) with helium-3 ($^3He^+$) beam. Other deposited materials have been studied using proton (H^+) back scattering (PBS), proton induced x-ray emission (PIXE) and heavy ion elastic recoil detection with time-of-flight detection (HIERDA, TOF-ERDA).

See the author list of 'Overview of JET results for optimising ITER operation' by J. Mailloux et al. to be published in Nuclear Fusion Special issue: Overview and Summary Papers from the 28th Fusion Energy Conference (Nice, France, 10-15 May 2021)

An example of fuel retention analysis on a JET component is shown in Fig. 1. Fig. 1(a) shows a castellated beryllium component from the JET main chamber inner wall guard limiter (IWGL) and Fig. 1(b) shows the deuterium deposition profiles measured using accelerator-based techniques following the three experimental campaigns of JET-ILW (ILW-1, ILW-2, ILW-3) and a profile on the tile exposed during all of them [2][3]. There are common features. Qualitatively and quantitatively all profiles are of the same character indicating: (i) the erosion zone in the central part of the limiters where the content of D atoms does not exceed 0.1×10^{18} cm^{-2}; (ii) deposition zones at the curved sides with the D concentration from co-deposition with eroded material reaches a maximum of 1.4×10^{18} cm^{-2}. Even those highest values of inventory are very low on this component both in absolute and relative terms when either extrapolated to tritium retention in 1:1 D-T operation (35 mg T m^{-2}) or compared to the situation in JET with carbon walls (JET-C) where fuel contents in some areas was over two orders of magnitude greater than in JET-ILW [4][5]. This type of analysis is repeated for all components retrieved from the machine and a global picture of material migration and fuel retention is constructed. From the global analysis the long-term retention in components is found to be 0.19% of fuel used in operations and the highest retention area is at the upper inner part of the divertor, accounting for 46% of fuel retained. Such global analysis can be used in estimating retention of tritium in JET during use of tritium in 100% tritium and D-T operations from 2021 to 2023 [6]. These results in turn can provide an assessment of tritium waste liability and also tritium inventory of components to inform the infrastructure requirements for handling in the case of future analysis by accelerator-based and other tritium sensitive techniques.

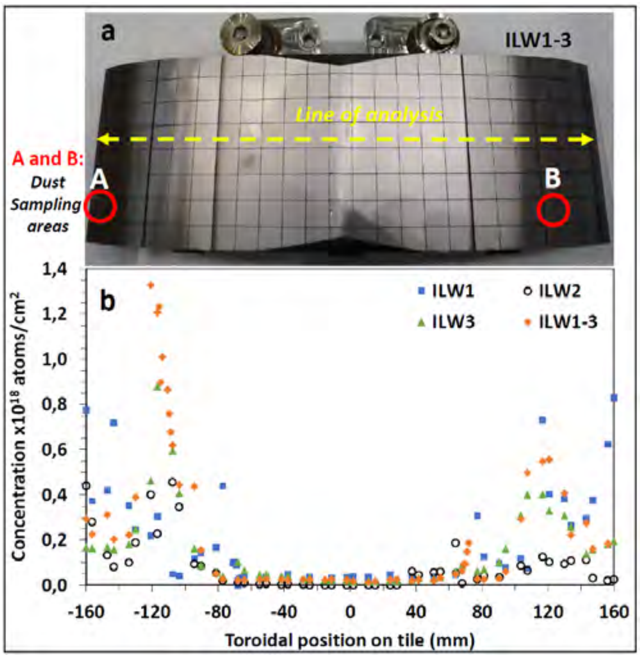

Fig. 1. (a) Castellated beryllium mid-plane IWGL tile after exposure in JET; (b) Deuterium areal concentrations at mid-plane measured after consecutive campaigns and after all three campaigns ILW1-3; data reproduced with permission of copyright holder UKAEA and author [2,3].

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ELECTRON BEAM TECHNOLOGY FOR PRESERVING QUALITY ATTRIBUTES OF MANDARINS FOR ENHANCING EXPORT POTENTIAL

Kendall HOWIE, Sara PARSONS and Suresh D. PILLAI

National Center for Electron Beam Research, Department of Food Science & Technology, Texas A&M University, College Station, Texas 77843.

There is a need for countries around the world to increase their exports of agricultural products. The export of agricultural products adds significantly to the economic development of a country. Agricultural exports such as mandarin oranges and other citrus fruits are of high commercial value especially tropical fruits are gaining in popularity around the world. However, to deal with strict transboundary phytosanitary requirements, these commodities have to be appropriately treated. Ionizing technologies such as gamma, electron beam (eBeam) and X-ray are suitable technologies. The focus of this study was to determine whether the accelerator technology, namely eBeam technology can be combined with cold temperature storage technology to preserve the quality of mandarins. The science question we were pursuing was whether cold storage before or after eBeam processing was the most beneficial to preserve mandarin quality. The study was performed with mandarins harvested in two different locations: one in California and the other in Chile. There were three different eBeam dose treatments namely, 0 Gy (un-treated), 50 Gy, and 150 Gy. The cold temperature+ eBeam combination treatments were as follows: 50 Gy + 3 days storage at 1°C, and 50 Gy + 5 days at 1°C. Additionally, two more experimental treatments were included namely 3 or 5 days of storage at 1°C prior to eBeam processing at 50 Gy. After these combination treatments, the fruit were stored for three weeks; 14 days at 7°C and one week at room temperature. The quality attributes from these combination treatments were evaluated based on standard methods normally utilized for evaluating the quality of fruit in commercial trade namely Citrus Color Index (CCI), maturity index, weight loss, extractable juice volume, pH, vitamin C, and overall appearance. Overall, the results indicate that the observable differences in these quality parameters were attributable to geographical origin of the mandarins and their stage maturity, rather than the eBeam + cold storage combination treatments. The study highlighted that 150 Gy was detrimental to the fruit quality. These results demonstrate the potential for a new phytosanitary treatment of mandarins which would be 50 Gy, followed by refrigerated storage for 3 days at 1°C. These results suggest that eBeam technology can be technologically compatible with citrus fruits. What is needed are economic and technical feasibility analyses to build and operate purpose built accelerator facilities in citrus growing regions of the world.

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THE USE OF IN-SITU TRANSMISSION ELECTRON MICROSCOPY TO INVESTIGATE MICROSTRUCTURE EVOLUTION UNDER ION IRRADIATION

DJAMEL KAOUMI
North Carolina State University, Raleigh, North Carolina, USA

Ion-irradiation produced by accelerators is a useful way to probe materials response to irradiation as it induces radiation damage microstructures that can be similar to those achieved under neutron irradiation without the complications of radioactivity. Because of the higher dose rate it is also a convenient way to reach high levels of radiation damage doses in a reasonable amount of time. When coupled with Transmission Electron Microscopy (TEM) it becomes a powerful tool to gain kinetics information on irradiation induced phenomena because the microstructure evolution of the irradiated material can be followed *in-situ* as the damage proceeds. Given the dynamic nature of irradiation induced phenomena, such direct in-situ observation is in fact often necessary to better understand the mechanisms, kinetics and driving forces of the processes involved. Thus, in situ TEM can be of great help. Indeed, the spatial resolution of TEM makes it an invaluable tool in which one can continuously track the real-time response of the microstructure to ion irradiation, which can help discover and quantify the rate-limiting microscopic processes and mechanisms governing the macroscopic properties.

Henceforward, this presentation will illustrate how in-situ ion irradiation in the TEM has proven successful for studying the basic mechanisms of radiation induced defect formation and evolution as a function of dose and temperature through a couple examples including (i) the investigation of the kinetics of grain growth under ion irradiation in nanocrystalline metals and the resulting thermal-spike based model which was derived to explain the kinetics observed experimentally, and (ii) the evidencing of surprisingly high defect mobility in oxide scales that can develop on Fe based alloys and which may affect the kinetics of corrosion under irradiation.

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PENELOPE-BASED USER-FRIENDLY FAST INTERFACE FOR CALCULATING DOSE DISTRIBUTION IN IRRADIATED PRODUCTS

Randolph SCHWARZ
Pacific Northwest National Laboratory, Richland, Washington, USA

Mark MURPHY
Pacific Northwest National Laboratory, Richland, Washington, USA

Suresh PILLAI
Texas A&M University, College Station, Texas, USA

Manufacturers of polymer-based products requiring sterilization, including medical devices and components used in biopharmaceutical production, use computer simulation and/or dosimetry measurements to determine the dose distribution within these products during irradiation. Such detailed dose distribution is required for the product sterilization validation process for approval by federal regulators (e.g., U.S. Food & Drug Administration and European Medicines Agency). The radiation field can be provided by cobalt-60 gamma-rays, X-rays or electron-beam. There are several commercially available software packages that can provide detailed dose distribution within such products, whether in the design phase or of actual product, but a tremendous amount of labor is needed for training and for the actual use of this software. In the attempt to improve on these existing dose distribution software tools, Team Nablo, an international collaborative team led by Pacific Northwest National Laboratory and funded by the U.S. National Nuclear Security Administration, is studying a particular novel approach. This approach would create a Penelope-based graphical user interface to calculate the dose distribution within individual and boxed products and utilize a voxel method. It is hoped that this software tool would allow 1) The flexibility to cover medium-to-high product complexities, 2) Sufficient accuracy and precision of the dose distribution, 3) Use by individuals who are novices at radiation modeling, 4) As compared to existing similar software, much less labor for training and for obtaining dose results, and 5) Availability to any user and at no cost. This presentation will describe the software package that Team Nablo is currently developing, and to what degree it is expected to meet these 5 goals.

APPLICATION OF ELECTRON BEAM ACCELERATOR FOR PRESERVATION BIODETERIORATED CULTURAL HERITAGE PAPER-BASED OBJECTS: MULTIPARAMETRIC ANALYSIS

D. CHMIELEWSKA, U. GRYCZKA, W. MIGDAŁ, J. SADŁO

Institute of Nuclear Chemistry and Technology, Warsaw, Poland

The cellulose, which is the main component of the paper additionally with proteins present in book bindings is the environment very prone to attack of the harmful microorganisms. The investigation of the atmospheric air in libraries revealed the presence of broad spectrum of fungi and bacteria [1-3]. Records show that large volumes of books and archival collections may be affected by bioburden because of improper storage conditions or accidents such as floods [4, 5]. The harmful influence of microorganisms on paper-based historical objects leads to their degradation and real loss for the culture. Moreover, microorganisms present in books or archives may influence the human health negatively.

Thus, effective disinfection methods of paper-based objects are still being developed in order to propose effective, fast and low-cost method that can be applied on the mass scale in emergency situations as well as for the preventive treatment.

Currently the most common method used for decontamination of library and archival collections is ethylene oxide treatment, which is toxic to humans and the natural environment. The promising alternative for this technique can be ionizing radiation. Electron beam (EB) irradiation can be effectively applied for decontamination of biodeteriorated archives as well as for preventive conservation of large volumes of books in short time [6]. Moreover, due to the high dose rate of EB irradiation, appropriate dose is delivered to the treated objects in several seconds therefore post-oxidation related effects of paper degradation are significantly limited.

Samples of different papers were exposed to electron beam irradiation using a 10 MeV-10 kW linear electron accelerator “Elektronika” and delivered doses were confirmed using Gammachrome Harwell dosimeters for lower doses, and the calorimetric method involving graphite and polystyrene calorimeters was applied to measure absorbed radiation doses in a range from 1.5 to 25 kGy.

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 with electron beam.

Changes in all samples properties were determined according to the relevant ISO and TAPPI standards. Microbiological investigation confirmed that dose of 5 kGy effectively eliminate bacteria and fungi in Whatman CHR 1 paper and office paper and did not influence the studied optical, thermal (Fig.1), physicochemical and mechanical parameters of these papers.

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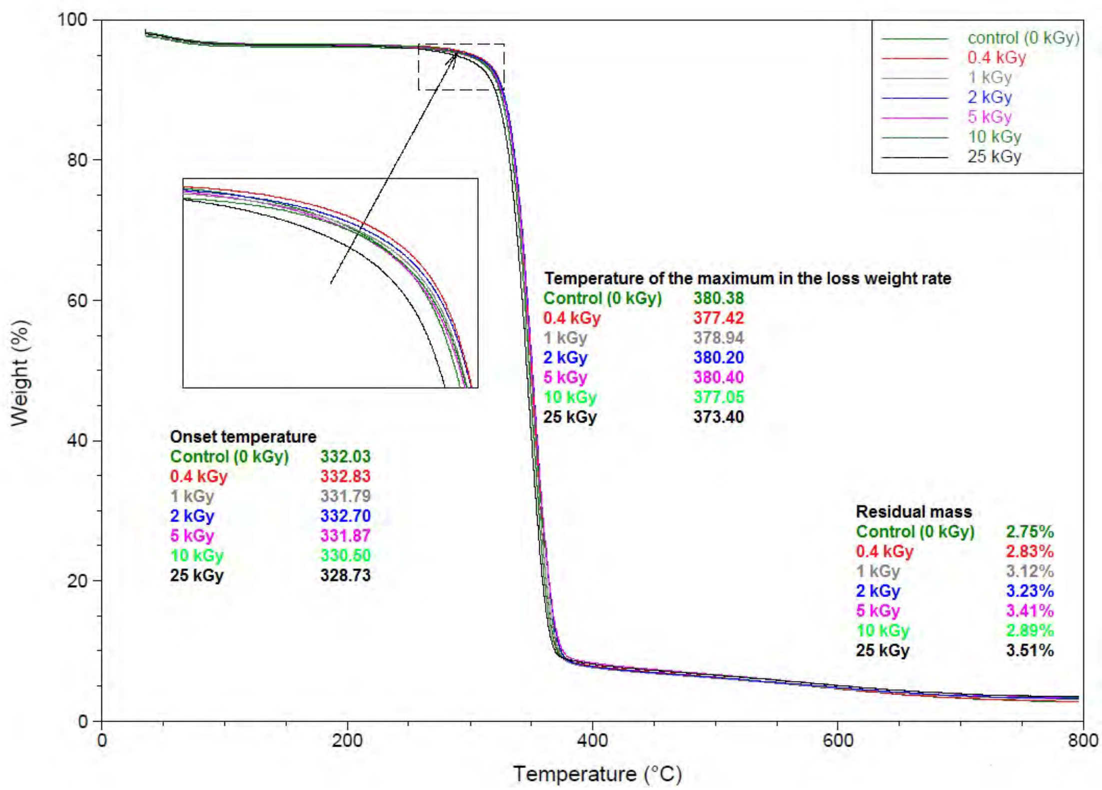

FIG. 1. TGA curve for thermal decomposition of Whatman CHR1 paper.

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RUBBER RECYCLING: COMPATIBILIZATION OD WASTE TIRE RUBBER AND POLY(ETHYLENE-CO-VINYL ACETATE) BLENDS USING LIQUID RUBBER AND ELECTRON BEAM IRRADIATION.

S. RAMARAD
Heriot-Watt University Malaysia, Engineering and Physical Sciences School, Putrajaya, Malaysia.

C.T. RATNAM
Malaysia Nuclear Agency, Bangi, Malaysia.

Accumulation of rubber waste is a pressing global issue. Tires are complex bulky rubber composite which has received global recycling attention. At the end of life, tires are collected, shredded, segregated, ground and down-sized into rubber recyclates, more commonly know as waste tire rubber. These waste tire rubber, having undergone a lifetime on the road and downsizing processes, has poor properties and is not favoured in high-end applications. Many researchers have attempted to blend waste tire rubber with plastic to produce thermoplastic elastomer. However, one of the most prominent drawbacks of these thermoplastic elastomers was the poor interfacial adhesion which results in poor mechanical properties.

In this study, the above-mentioned problem was addressed by blending 50 wt% of reclaimed waste tire rubber (WTR) with 50 wt% of poly(ethylene-*co*-vinyl acetate) (EVA) which was compatibilized using liquid styrene-butadiene rubber (LR). Compatibilized blends were prepared using an internal mixer. The blends were later subjected to electron beam irradiation with doses ranging from 50 to 200 kGy. While compatibilization on its own did not distinctly enhance the properties of the blends, the irradiation remarkably enhances mechanical, thermal and dynamic mechanical properties of the blend by at least 2 folds compared to un-irradiated blends.

FIG 1 shows the schematic representation of RTR/EVA blend compatibilization by LR. RTR phase is encapsulated by LR, efficiently decreasing the interfacial tension. This improves the dispersion of RTR in EVA matrix. Similar observation was also reported in GTR/LDPE blends compatibilized by elastomers [1]. Furthermore, the free chains of LR can co-mingle with both free devulcanized chains of RTR and EVA matrix, improving the interfacial adhesion. Upon irradiation, both EVA and RTR can be adhered together through formation of crosslinks between these co-mingling chains.

FIG 2 illustrate the storage modulus of the control blend (50RTR) and 3 wt% LR compatibilized blends (50RTR/3LR) before and after irradiation. All the blends, before and after irradiation clearly displayed glass, transition and rubbery characteristics in the storage modulus curve. Storage modulus was highest in the glassy region and rapidly decreases from transition region and displayed a plateau rubbery curve. Before irradiation, LR compatibilized blend showed decrease in the storage modulus in glass and transition region compared to 50RTR blend. This is expected due to plasticizing effect of LR. However, irradiation tremendously improved the storage modulus throughout the temperature range. This is due to increase in the elasticity of the blend with efficient crosslink formation in LR.

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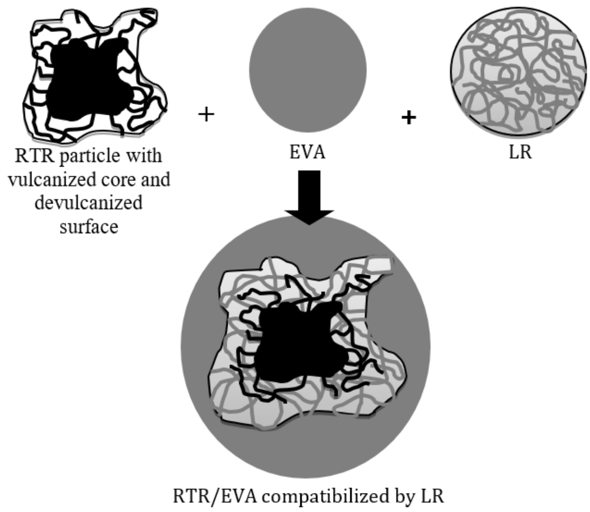

FIG 1 Schematic representation of RTR/EVA blend compatibilization by LR

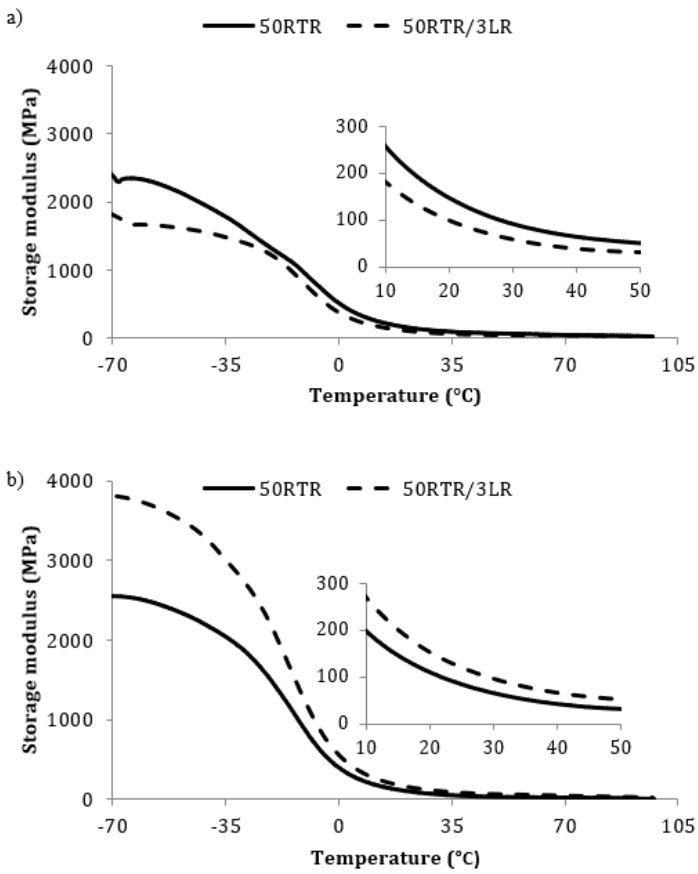

FIG 2 Storage modulus of 50RTR and 50RTR/3LR a) before and b) after irradiation

SWIFT HEAVY ION MODIFIED MATERIALS: APPLICATIONS AND CHARACTERISATION USING SYNCHROTRON SMALL ANGLE X-RAY SCATTERING

P. KLUTH
Research School of Physics, Australian National University, Canberra, Australia

When highly energetic heavy ions pass through a target material, the high electronic excitations can generate long cylindrical damaged regions termed 'ion tracks'. Ion tracks have many interesting applications across a variety of scientific areas such as materials science and engineering, nanotechnology, geology, archaeology, nuclear physics, and interplanetary science. Ion track damage often exhibits preferential chemical etching over the undamaged material. This etch-anisotropy can be used to create pores of up to tens of microns in length, with pore diameters as small as several nanometres. Membranes formed by this method are ideal for many advanced applications including ultra-filtration, bio- and medical sensing, nano-fluidics, and nano-electronic devices. One major advantage of the technique is the ability to generate arrays of pores that are highly parallel with extremely narrow size distributions.

Small angle X-ray scattering (SAXS) provides an interesting tool to study the structure of ion tracks and track-etched nanopores, as it is sensitive density changes on the nanometre length scale [1-5]. It is non-destructive and can yields high precision measurements of the track and pore structure in many materials. Short acquisition times associated with the high photon flux at 3rd generation synchrotron facilities enable *in situ* studies.

The presentation will give an overview of our recent results on the development of functional nanopore membranes in polymers and inorganic materials using ion track etching. This will include fabrication of conical pores in SiO_2 and their application in nanofluidic diodes, separation membranes and biosensors. A particular focus will be put on the characterisation of ion tracks and nanopores using SAXS which ultimately enables precise fabrication of the nanopores. Results include the determination of the detailed morphology and etching kinetics of nanopores in polymers [1,2] as well as the annealing kinetics of ion tracks in diamond anvil cells to investigate track stability under high pressure conditions [5].

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THREE DIMENSIONAL NANOCHANNEL NETWORKS FABRICATED WITH ION TRACK-ETCH TECHNOLOGY AND THEIR APPLICATIONS

M.F.P. WAGNER[1], M.E. TOIMIL-MOLARES[1], C. TRAUTMANN[1,2]
[1] *GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany*
[2] *Technical University of Darmstadt, Darmstadt, Germany*

Large scale accelerator facilities such as the GSI Helmholtz Center for Heavy Ion Research provide unique opportunities in the field of materials science and ion-track technology using heavy ions in the MeV - GeV energy range. The interest in such beams is based on the large energy deposition along the trajectory of each individual ion creating long few nm-wide damage trails. The small diameter of ion tracks in combination with their large range (several tens of µm and more) allows us to generate nanostructures of extremely high length-to-diameter ratio and thus to overcome limits of planar structuring techniques.

The ion track technology combines ion irradiation and chemical etching where each individual ion track is converted into an open pore. Nowadays, the technique is commercially available and track-etched membranes are used as filters, cell cultivation substrates, and many other applications. Due to the excellent control of the pore diameter and shape, pore density and pore alignment, these membranes are also of great interest for the synthesis of micro- and nanowires. The membrane acts as templates for the electrodeposition of material into the pores. [1,2]

The presentation will focus on recent research developments and give a glimpse on novel possibilities based on the generation of nanowire networks. For networks, the membranes are irradiated from several directions. After track etching and electrodeposition, interconnected nanowire systems are obtained. By optimization of the fabrication processes, homogeneous, uniform nanowire networks with well controlled and systematically adjusted wire diameter, wire density and composition can be grown. Upon removal of the matrix these tailored nanowire systems are available for various scientific projects and new applications.

Figure 1 shows a representative scanning electron microscopy (SEM) image of a bismuth nanowire network together with a close-up that illustrates individual interconnections between the nanowires. Compared to arrays of parallel nanowires, the numerous junctions between adjacent nanowires in such a network renders great mechanical stability and higher electrical reliability. Samples of several cm^2 can be handled like bulk materials, while the properties of the individual nanowires are maintained. [3, 4, 5]

The latest results and emerging applications will be presented including fields such as thermoelectric sensing, transparent conductors, or selective catalysis for green fuels. [3, 4, 5]

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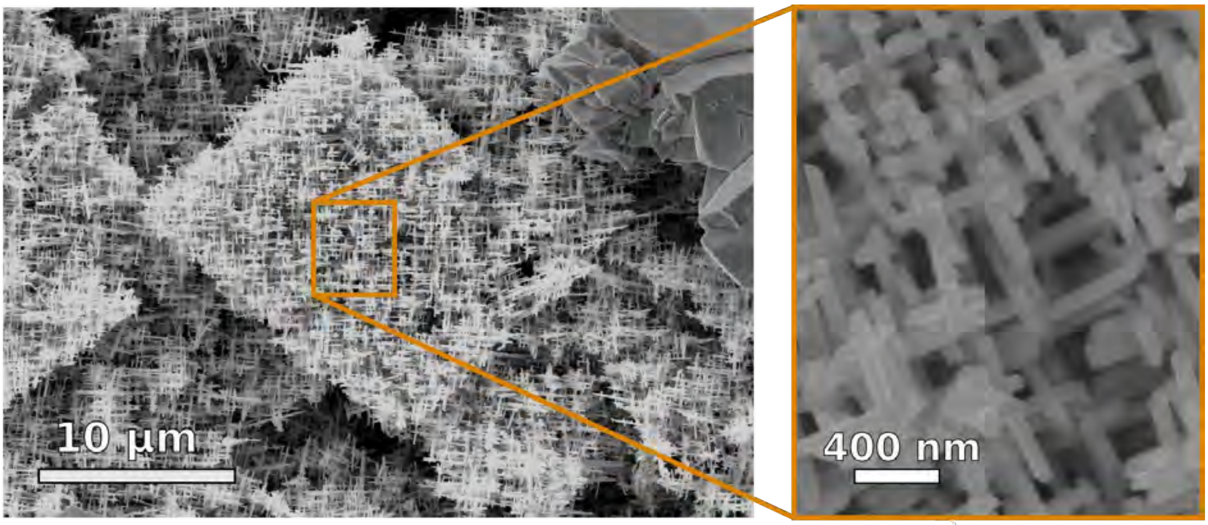

Fig. 1 SEM image of a Bi nanowire network consisting of 1.4·× 10^9 wires per cm^2 with a wire diameter of ~100 nm together with a close-up illustrating the wires interconnected within the network.

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SPECIFIC CONSIDERATIONS AND GUIDANCE FOR THE ESTABLISHMENT OF IONIZING RADIATION FACILITIES

N. PESSOA BARRADAS and D. RIDIKAS

Physics Section, Division of Physical and Chemical Sciences,
Department of Nuclear Sciences and Applications, International Atomic Energy Agency,
Vienna International Centre, PO Box 100, A-1400 Vienna, Austria

Various nuclear techniques have led to opportunities to enhance quality of life through services offered by ionizing radiation facilities (IRFs). National nuclear institutions, universities, medical centres, and private companies have established and used IRFs not only for research and development purposes but also for the provision of commercial services and goods. The IAEA recently developed a publication that provides guidance for organizations and institutions working on IRF projects to enable them to undertake them in a well-organized manner. It includes considerations for a feasibility study, provides detailed methodologies on how to assess the status of the necessary infrastructure, and aims to help Member States as well as their respective organizations to understand their commitments and obligations associated with an IRF project. It is intended to be used by managers, staff, decision makers at the national level and other stakeholders at institutions that are seeking or supporting the establishment of an IRF. The presentation will introduce the most important aspects of guidance.

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INVESTIGATING RADIATION EFFECTS IN MATERIALS USING STATE-OF-THE-ART PARTICLE ACCELERATORS

Maik LANG, Devon DREY, Eric O'QUINN, William CURETON
University of Tennessee, Knoxville, TN, USA

Changyong PARK
Argonne National Laboratory, Argonne, IL, USA

Jörg NEUEFEIND
Oak Ridge National Laboratory, Oak Ridge, TN, USA

Christina TRAUTMANN
GSI Helmholtzzentrum für Schwerionenforschung & Technische Universität

We describe in detail a methodology for comprehensively characterizing radiation effects in nuclear and other materials using large-scale particle accelerator facilities [1]. Key to this approach are swift heavy ions with a penetration depth of ~100 µm, which is high enough to produce sufficient quantities of irradiated material for characterization using bulk techniques [2]. Irradiation experiments are performed at the UNILAC accelerator at the GSI Helmholtz Center using Au ions of 2 GeV kinetic energy (Figure 1). The irradiated samples are complementarily characterized by means of advanced (accelerator-based) scattering techniques at the Advanced Photon Source (APS) and Spallation Neutron Source (SNS). High resolution diffraction, absorption, and total scattering experiments reveal ion-beam induced structural and chemical modifications, such as defect formation (*e.g.*, CeO_2), disordering (*e.g.*, $Ho_2Ti_{2-x}Zr_xO_7$), crystalline-to-crystalline phase transformations (*e.g.*, Gd_2O_3) and amorphization (*e.g.*, Dy_2TiO_5). Diffraction techniques give information on phase behaviour and disordering/amorphization of the average crystal structure (long-range), while pair distribution function (PDF) analysis from total scattering data provides detailed real-space information on the local defect structure. X-rays provide excellent sensitivity to high-*Z* elements, while neutrons scatter strongly from low-*Z* elements. The combination of short and long length scale characterization techniques with high sensitivity to both cations and anions is particularly important for characterizing radiation effects in oxide materials for nuclear application (*e.g.*, UO_2). Based on several examples, we demonstrate that accelerator-based characterization techniques yield fundamental insight into radiation effects in materials that are much more complex than previously thought [3-6].

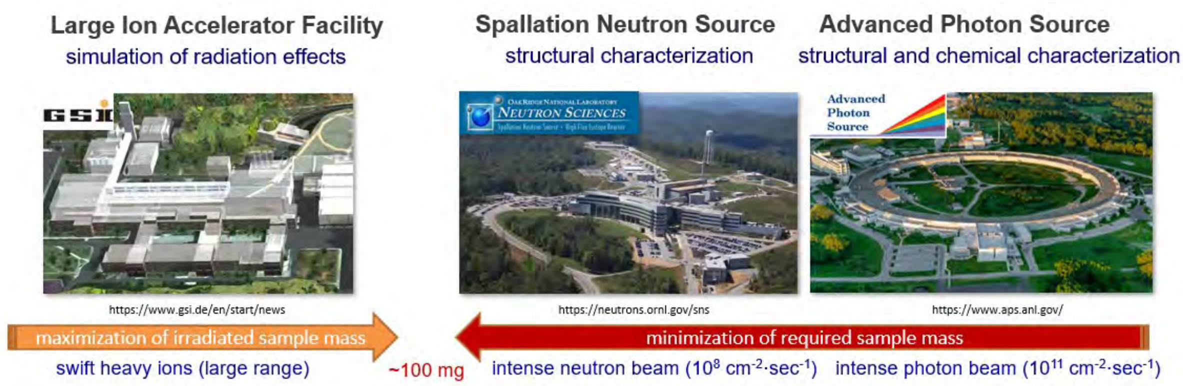

FIG. 1. Swift heavy ions with large penetration depths are required to produce sufficiently large quantities of homogeneously irradiated materials (~100 mg) that can be analysed by spallation neutron and synchrotron X-ray probes.

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ISOTOPE HARVESTING PROJECT: FROM WHITE PAPER TO IMPLEMENTATION

C.K. VYAS and G.W. SEVERIN
Facility for Rare Isotope Beams, Michigan State University,
640 S. Shaw Lane, East Lansing, Michigan - 48824, USA.

The Facility for Rare Isotope Beams (FRIB), at Michigan State University, is a premier nuclear science facility with the capability to accelerate beams of stable heavy ions up to hundreds of MeV/u. These primary heavy ion beams will be used to produce exotic secondary beams through a process that leaves 85-90% of the primary beam unreacted. The unreacted beam ultimately is delivered to a water-filled beam dump where a large number by-product radionuclides are formed. The Isotope Harvesting Project (IHP) is an upgrade for FRIB that will enable these otherwise-unused by-product radionuclides to be collected, or "harvested", for additional research in medicine, biochemistry, stewardship science, materials science, horticulture, and astrophysics. The scientific basis and justification for the IHP were captured in a whitepaper with inputs from researchers at multiple universities and U.S. national labs from diverse fields of study [1].

Specific infrastructure is required to realize the promise of radionuclide harvesting, and the U.S. Department of Energy's Isotope Program (DOE-IP) has agreed to support the IHP with an infrastructure grant of $13.2 M over a four-year period which started in September 2020. The proposed IHP infrastructure integrates state-of-the-art radiochemistry equipment and engineering upgrades into FRIB and provides a contiguous laboratory via which these radionuclides will be collected and purified for off-site use.

The major functions of the IHP's radiochemistry laboratory, called the "Isotope Harvesting Vault" (IHV), are summarized as five processes:

- Capturing radionuclides embedded in solid materials, or as ions or gases in FRIB's primary beam-dump cooling water and off- gas circuit via a direct connection to the IHV.
- Chemically processing the radionuclides to remove the majority of impurities.
- Purifying radionuclides to meet user specifications.
- Quantitatively assessing the quality of the produced radionuclides.
- Distributing the radionuclides to off-site laboratories.

This talk will cover the IHP's mission objectives, technical designs, plans for transitioning to operations, and proposed research and training opportunities for early career scientists.

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HOW SUPPORT FOR MACHINE-BASED SOURCES OF RADIATION CONTRIBUTES TO SUSTAINABLE DEVELOPMENT

Sarah NORRIS
Office of Radiological Security (ORS) - Department of Energy/National Nuclear Security Administration (DOE/NNSA), Washington, DC, USA

Shea COTTON
SMS Contractor for ORS – DOE/NNSA, Washington, DC, USA

Matthew KESKULA
Argonne National Laboratory, Washington, DC, USA

As stated by the International Atomic Energy Agency (IAEA), radiation-generating technologies can be used in support of 9 of the 17 UN Sustainable Development Goals. The U.S. Department of Energy/National Nuclear Security Administration's Office of Radiological Security (ORS), with the mission to prevent radioactive materials from being used in malicious acts, has been working to improve options for and adoption of advanced machine-based sources of radiation. In addition to supporting radiological security, these activities directly support the broader development goals of the IAEA. This paper will focus on how the following three areas of ORS work contribute to both security and sustainable development: cancer therapy with medical Linear Accelerators (LINACs), x-ray blood irradiation, and electron beam (e-beam) technologies for reuse of resources and wastes.

Machine-based sources of radiation often provide key advantages over traditional, radioactive source-based means of generating radiation. For instance, x-ray blood irradiators allow consistent, and typically higher, throughput across the lifespan of the device. And e-beam technology can play a significant role in providing clean water for growing urban populations around the world. Despite these technologies having operational, business, and security benefits, ORS recognizes that these technologies present challenges in terms of needing reliable electricity supply, trained/educated staff, and accessible service providers. Therefore, this paper also will highlight these challenges and ORS's perspectives on how the international community can work to address these challenges. Time is of the essence, and advanced machine based radiation generating technologies are essential to confronting the challenges associated with ensuring sustainable development.

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ON THE USE OF ION AND CLUSTER BEAMS ANALYSIS AT LAEC FOR FORENSIC SCIENCES: INFRASTRUCTURE AND APPLICATIONS

B. NSOULI, A. BEJJANI, M. ROUMIE
Lebanese Atomic Energy Commission, Lebanese CNRS, Beirut, Lebanon

G. CHALHOUB, M. HAMDAN
Central Bank of Lebanon, Beirut, Lebanon

Ion Beam Analysis techniques can present some unique analytical capabilities to characterize and investigate materials in cultural heritage, environment and biomedicine. These techniques are well established at the accelerator laboratory of the Lebanese Atomic Energy Commission, for more than 20 years, and they are widely used in different related studies and applications. Moreover, a new powerful tool is added to the analytical arsenal of the lab which is the Time-of-Flight Secondary Ion Mass Spectroscopy (TOF-SIMS) where molecular and elemental characterization of materials, as well as imaging, becomes possible and more information about the investigated objects are obtained. Some case studies were already performed on the investigation of archeological pottery and coins, for questions of provenance and authenticity, as well as on the quality of pharmaceutical drugs by quantifying their active ingredients. In addition, the forensic capabilities of IBA methods combined with ToF-SIMS were examined, in cooperation with the "Central Bank of Lebanon", for exploring the possibility of these techniques to reveal counterfeiting techniques of banknote denominations. The results of such application will be highlighted and discussed.

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SOCIETAL IMPACT OF THE COMPACT LINEAR COLLIDER STUDY

A. MAGAZINIK
CERN / Tampere University
Geneva, Switzerland / Tampere, Finland

N. KOKKINIS NTRENIS
University of Applied Science and Arts of Western Switzerland, Geneva, Switzerland

N. CATALAN LASHERAS
CERN
Geneva, Switzerland

S. MAKINEN
Tampere University
Tampere, Finland

J. SAUZA BEDOLLA
Lancaster University
Lancaster, The United Kingdom

S. STAPNES
CERN
Geneva, Switzerland

Over the past decade, an interest on the Societal Impact Assessment topic has increased. However, there is still a well-known problem in measuring the impact. Different developed methodological approaches such as econometric studies, surveys, case studies, do not create the full picture of the impact. Assessing the basic research outcomes is even more challenging, since it is usually required large government public funds, while the societal benefits are often implicit comparing to an applied science project. Therefore, the societal impact assessment of research infrastructure becomes essential for scientists in demonstrating and highlighting the source of economic value generated for society and economy, besides its absolute technological or scientific aspects.

Moreover, the European particle physics community repeatedly raises the question on the societal impact during discussions. The community meets to define a strategy for the future developments in fundamental research on physics by evaluating ongoing studies. Thereby in an open symposium in Granada in May 2019 [1], the committee highlighted a pure academic significance of an international collider study and its unclear technical and economic ripple effects for general public. Likewise, the European Strategy update in June 2020 again recommended to emphasize the scientific impact of particle physics, as well as its technological, societal and human capital outcomes [2]. Additionally, the committee underlined an importance of partnership with industry and other research institutes, as these collaborations are key for sustaining scientific and technological progress, helping to drive innovation, and bringing societal benefits. Furthermore, the particle physics attracts young minds and provide their education and training, so vital for the functionality of research infrastructure (RI) and of society at large.

Together with the elevated interest on the stated topic, the community of assessing societal impact of RI is expanding. Big scientific centres, institutes and laboratories around the World reunite their experience and knowledge to build a comprehensive assessment model. RI-PATHS [3] as a European project funded by EU with consortium of EFIS, CSIL, ESF, ALBA, DESY, CERN, ELIXIR and Fraunhofer ISI is one of the latest examples. A conceptual model for evaluation of social benefits has been proposed even earlier for the Large Hadron Collider [4]. The authors are introducing the Cost-Benefit Analysis (CBA) supported by a guide to CBA of investment projects issued by European commission [7]. Also the model has been employed in the appraisals of the HL-LHC [5] and a health care proton therapy centre [6].

The present paper is relevant to a big scientific study, Compact Linear Collider (CLIC) and scientific contexts within which a research organization, CERN, operates. CLIC is an international study for a future high-gradient machine (50.1 km long) to collide electrons and positrons head-on at energies up to several Teraelectronvolts (TeV). Building and operating such a large machine with its corresponding

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infrastructure is extremely costly. To prove required investment needs and importance of possible scientific discoveries we study potential effects on different concerned groups such as society, industry, and science world. Since CLIC is still at a study phase at this point, a societal impact can reinforce the decision-making process on the project implementation.

The research aims to identify the scale, nature, and sustainability of the impacts for main actors. The applied methodology is established based on the previous studies and describes concerned evaluating fields and proposed methods of appraisal (see Fig. 1).

FIG. 1. Societal impact assessment frame for CLIC study.

The paper will introduce the methodology and the valuation of human capital formation, technological impact, and knowledge formation. The document will also discuss the future study to be done to complete the societal impact assessment of CLIC.

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IFAST ACCELERATORS FOR SOCIETAL APPLICATIONS

T.R. EDGECOCK
University of Huddersfield, Huddersfield, UK

T. TORIMS
Riga Technical University, Riga, Latvia

A. SAGATOVA
Slovak University of Technology, Bratislava, Slovakia

G.C. BURT
Lancaster University, Lancaster, UK

A. CHMIELEWSKI, D. CHMIELEWSKA-ŚMIETANKO
INCT, Warsaw, Poland

A. FAUS-GOLFE
CNRS, France

C. OLIVER, D. OBRADORS-CAMPOS
CIEMAT, Spain

F-H. ROEGNER
Fraunhofer FEP, Dresden, Germany

The Accelerators for Societal Applications work package of the IFAST H2020 project is studying the novel applications of particle accelerators in the medical, environmental, industrial and imaging areas. It is building on the work of two previous H2020 and FP7 projects, ARIES and EuCARD2. All three of these projects were coordinated by CERN.

EuCARD2 did a thorough analysis of the existing and potentially new applications of accelerators at that time and published the results in a book entitled "The Applications of Particle Accelerators in Europe" [1]. Subsequently, ARIES and now IFAST have identified the novel applications with the best potential for commercialisation, studied them in detail and initiated development and prototyping activities to promote their industrial use.

In particular, IFAST is undertaking the following tasks:

— Novel forms of radiotherapy: this is studying new forms of radiotherapy for cancer treatment that are currently being developed, like FLASH, mini-beams and ion beams, and investigating accelerator developments able to achieve the optimal requirements for these treatments

— Environmental applications of electron beams: this is considering how to push forward environmental applications of electrons beams, in particular for the treatment of (a) wastewater and sewage sludge, (b) marine diesel engine exhaust gases and (c) ship ballast water

— Accelerator imaging: this is exploring innovation in the use of particle beams for imaging, in particular in the security and medical areas. The applications being studied are X-ray cargo scanning

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and non-destructive testing, neutron sources for non-destructive testing, proton radiography, X-ray imaging of dense targets and compact Compton sources

— Accelerator production of radioisotopes for imaging and therapy: this is investigating radioisotopes that have a large potential for medical imaging and therapy but are not available in sufficient quantities for regular use due to limitations arising from current accelerator technology. It is studying how new technology could be used to make them more available and how this could be implemented in practice, in particular in or close to hospitals

— Barriers to accelerator adoption by industry: this is studying the barriers which are discouraging some companies from benefitting from accelerator technologies. These include financial concerns, legal barriers, security concerns and lack of specialized knowledge. It is using experience from companies that have successfully introduced their use to address these concerns.

This presentation will describe many of these applications, show what has been learnt from the work being done and discuss the steps being taken towards commercialisation.

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SUSTAINABILITY STUDIES FOR LINEAR COLLIDERS

S. STAPNES
CERN, Geneva, Switzerland

B. LIST
DESY, Hamburg, Germany

S. MICHIZONO
KEK, Tsukuba, Japan

Two large electron-positron linear colliders are currently being studied as potential future Higgs-factories, the International Linear Collider (ILC) in Japan, and the Compact Linear Collider (CLIC) at CERN, Switzerland. The former is based on Super-Conducting 1.3 GHz RF technology and will start operation at 250 GeV (with length ~20.5km) centre-of-mass energy and the latter is based on room temperature 12 GHz copper RF structures starting at 380 GeV (~11.5km). The initial luminosities are in both cases estimated to be around $1.5 \cdot 10^{34}$ $cm^{-2}s^{-1}$, but either facility would be upgradable in energy and luminosity as part of a longer-term electron-positron collider programme. The facilities are extensively documented in (1) and (2).

Linear colliders rely on low emittance high intensity beams created in damping rings and ultimately being focussed to the nano-meter level at the collision point. Although very large facilities, ILC and CLIC have many common features, challenges, and proposed solutions with existing or planned Free Electron Laser Linacs and, for injector and damping rings, the Synchrotron Light Sources worldwide. ILC can be implemented rather quickly starting construction around ~2026, CLIC is an option for a post LHC accelerator at CERN and is being developed with this timescale in mind.

Sustainability has become a prioritized goal in planning and implementation of future large accelerators. Both linear collider projects, collaborating in many areas, have extensively studied novel design and technology solutions to address power efficiency and reduce the environmental impact of the facilities. The sustainability considerations, in addition to the more traditional cost concern and need for developing core technologies, are today the primary R&D drivers for the projects.

Concerning energy consumption, the ILC power consumption has been estimated to 110 MW at 250 GeV and CLIC to 170 MW at 380 GeV. The ILC numbers are optimised while the CLIC numbers might still have a 10-15% potential for improvement. Turning these power numbers into yearly energy consumption gives estimates in the range of 600-800 GWh. As a reference CERN uses around 1.2 TWh of electricity yearly.

To achieve these numbers several dedicated studies have been conducted to control and reduce the power consumption, in parallel with studies considering the environmental impact of the facilities in a wider sense. Many of these studies are widely applicable and generally relevant for future accelerator facilities. Among these are:

— The designs of ILC and CLIC, including key performance parameters as accelerating gradients, pulse lengths, bunch-charges and luminosities, have been optimised for cost but also increasingly focussing on reducing power consumption.

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— Technical developments targeting reduced power consumptions at system level, primary examples are developments of high Q and high gradient SC cavities (3), high efficiency klystrons (4), and super conducting and permanents magnets for damping rings and linacs. In many cases these studies are equally applicable and relevant for other accelerator facilities, and cover a wide range of possible installations.

— Local impact studies of establishing ILC as a new laboratory in the Tohoku region in Japan (5). These studies focus on establishing a "thermal eco-community", utilizing excess heat for agriculture and fishery. Other elements are use and production of local materials for construction, also utilizing waste heat, reducing the ecological footprint, use and development of local infrastructure benefitting the entire community, availability of "green" energy and other key resources for establishing a new large laboratory, etc. Implementing CLIC in a tunnel below the existing LHC ring at CERN have similar challenges but can also benefit from the fact that the LHC accelerator was already constructed in this area.

— The possibility of making use of the fact that the linear colliders are single pass, i.e. the beams and hence power are needed "shot by shot", possibly allowing to operate in daily or weekly time-windows when power is available in abundance from suppliers and costs are reduced (2). Seasonal operation is already being used for energy cost reasons.

— Estimating the renewable power that can be made available for running the colliders by investing for example 10% of the overall construction costs in solar and wind energy capabilities, again profiting from the fact that single pass colliders can quickly adapt to changes in energy output from such sources (2).

— Technical solutions for recovering energy losses in all parts of the accelerator, to be reused for acceleration and/or for use in the local area (homes, industry) near the facility.

In many cases the studies mentioned are still on-going and the programme for further work will also be presented. The studies above provide some possible answers that can help to construct sustainable future accelerator facilities, but a full analysis of the start to end environmental impact including carbon footprints will still need to be done for ILC and CLIC.

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RIKEN Accelerator-driven compact neutron systems and RANS project - RANS developments and achievements for a sustainable society -

Yoshie OTAKE

Neutron Beam Technology Team, RIKEN Center for Advanced Photonics, RIKEN

At RIKEN, two accelerator-driven compact neutron systems are currently operating independently and are used daily by companies and researchers for experiments and advanced developments using neutrons.

The objective of the RANS (RIKEN Accelerator-driven compact neutron systems) project is to maximize the potential of compact neutron sources from the point of view of on-site use and to develop a n novel model of easy-to-use compact neutron system that meets the needs from the point of view of non-destructive testing, in order to realize a sustainable society. There are two main needs: indoor applications for the non-destructive testing and analysis of various materials and products, and outdoor applications for the detection of deterioration to ensure the safety of infrastructure. In both cases, on-site use is a key feature.

In order to maximize the potential of the compact neutron source, the first RANS instrument including cold source system has been improved and RANS-II has been further developed as a more compact system. RANS has succeeded in developing a new development that enables stress measurement. RANS-II produces the same characteristics of the neutron beam as the trans-portable system of RANS-III and has succeeded in developing new measurement techniques such as floor slab deterioration, detection of thin water existence in suspension bridge cables, etc. as a non-destructive visualization technique for outdoor use of as a non-destructive inspection technique for infrastructure, which is one of the important development goals of the RANS project. The design of the shielding system around the neutron source and detectors for outdoor use of RANS-III has been started, and the construction for indoor tests before outdoor use will be started in the next fiscal year.

The development of the RANS-μ with 252Cf, initiated to meet urgent requirements, is progressing steadily and outdoor tests were carried out in December 2021

All the activities including T-RANS (Technical research association of neutron next generation system) and the potential of the compact neutron system will be discussed.

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LASER-DRIVEN ION ACCELERATORS: UNIQUE BEAMS AND COMPACT NEUTRON SOURCES

Markus ROTH

Institute for Nuclear Physics, 64289 Darmstadt, Germany

Ultra-intense lasers have matured to the point where they reliably can create relativistic plasmas. The limiting breakdown voltage, a common constraint in conventional accelerators is of no concern in a plasma, and the accelerating fields, created by charge separation of electrons and ions can reach levels, million times stronger compared to RF-based accelerators.

Laser-plasma accelerators have reached ten's of MeV of ion energy in sub-millimeter structures and currents of hundreds of kiloamperes. The ion beams can be used for material modification, medical applications, non-destructive testing and most recently as a driver for a compact neutron source.

One exciting application was nondestructive testing methods and material selective imaging of compound large objects, which is possible using thermal and fast neutrons.

After presenting the underlying mechanism to create an intense pulsed and highly directed beam of neutrons and recent experimental results I will focus on a few examples of using such sources for applications that are either important for the security of our countries or will have large economical potential in industrial applications. These range from the remote sensing of illicit nuclear material in cargo to the non-destructive analysis of large civil constructions using compact laser systems. Finally, a possible path forward is sketched that will lead to a useable tool for member states to accomplish their goals securing the peaceful use of the atom.

ACCELERATOR TECHNOLOGIES FOR FOOD SAFETY AND FOOD QUALITY: RESPONSE OF MICROBIAL POPULATIONS TO IONIZING TECHNOLOGIES.

Suresh D. PILLAI
National Center for Electron Beam Research, Texas A&M University

There have been major advances in accelerator technologies over the past two decades. Today, electron beam (eBeam) and X-ray accelerators of varying energies and beam power are commercially available. The technological advances in accelerator technologies are still on-going in terms of modularity, reduced footprint, self-shielding capabilities, advanced control and troubleshooting and compactness. There is a need for a greater adoption of these technologies in the food industry around the world. Presently, phytosanitary treatment applications are driving the adoption of accelerator technologies. However, reducing food spoilage by extending the shelf- life of foods and reducing the potential for pathogens in and on foods will also become major drivers for the adoption of these technologies. There is a significant diversity in the types of microbial pathogens and spoilage organisms that need to be addressed by this technology. The inherent resistance of enteric viruses (eg. Norovirus) to ionizing radiation is significantly greater than bacterial pathogens, and spoilage-causing fungal spores require higher doses vegetative bacterial cells. Still, spore-forming bacterial pathogens such as Cl. Perfringens are still major concerns to the food industry. The emergence of toxin producing algal cells is a also an emerging threat in foods from aquatic sources. Historically, traditional culture-based methods have been used as the cornerstone of identifying the response of microbial cells to ionizing radiation. However, today we know that even though cells when exposed to lethal doses and are unable to replicate and multiply (ie., inactivated), these microbial cells are exhibiting very defined metabolic processes several days post irradiation treatment. These Metabolically Active yet Non-Culturable (MAyNC) cells are of particular significance. We know that the transcriptomic and metabolite profiles of inactivated cells are different at varying days post irradiation treatment and completely different from the unirradiated cells. We, however, do not know the microbiological significance of MAyNC state especially because when low dose irradiation treatments are used on fresh produce (during phytosanitary treatment) and for shelf-life extension. There is an urgent need to better understand the microbiological relevance of metabolically active microbial cells that are expected to be present when food irradiation doses are utilized.

CANS PRODUCTION OF TECHNETIUM-99M AND TECHNETIUM-101

N. MAYORDOMO
Institute of Resource Ecology, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

E.J. MAUSOLF, E.V. JOHNSTONE
Innovative Fuel Solutions LLC, Las Vegas (NV), USA

D.L. WILLIAMS, E.Y.Z. GUAN, C.K. GARY
Adelphi Technology, Inc., Redwood (CA), USA

J. DAVIS
Shertech Laboratories, Duncan (SC), USA

Technetium-99m (^{99m}Tc, $t_{1/2}$ = 6.007 h) has been widely used for radiodiagnostic purposes for decades, and it is still one of the most used radioisotopes worldwide with an estimated 40 million doses consumed annually. Tc-99m can be produced through various nuclear transmutation methods, but commercially speaking, it is generally derived from molybdenum-99 (^{99}Mo, $t_{1/2}$ = 65.925 h), where the origin of it is dependent upon chemistry and isotopic composition of the target material, e.g., natural or enriched Mo, or enriched ^{235}U targets. However, the production and distribution of ^{99m}Tc relies on a complex supply-chain that has proven itself prone to disruptions in years past and was most recently observed during the SARS-CoV-2 pandemic.[1] Ultimately, this leads to delays on diagnoses of patients due to postponed imaging procedures as well as the loss of material and capital.

As a solution to this problem, the deployment of a decentralised network of compact accelerator neutron sources (CANS) for producing ^{99m}Tc and ^{101}Tc ($t_{1/2}$ = 14.22 min) using the (n,γ) reaction on Mo-based targetry has been proposed.[2] For example, the use of fusion-driven deuterium-deuterium (D-D) neutron generators for producing both ^{99m}Tc and ^{101}Tc has been demonstrated along with their subsequent isolation using a separation tailored for low-specific activity ^{99}Mo targets.[2]

Another under-utilised source of neutrons already being generated in this fashion is during the production of many positron emission tomography (PET) radionuclides in cyclotrons, where parasitic neutrons are liberated from the cyclotron target, e.g., ^{18}O(p,n)^{18}F. The implementation of larger production batches, high yield targetry, and more production runs are all complementary to generating neutrons. From this, the hybridised production of ^{99m}Tc and ^{101}Tc concurrently during [^{18}F]FDG has been demonstrated and its feasibility explored (FIG. 1).[3]

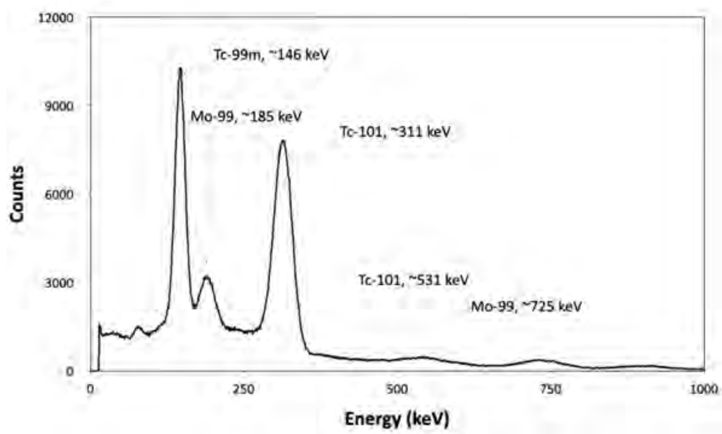

FIG. 1. NaI gamma spectrum of Mo / Tc isotopes generated from the irradiation of a natural Mo target during [^{18}F]FDG manufacturing

The aim of the work presented herein is to compare various CANS production modes for ^{99m}Tc and ^{101}Tc production in regard to their subsequent applications. Further, it provides potential alternatives for the future production of radiopharmaceuticals, meanwhile meeting the objectives of several Unesco and sustainable development goals.

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A COMPACT ACCELERATOR DRIVEN NEUTRON SOURCE AT THE NUCLEAR-APPLICATIONS LABORATORY, LUND UNIVERSITY

FROST, R.J.W., ELFMAN, M., FISSUM, K., KRISTIANSSON, P., MAURITZSON, N., PALLON, J., PERREY, H., STENSTRÖM, K.E.
Division of Nuclear Physics, Lund University, Lund, Sweden

PEDEHONTAA-HIAA, G.
Division of Nuclear Physics, Lund University, Lund, Sweden
Medical Radiation Physics, Lund University, Malmö, Sweden

SJÖLAND, A.
Division of Nuclear Physics, Lund University, Lund, Sweden
Swedish Nuclear Fuel and Waste Management Company, SKB, Solna, Sweden

The Applied Nuclear Physics Group at Lund University has constructed a prototype CANS (Compact Accelerator-driven Neutron Source) [1,2], which is entering pre-commissioning. The CANS is based around a 3 MV, single-ended, Pelletron accelerator, which is used to direct a 2.5 MeV deuterium beam into a beryllium target. The anticipated neutron production will be on the order of 10^{10} n/s in 4π str. A further upgrade to the ion source of the Pelletron is expected to increase neutron production to 10^{11} n/s. Neutron energy will be up to 7 MeV with peak emission at ~5 MeV. Shielding and moderation will be provided by a large water tank surrounding the target, with exit ports to allow moderated-neutron beams to be directed to experiments. The anticipated thermal-neutron flux at the exit port of the shielding tank is ~10^6 n/cm^2/s. The immediate application of the CANS will be to forward the activities of the group in the area of NAA (Neutron Activation Analysis) [3], as part of a project (SSM2021-787-8) funded by SSM (Swedish Radiation Safety Authority). The project will aim to monitor for the presence of specific radionuclides in environmental samples, taken from around the ESS (European Spallation Source) [4]. In addition to NAA, the CANS will be used: in the develop of novel state-of-the-art instruments and methods for the characterisation of spent nuclear fuel, with the purposes of enforcing nuclear safeguards [5]; to test and categorise detectors for neutron-scattering instrumentation [6]; for work on thermal-neutron tagging [7]; and as an educational platform. The CANS will also be made available to external users. An overview of activities at the Nuclear-Applications Laboratory will be presented, focusing on details of the design and construction of the CANS, as well as its current and future applications. The question of how this and other such small-scale facilities are anticipated to fit in to the future neutron-production infrastructure within Scandinavia will also be addressed.

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THE SONATE PROJECT, A NEW NEUTRON SCATTERING PLATFORM FOR MATERIALS SCIENCE RESEARCH.

F. OTT and A. MENELLE

Laboratoire Léon Brillouin, CEA/CNRS, Univ. Paris-Saclay, CEA Saclay, 91191 Gif sur Yvette.

The European neutron scattering community is the largest in the world, gathering more than 6000 scientists performing experiments around neutron research reactors and spallation sources. The European landscape of neutron facilities is evolving quickly with the closure of a number of aging research reactors: for example the reactor Orphée in France, BER in Berlin and Kjeller in Norway closed in 2019; the closure of the High Flux Reactor in Grenoble is also planned to take place early in the next decade. While the European Spallation Source (ESS) should start later in this decade, its capacity will not be sufficient to replace the closed facilities. Hence, the Laboratoire Léon Brillouin (LLB), operated by the CEA and the CNRS in France, is developing a project plan to build a facility using a High Current Compact Accelerator driven neutron source (HiCANS). The aim is to provide the needed access to neutrons to the French research community in the next decade. In collaboration with accelerator and neutron experts from the CEA, a reference design for a source dubbed SONATE ('Source cOmpacte de Neutrons s'Appuyant sur la Technologie des accélératEurs') emerged and first proofs of concept have been established on the IPHI – Neutron platform [1]. We will present the latest progress in the development of the different technologies (accelerator & target) necessary to build a CANS with performances on par with medium power nuclear reactors in the field of neutron scattering.

[1] The *IPHI – Neutron* project is supported by the region Ile-de- France. For more information, see the SONATE and IPHI – Neutron Project website.

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TOWARDS COMPACT LASER-DRIVEN ACCELERATORS : EXPLORING THE POTENTIAL OF ADVANCED DOUBLE-LAYER TARGETS

A. MAFFINI, F. MIRANI, A. FORMENTI, D. VAVASSORI, D. DELLASEGA, V. RUSSO, M. ZAVELANI ROSSI, M. PASSONI
Politecnico di Milano Milano, Italy

The interest towards compact, cost-effective and versatile hadron accelerators is increasing for many applications of great societal relevance, ranging from nuclear medicine to agriculture, pollution control and cultural heritage analysis and conservation. In this context superintense laser-driven ion acceleration represents a promising alternative to conventional accelerators, addressing some of their limitations such as limited flexibility in terms of particle energy and nature, radioprotection issues, high costs, high energy consumption and non-portable size [1]. Among the different laser-based ion acceleration mechanisms that have been proposed in the last two decades, the so-called target normal sheath acceleration (TNSA) is arguably the most studied and understood acceleration scheme. In TNSA ultra- short (pulse duration < 100 fs), ultra-intense ($I > 10^{18}$ W cm^{-2}) laser pulses irradiate a μm- thick solid target, generating a hot electron population which expand at relativistic energies towards the back side. The resulting charge separation give rise to a very strong sheath electric field (few MV μm^{-1}) which is responsible for the acceleration of bunches of light ions (around 10^9 protons per shot) up to energies of tens of MeV per nucleon [1].

The great potential of laser-driven ion acceleration has stimulated different research approaches aimed at the enhancement of the acceleration performances, especially in terms of energy and number of accelerated ions. A widely investigated strategy relies on the continuous progress in laser technology, which can ensure an improvement of the relevant laser parameters (pulse energy, intensity, repetiton rate) and hence of the overall acceleration performance. This approach is of primary importance for the advancement of fundamental research and the study of novel laser-plasma interaction regimes; however, since it ultimately relies on the availability of a limited number of top-class, state-of-the-art laser facilities, it cannot find a widespread diffusion in developing countires and will hardly lead to a practical compact and cost-effective alternative to conventional accelerators in the near future. A complementary approach focuses on the optimization of the laser-target coupling, since a more efficient laser absorption results in an enhancement of ion current and energy with reduced requirement on the laser side. Among the advanced target concepts that have been explored, one appealing option is given by double-layer targets, where a very low-density layer, which acts as the enhanced absorbers, is attached to a micrometic solid foil [2,3].

In this contribution we present and review the most recent result we obtained in the field of laser-driven ion acceleration with advanced double-layer targets [2,3], with a specific focus on the applications of relevant societal interest like non-destructive material characterization [4], neutron generation [5] and medical radioisotope production. We believe that our results could prove critical toward the development of compact, smart and cost-effective laser-driven accelerators, which could be available to a much broader pool of potential users (including hospitals and high-tech enterprises) compared with present-day conventional accelerators. Moreover, a new community of scientists (especially from emerging and developing countries) could be empowered with a research capability that today is only accessible within large-scale facilities.

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IAEA ACTIVITIES IN SUPPORT OF COMPACT ACCELERATOR BASED NEUTRON SOURCES

Ian SWAINSON, Haifa BEN ABDELOUAHED, Sotirios CHARISOPOULOS, Kalliopi KANAKI, Steven MELLARD, Milan MATOS, Nuno PESSOA BARRADAS, Danas RIDIKAS, Natko SKUKAN

Division of Physical and Chemical Sciences, International Atomic Energy Agency, Vienna, Austria

The IAEA has several on-going activities in the area of compact accelerator based neutron sources (CANS) and their applications. In 2021, TECDOC-1981 was published on this topic giving an overview of types of CANS available, their potential applications, and issues such as licensing and decommissioning such facilities. Currently we are finalizing another technical document on boron neutron capture therapy (BNCT), a field which is being "revolutionized" by the availability of several CANS technologies that can be readily installed in a clinical environment. Japan led the world by giving approval to one system for routine clinical use in locally recurrent non-resectable head and neck cancer in 2020. We expect to have further development in this field in the coming years. Finally, at our Seibersdorf Laboratories, we are commissioning a new Neutron Science Facility (NSF) based on DD and DT generators to be used mainly for education and training purposes but also to demonstrate some of the neutron techniques such as neutron activation analysis, prompt gamma activation analysis, delayed neutron counting, neutron radiography/tomography, and some others.

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ILU RF ELECTRON ACCELERATORS FOR E-BEAM AND X-RAY APPLICATIONS.

A.A.BRYAZGIN
Budker Institute of Nuclear Physics, Novosibirsk, Russia

ILU type industrial accelerators are RF pulse accelerators with energy range from 0.8 to 10 MeV. First of these accelerators where designed 1970's. But market development requires continuous modernization of accelerators. Great prospects for the use of accelerators in industry are provided by a new market - food irradiation. The report describes accelerator upgrades associated with food irradiation and sterilization. For this, accelerators must operate with energies from 5 MeV to 10 MeV in the electronic mode and in the mode of bremsstrahlung gamma radiation. Two branches of ILU accelerators are described. One is based on an ILU-10 single-cavity accelerator and a vertical beam. The second is based on the ILU-14 multi-cavity accelerator, which has a horizontal beam, see Fig. 1. Both families are modular and upgradeable.

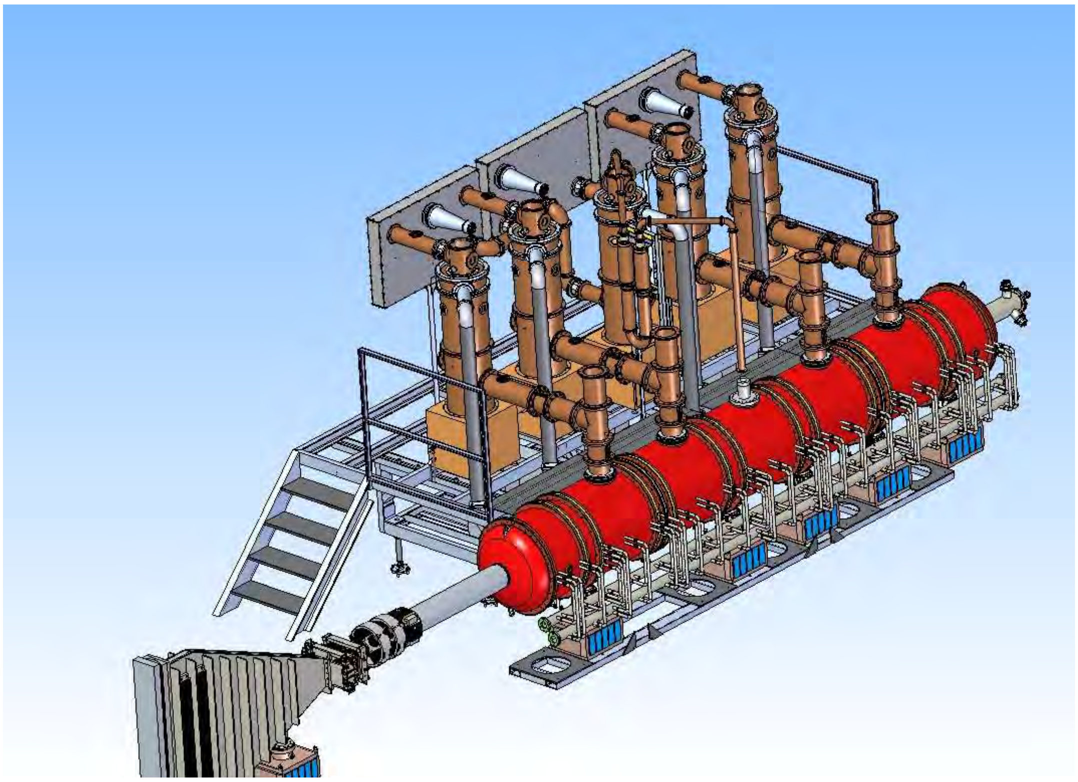

FIG. 1. Accelerator ILU-14

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ELECTRON BEAM PROCESSING TO IMPROVE BIODEGRADABLE POLYMERS AND FOR INDUSTRIAL WASTEWATER TREATMENT AND RECYCLING

W.A.P. CALVO; P.M. MUNHOZ; S.L. SOMESSARI; C.L. DUARTE; F.E. SPRENGER; A. FEHER; F.F. LAINETTI; R.R. GASPAR; F.C. NASCIMENTO; L.G.A. SILVA; J. HARADA; A. BRAGA; M. RODRIGUES; M.H.O. SAMPA.
Nuclear and Energy Research Institute (IPEN-CNEN), São Paulo/SP, Brazil

Radiation technology has been used to control environmental pollution. The aim of these studies was to apply the electron beam radiation technology for controlling plastic pollution and environmental protection.

(1) Mobile irradiation unit:

The treatment of wastewater and industrial effluents by electron beam irradiation is a promising technique. The design and construction of a mobile unit by the Nuclear and Energy Research Institute (IPEN-CNEN), containing an electron beam accelerator of 0.7 MeV and 20 kW is innovative to demonstrate the effects and positive results of this technology, as shown in Fig. 1. The mobile unit has as one of its main advantages the possibility of treating effluents in the place where the source is located, eliminating costs and bureaucratic problems associated with the transportation of waste, besides publicizing the technology in several places in the country. To implement the project, IPEN-CNEN has been consolidating partnerships with national and international companies. The resources for the development of the unit have been supplied by the Brazilian Innovation Agency (FINEP) and International Atomic Energy Agency, financing the "IAEA TCProject BRA1035 - Mobile electron beam accelerator to treat and recycle industrial effluents". The Institute has associated with a specialized company (Truckvan Industry) in an innovation project for the unit design and development. A 3D model study of the control room and laboratory space was done to facilitate understanding the internal distribution of the laboratory analysis equipment (Gas Chromatography Mass Spectrometry, Total Organic Carbon and UV-Visible Spectroscopy). The irradiation system with electron accelerators allows treating different types of effluents. Depending on the effluent, the amount of ionizing radiation energy required for treatment may vary, as well as the amount of treated effluent per day. For the construction of the mobile unit, the estimated cost is about US$ 1.5 Million. The type of treated effluent, the treatment cost per m3/day and other information regarding the cost of maintenance and operation of the mobile unit are obtained from the Business Plan of the Mobile Unit.

FIG. 1: Mobile electron beam irradiation unit for the treatment of industrial effluents in Brazil.

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(2) PBAT/PLA polymeric blend Ecovio®

The mechanical properties of the PBAT/PLA polymeric blend Ecovio® irradiated by electron beam were evaluated, as shown in Fig. 2. A reduction of 78.6% was observed in relation to tensile strength at the highest radiation dose of 80 kGy. There was also a reduction of 80% in Yong's modulus at this absorbed dose. A significant change in hardness was not observed at a dose of 65 kGy in relation to the non-irradiated material. The absorbed dose of 65 kGy was noteworthy, because at this dose, there was an increase of 43% in impact strength resistance and an increase of 17.4% in thermal stability of the polymeric blend**.**

Therefore, products made with the biodegradable polymeric blend need to be resistant to cross- sectional demands, impact and thermal stability and should have an average lifetime of 1 to 5 years. Then, for products, such as injected packaging, films for tube production, plastic bags, packaging for cosmetics and food packaging, among others, it is recommended to use the PBAT/PLA polymeric blend Ecovio® irradiated by electron beam with adsorbed dose of 65 kGy.

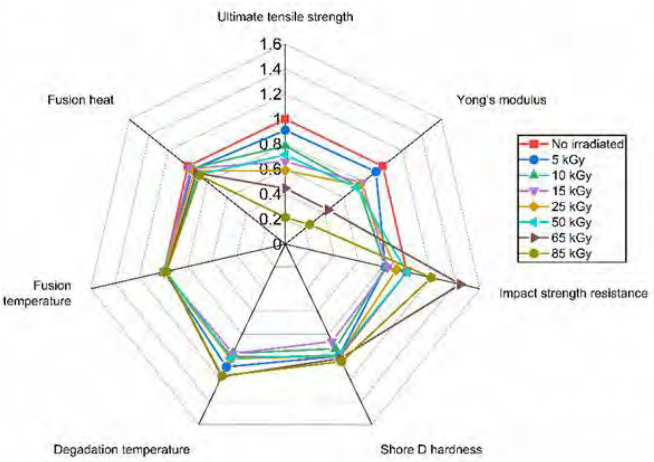

FIG. 2: Results of mechanical and thermal analyzes of the PBAT/PLA polymeric blend as a function of the absorption dose.

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EFFECT OF E-BEAM IRRADIATION ON THE MICROBIAL QUALITY OF MINIMALLY PROCESSED PRODUCTS : A CASE OF A COMMERCIALIZED READY TO EAT SALAD.

Sihem JEBRI, Faten RAHMANI, Widad ZERNADJI, Mariem YAHYA, Fatma HMAIED

National Center of Nuclear Sciences and Technologies, SidiThabet/Ariana, Tunisia

Socio-economic development during last decades in Tunisia has led to changes in eating habits such as the consumption of ready to eat products, mainly fresh vegetables and commercialized ready to eat salad [1]. Fresh vegetables do not undergo bacterial heat treatment before consumption and may constitute a potential health-risk product. Therefore, spoilage microorganisms could contaminate fresh salads and cause several food-borne diseases [2]. To meet consumers demand in providing nutritious, safe, and sustainable supplies of food, industrials are investing in non-thermal processing for pathogens elimination and shelf-life extension. Hence, the use of safe disinfecting treatment like gamma and E-Beam irradiation seems to be a good alternative to ensure good quality and safe salads [3,4]. In this study, freshly packaged carrot salads were collected from an agri-food industry before and after packaging process just before its distribution to be commercialized. The mean concentrations of total aerobic plate count, *Staphylococcus spp.* molds and yeast on fresh carrot salads were 4.87; 2.08; 7.47 and 2 Log_{10}/25g respectively. The concentration of *Staphylococcus spp.* yeast and molds increased on final packaged product. This could be related to grating or packaging process that might be a potential source of final product contamination. Collected samples were irradiated with gamma rays (Co^{60} source) at various doses (0.5, 1.0, 2.0 kGy). Then, in a second step, ready to eat salads were processed at an E-Beam accelerator (CIRCE 3, SGN, France). Doses were ranging from 1kGy to 5kGy. Irradiated products were analyzed for total aerobic plate count, *Staphylococcus spp.*, yeasts and molds during 15 days of storage period. Results of gamma irradiation showed that an optimal dose of 2kGy offered a pathogen-free, hygienic product in comparison with controls. Furthermore, it extended the shelf-life of commercialized ready to eat salad at refrigeration temperature. Microbiological quality of processed food during storage period was evaluated. Preliminary results showed that E-Beam is effective regarding pathogens reduction and shelf-life extension at a dose of 4kGy. The validity of both processing treatments at 2kGy and 4kGy was challenged by artificial contamination of sterilized product using *Staphylococcus aureus* strain (ATCC 25823). D_{10} values were determined, as the irradiating dose needed to reduce microorganisms by 90% for irradiated samples. Preliminary results of artificial contamination corroborate the use of E-Beam irradiation of ready to eat salads at a dose of 4kGy after packaging process and prior to commercialization. E-Beam irradiation seems to be more adequate for ready to eat food treatment to avoid contamination occurring during packaging process and to extend its shelf-life while maintaining its original organoleptic characteristics with a reduced processing time.

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LOW-ENERGY ELECTRON ACCELERATORS AND SOURCES WITH PLASMA EMITTERS FOR SCIENTIFIC AND TECHNOLOGICAL PURPOSES

M.S. VOROBYOV, N.N. KOVAL, S.A. SULAKSHIN, V.V. SHUGUROV, V.N. DEVYATKOV, P.V. MOSKVIN, V.I. SHIN, S.YU. DOROSHKEVICH, M.S. TORBA

Institute of High Current Electronics SB RAS Tomsk, Russia

At present, low-energy sources (up to 30 keV) and accelerators (up to 200 keV) of electrons find wide practical and scientific use and have a wide range of parameters of the generated electron beam, which is determined by the problem being solved. Thus, electron sources can also be used for processing various organic materials (polymers, gases, food or medical products, etc.) [1–8], generating beams with a relatively low energy density, most often outputted into the atmosphere through an output foil window, or for processing various inorganic (metallic and cermet) materials in vacuum in order to change the functional and operational properties of their surface [9–12]. Such problems can be rationally solved using sources of electrons with plasma emitters based on arc or glow discharges. The work will consider three systems, each of which is unique in terms of a set of basic parameters, namely:

1) Low-energy source of electrons "SOLO" (Fig. 1), which allows generating a wide intense electron beam of submillisecond duration for the implementation of the purposes of pulsed modification of the surface of metallic materials and simulation of extreme thermal effects. Beam parameters: electron energy up to 30 keV, beam current up to 500 A, pulse duration up to 1 ms, pulse repetition rate up to 10 s^{-1}, beam diameter up to 5 cm). The source has the ability to control the beam power, based on the unique property of sources with plasma cathodes, which consists in a weak dependence of the parameters of the generated electron beam from each other, which makes it possible to control the rate of energy input into the surface of the metal material, and, in particular, the temperature of this surface, which can be extremely important in the implementation of a scientific search for the optimal exposure regime.

2) Low-energy electron accelerator "DUET", which generates a beam of large cross-section (≈1000 cm^2) with its extraction into the atmosphere or high-pressure gas. This electron accelerator operates in a repetitively pulsed mode (electron energy up to 200 keV, beam current up to 50 A, pulse duration up to 100 μs, pulse repetition rate up to 50 s^{-1}) and can be used to solve environmental problems (dioxin-free conversion of polyvinyl chloride into carbon films), chemically pure modification of the properties of natural latex, utilization of gaseous silicon tetrafluoride to obtain pure silicon at the output, in the agricultural field for disinsection, disinfection and growth stimulation, for example, cereals, etc. One of the unique features of the accelerator, in addition to the range of parameters of the generated beam, is the ability to control the width of the energy spectrum of the beam ejected into the atmosphere, which determines the depth of passage of an electron in matter (liquids, gases, polymeric materials, etc.) can be an extremely important factor in solving various technological tasks.

3) Low-energy electron accelerator "HELION", the principle of operation of which is based on ion-electron emission, which generates a beam of large cross-section (≈3000 cm2) with its outputting into the atmosphere or high-pressure gas. Unlike the DUET accelerator, the HELION accelerator has a constant generated electron beam current (electron energy up to 160 keV, beam current up to 100 mA), but it can be used to solve problems similar to the DUET accelerator. "HELION" has a simpler design, smaller weight and dimensions, as well as a longer service life of the high-voltage cathode, which is a

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metal plate. A method for high-frequency (tens of kilohertz) generation of an auxiliary discharge generating emission plasma, and, accordingly, high-frequency generation of an electron beam of the same frequency, ejected into the atmosphere, is demonstrated.

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PRESERVATION OF PHOTOGRAPHIC AND CINEMATOGRAPHIC FILMS BY ELECTRON-BEAM IRRADIATION

P.A.S. VASQUEZ, M.L.E. NAGAI, M.J.A. OLIVEIRA, L. OTUBO, E.S.R. SOMESSARI

Nuclear and Energy Research Institute– IPEN/CNEN/SP, Sao Paulo, SP, Brazil

The Nuclear and Energy Research Institute – IPEN through the Multipurpose Gamma Irradiation Facility and the Electron Beam Irradiation Facilities has disinfected several tangible cultural collections from the University of São Paulo – USP. Brazilian weather conditions added to the actions of insects and fungi promote biodegradation especially in cellulose-based materials. In this sense, ionizing radiation is an excellent alternative to the traditional preservation process mainly because the biocidal action. Electron beam irradiation also presents new possibilities for processing materials with greater speed, despite having limited penetration. Adequate storage of photographic and cinematographic materials is a challenge for experts from preservation institutions. Contamination by fungi is one of leading causes of problem in this kind of collections. In addition, another common physicochemical degradation affecting cellulose triacetate films causing deacetylation of polymer chain is called "vinegar syndrome". In this work are presented results of the effect of the electron beam irradiation on photographic and cinematographic films using an electron beam accelerator with energy of 1.5 MeV and beam power of 37.5 kW. Selected film samples were characterized by FTIR-ATR spectroscopy and FEGSEM-EDS microscopy. Samples were irradiated with absorbed dose between 2 kGy and 200 kGy. Irradiated samples were analyzed by UV-Vis spectrophotometry, FEGSEM, thermogravimetric analysis (TG) and differential scanning calorimetry (DSC). Results showed that disinfection by electron beam radiation can be achieved safely applying radiation absorbed doses between 6 kGy to 10 kGy with no significant change or modification of main properties of the constitutive polymeric materials. Electron beam irradiation, due to the effect of crosslinking is presented as an alternative to treat films affected by "vinegar syndrome" applying absorbed dose of 80 kGy in order to increase shelf life of cultural heritage materials.

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PIGE ANALYSIS OF FLUORINE IN MATERIALS FOR THE CIRCULAR ECONOMY

Massimo CHIARI
INFN – Division of Florence, Sesto Fiorentino, Italy

Per- and polyfluoroalkyl substances (PFASs) are highly persistent synthetic chemicals, some of which have been associated with cancer, developmental toxicity, immunotoxicity, and other health effects. PFASs in grease-resistant recyclable food packaging can leach into food and increase dietary exposure and can also contribute to environmental contamination during production and disposal.

Samples of food paperboard containers and beverage containers from canteens and restaurants throughout Italy were collected and the total fluorine content was measured using particle-induced γ-ray emission (PIGE) spectroscopy at the LABEC ion beam laboratory of INFN in Florence, Italy. The measurements were carried out using a 4 MeV proton beam extracted into ambient atmosphere and detecting the characteristic γ-rays at 197 keV emitted from the de-excitation of ^{19}F in the $^{19}F(p,p'\gamma_{2\text{-}0})^{19}F$ reaction.

This study demonstrates how external beam PIGE can be very useful for rapidly measuring total fluorine in as-is solid samples, without any pre-treatment.

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STUDY OF SILVER NANOPARTICLES UPTAKE BY *Helianthus annuus* CROP IN SALINITY CONDITIONS

C.E.I dos SANTOS
Physics, Statistics and Mathematic Institute, Federal University of Rio Grande Santo Antonio da Patrulha, Brasil

A. KAVČIČ
Biotechnical Faculty, University of Ljubljana Ljubljana, Slovenia

M. KELEMEN
Low and Medium Energy Departament, Josef Stefan Institute Ljubljana, Slovenia

P.F.C. JOBIM
Departament of Basic Science/Phisilogy, Federal University of Health Science of Porto Alegre Porto Alegre, Brazil

P. PELICON, P. VAVPETIC
Low and Medium Energy Departament, Josef Stefan Institute Ljubljana, Slovenia

K. VOGEL-MIKUS
Biotechnical Faculty, University of Ljubljana Ljubljana, Slovenia

Engineered nanoparticles (NPs) are used in different industrial products, including cosmetic, pharmaceutics, clothes, electronic and agriculture products. In the past years the use of silver nanoparticles (AgNPs) expanded significantly, especially due to their antibacterial and antifungal properties. Despite the benefits in using AgNPs for different purposes, they enter in the environment can be problematic and have different mechanisms of accumulation, internalization and toxicity in plants [1]. Moreover, plant growth and development is limited by salinity conditions, an abiotic stress parameter, especially in arid, semi-arid and irrigated areas in tropical and sub-tropical place. In general, the germination, seedling and plant growth and, consequently, the productivity of the plants decrease, causing economic and social impacts [2]. In this context, the aim of this study was to track the uptake of AgNPs by sunflower (*Helianthus annuus*), a metal hyperaccumulator plant [3], and the possible translocation of them in those plants. For this, experiments were conducted in soil and hydroponic mediums where plants were treated with different concentrations of AgNPs and salinity. Four groups were studied: control (without exposure to AgNPs and NaCl), salinity (group exposed to 100 mM of NaCl), AgNPs (group exposed to 5 and 100 $mg.kg^{-1}$ of AgNPs (the lowest concentration was used only in hydroponic experiment) and AgNPs plus salinity (group exposed to 5 and 100 $mg.kg^{-1}$ of AgNPs and 100 mM of NaCl). At the end of the experiments, plants were harvested; roots, shoots and leaves were separated, and samples were prepared for micro-PIXE, XRF, XANES, lipid peroxidation and pigment analysis. Results showed the internalization of Ag in the cortex of roots from sunflower crop in hydroponic medium. K content in roots was negatively affected by nanoparticles and salinity treatments. Moreover, a translocation of silver to leaves of plants cultivated in soil was observed. In this case, the combination of AgNPs and salinity seems to intensify silver accumulation in leaf and root tissues.

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USING MICRO-PIXE TO EVALUATE NUTRITIONAL VALUE OF EDIBLE PARTS OF PLANTS

P. PONGRAC[1,2], K. VOGEL-MIKUŠ[1,2], P. VAVPETIČ[2], M. KELEMEN[2], M. REGVAR[1], P. PELICON[2]

[1]*Biotechnical Faculty, University of Ljubljana, Ljubljana, Slovenia*

[2]*Jožef Stefan Institute, Ljubljana, Slovenia*

Optimal development of all organisms depends upon proper provision of sufficient amounts of essential mineral elements, and the exclusion of those that are potentially harmful. The continuous cycling of elements in the food chain begins in the soil solution, where plants acquire elements with roots and transport them across their tissues, ending up, directly or indirectly, on our plates. Variation in the element compositions of edible plant-based produce is therefore of considerable importance for human nutrition. Particularly, seven elements (iron, zinc, magnesium, copper, calcium, selenium and iodine) are often lacking in human diets with the resulting negative impacts on health and wellbeing of more than two billion people worldwide. Substantial progress has been made in increasing concentrations of these elements in edible plant tissues to reduce malnutrition in a process called biofortification. This increase in density of elements in a crop can be achieved through plant breeding, transgenic techniques, or agronomic practices, and when biofortified produce is consumed regularly, measurable improvements in human health and nutrition are seen. Besides increasing density of essential elements, we also need to limit accumulation of those potentially harmful (e.g., cadmium, lead, arsenic, mercury) to edible plant tissues. However, concerted action is required to expand our understanding of uptake, transport and final deposition of essential elements and potentially harmful elements in edible plant tissues. Since majority of these elements can be detected using PIXE, we will present case studies (examples in Figure 1) where it was used to determine composition of edible parts of plants.

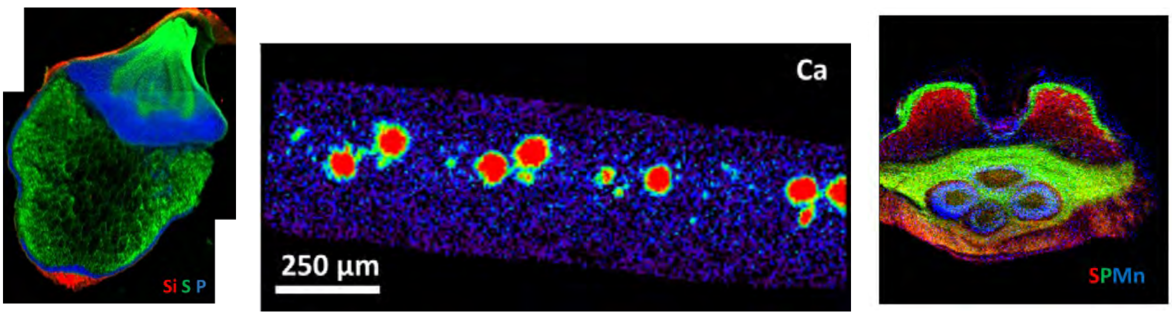

FIG. 1. Micro-PIXE analysis of rice grain (left), spinach leaf (middle) and barley grain (right). Si, silicon; S, sulphur; P, phosphorus; Ca, calcium; Mn, manganese.

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QUANTITATIVE LITHIATION DEPTH PROFILING IN SILICON CONTAINING ANODES INVESTIGATED BY ION BEAM ANALYSIS

Sören MÖLLER
Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung, 52425 Jülich, Germany

Hyunsang JOO
Helmholtz Institute Münster (HI MS), IEK-12, Forschungszentrum Jülich GmbH, Jägerstr. 17-19, 52066 Aachen, Germany

Marcin RASINSKI, Markus MANN
Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung, 52425 Jülich, Germany

Egbert FIGGEMEIER
Helmholtz Institute Münster (HI MS), IEK-12, Forschungszentrum Jülich GmbH, Jägerstr. 17-19, 52066 Aachen, Germany
Institute for Power Electronics and Electrical Drives (ISEA), RWTH Aachen University, Jägerstr. 17-19, 52066 Aachen, Germany
Jülich Aachen Research Alliance, JARA-Energy, 52425 Jülich, Germany

Martin FINSTERBUSCH
Forschungszentrum Jülich GmbH, Institut für Energie- und Klimaforschung, 52425 Jülich, Germany

The localization and quantitative analysis of lithium (Li) in battery materials, components, and full cells are scientifically highly relevant, yet challenging tasks. The methodical developments of MeV ion beam analysis (IBA) presented here open up new possibilities for simultaneous elemental quantification and localisation of light and heavy elements. It describes in detail the technical prerequisites and limitations of using IBA to analyse and solve current challenges in Li-ion and solid-state battery related research and development. Nuclear reaction analysis and Rutherford backscattering spectrometry can provide spatial resolutions down to 70 nm and 1% accuracy. To demonstrate the new insights gained by our technique, Silicon (SiO_x)-containing Carbon anodes are lithiated to six states-of-charge (SoC) between 0-50% in a 2032 coin-cell setup as shown in Fig. 1.

The quantitiative Li depth profiling of the anodes shows a linear increase of the Li concentration with SoC, as shown in Fig. 2, and a match of injected and detected Li-ions. This unambiguously proofs the electrochemical activity of Si. Already at 50% SoC, we derive C/Li=5.4 (< LiC_6) when neglecting Si, proving a relevant uptake of Li by the 8 atom % Si (C/Si≈9) in the anode with Li/Si≤1.8 in this case. Extrapolations to full lithiation show a maximum of Li/Si=1.04±0.05. The analysis reveals all element concentrations are constant over the anode thickness of 44 µm, except for a ~6 µm thick separator-side surface layer. Here, the Li and Si concentrations are a factor 1.23 higher compared to the bulk for all SoC, indicating preferential Li binding to SiO_x. These insights were so far not accessible with conventional analysis methods and are a first important step towards in-depth knowledge of quantitative Li distributions on the component level.

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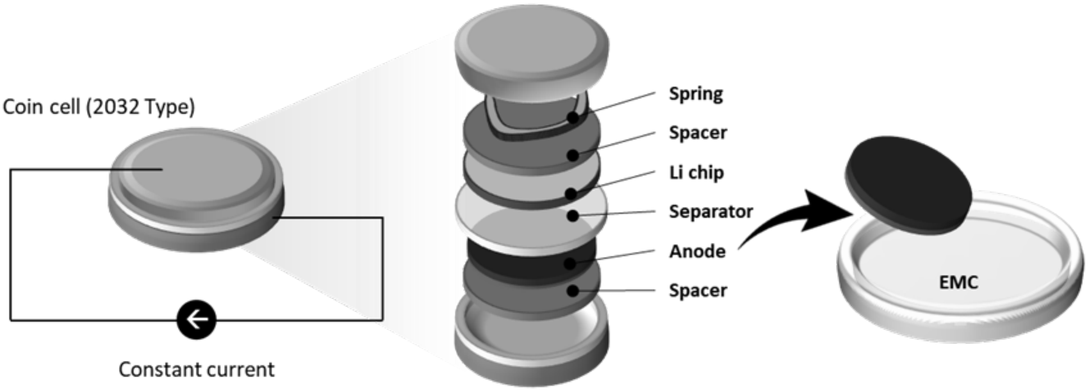

FIG. 1. Sample preparation/lithiation in a coin cell setup for later post-mortem analysis through IBA.

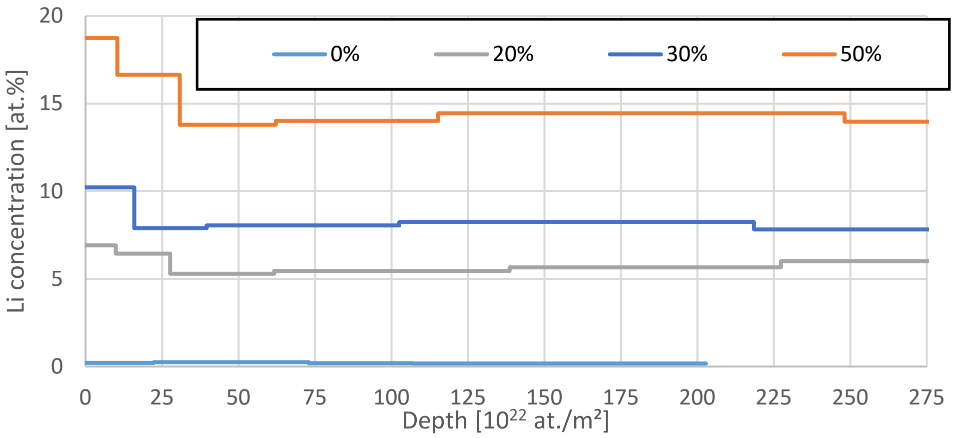

*FIG 2: Comparison of the Li depth profiles. The first ~6 µm are enriched with Li. The region >200*10^{22} at./m² has to be considered with care due to the dominance of the pile-up signal in this deep region.*

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STUDY OF CHARGE TRANSPORT IN SEMICONDUCTORS BY ION BEAM INDUCED CHARGE (IBIC) MICROSCOPY

G. PROVATAS, M. JAKŠIĆ, D. COSIC, A. CRNJAC, M.R. RAMOS, M. VIĆENTIJEVIĆ

Laboratory for Ion Beam Interactions, Ruđer Bošković Institute, Zagreb, Croatia

The ion beam induced charge (IBIC) technique is a well-established, powerful experimental tool for the study of charge transport properties in semiconductor materials, providing the unique advantage of individual charge pulse measurement, produced while fast ion interacts with the sample material. The information about the electronic transport of semiconductors measured by IBIC is obtained down to the micrometer level by modulating the analytical depth, using ions of different energies, and with the use of a focused ion beam which is scanned over the surface of the samples.

In the Laboratory for Ion Beam Interactions of the Ruđer Bošković Institute (RBI), two microbeam end stations are installed and the group has a long experience in the characterization of electronic materials and devices by means of all variations of the IBIC technique. In this presentation we highlight examples of the recent IBIC applications, done on a variety of samples and carried out within the RBI and with collaborators from different research fields, in the framework of the EU projects RADIATE, AIDA2020 and EUROfusion, IAEA CRP project G42008 - Facilitating Experiments with Ion Beam Accelerators and CERIC-ERIC analytical infrastructure network.

The presented applications will cover the exploration of the charge transport properties in detectors with three-dimensional structure, used in the development of high radiation tolerance detector devices. The study of the electronic properties of single-crystal diamond (scCVD) detectors operated at extreme temperature environments, from cryogenic temperatures (~20 K) up to 700 K, will be described too, while the IBIC study of the deterioration of the charge collection efficiency in diamond due to the trapping of charge carriers, will be discussed to stress limitations of the detector's spectroscopic properties. Furthermore, by aiming in developing a single-ion deterministic implantation technique for applications in quantum information processing devices, IBIC studies of diamond detector signals to several low penetrating ions will be discussed. Finally, an experimental methodology for the characterization of the electronic features of silicon power diodes, based on polychromatic angle resolved IBIC analysis, will be presented.

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ULTRA-TRACE ANALYSIS OF ANTHROPOGENIC LONG-LIVED RADIONUCLIDES IN THE ENVIRONMENT WITH ACCELERATOR MASS SPECTROMETRY

K. HAIN(1), M. MARTSCHINI(1), S. MERCHEL(1), J. PITTERS(1), A. SAKAGUCHI(2), P. STEIER(1), A. WIEDERIN(1), A. WIESER(1), A. YOKOYAMA(3), M. WAGREICH(4), J. WOLF(1), R. GOLSER(1)

(1) University of Vienna, Faculty of Physics, Isotope Physics, Vienna, Austria
(2) University of Tsukuba, Center for Research in Isotopes and Environmental Dynamics, Tsukuba, Ibaraki, Japan
(3) Kanazawa University, Institute of Science and Engineering, Kanazawa, Japan
(4) University of Vienna, Department of Geology, Vienna, Austria

Long-lived actinides, e.g., ^{236}U, ^{237}Np, ^{239,240}Pu, ^{241}Am can be measured largely background-free by Accelerator Mass Spectrometry (AMS) due to the absence of stable isobars. The minimum sample size is basically defined by the detection efficiency including chemical sample preparation. The overall detection efficiency for actinides was successfully increased at the Vienna Environmental Research Accelerator (VERA) laboratory by around one order of magnitude to $5\cdot10^{-4}$ by several improvements of the setup and the measurement procedure [1]. This either significantly simplifies sample preparation eliminating the need for chemical separation of actinides from each other [2] or it allows the analysis of all the major long-lived actinides listed before from a single sample at ultra-low levels (below 10^{-3} ppq for ^{241}Am) after chemical separation. The latter approach was used to search for a marker to identify the basis of the proposed new geological age of “the Anthropocene” in urban sediments from the Vienna underground (Karlsplatz). This exemplary project will be presented in more detail in this talk covering also other on-going projects related to actinide detection at the VERA laboratory. This includes the production of an isotopic spike for the quantitative analysis of environmental ^{237}Np and the characterization of the ^{233}U/^{236}U ratio from different emission sources which has the potential to become a novel sensitive fingerprint for nuclear weapons fallout from the 1950s.

The analysis of long-lived fission products such as ^{99}Tc ($t_{1/2} = 2.1\cdot10^5$ yrs) or ^{135}Cs ($t_{1/2} = 2\cdot10^6$ yrs) in the general environment requires the suppression of background from stable isobars, i.e., ^{99}Ru and ^{135}Ba. Both radionuclides are considered promising oceanographic tracers. The worldwide unique technique of Ion-Laser Interaction Mass Spectrometry (ILIAMS), recently implemented at VERA achieved a Ru and Ba suppression of 5 orders of magnitude when overlapping a green (532 nm) continuous-wave laser with the ion beam before injection into the accelerator [3]. I will discuss the status of development focusing on ^{99}Tc analysis for which a suitable normalisation method is needed to overcome the lack of a stable Tc isotope. As for the normalisation of ^{237}Np, the most reliable normalisation can be expected from measurements relative to a second artificial isotope produced by irradiation at accelerator facilities providing higher beam energies than VERA.

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CHARACTERIZATION OF NUCLEAR WASTE BY ACCELERATOR MASS SPECTROMETRY

J.Mª. LÓPEZ-GUTIÉRREZ, E. CHAMIZO CALVO, D. SANCHEZ JIMENEZ
Universidad de Sevilla, Centro Nacional de Aceleradores, Sevilla, Spain

Nuclear energy continues being commonly used nowadays in spite of the general tendency to substitute it by cleaner ways of energy production. In any case, one of the disadvantages of this method of energy production is the necessity of environmental control of the radioactivity especially close to the vicinity of nuclear facilities. Another important drawback is the large amount of residues that it produces. These are originated either in the normal activity of the nuclear power plants and/or on the decommissioning of these plants.

A big part of these residues will need to be stored in special facilities especially designed for this purpose. In order to optimise this process, it is very important to characterize them very well so that only the ones that strictly need this storage treatment are sent to these special stores. This would reduce strongly the amount of material that must be treated as radioactive and, consequently, the loading rhythm of the stores and their economic and social impact.

The long-lived radionuclides fulfil two important characteristics: they remain for a very long time in the nuclear residues and, in many cases, they are very difficult to detect by radiometric methods, as these do not have always enough sensitivity. In spite of this, the knowledge of their activities is essential for their appropriate evaluation. In these cases, a maximum level is fixed although the real level of the radionuclide in the residue will be much lower. The lack of sensitivity is clearly also an inconvenient for environmental samples.

To overpass this drawback, it has been shown that the use of high sensitivity radiometric methods and mass spectrometry methods can reduce strongly the detection limits for several long-lived radionuclides and can be used as an alternative for a series of nuclides whose emissions are difficult to evaluate by traditional counting techniques. Few years ago, the AMS group at CNA carried out a project dedicated to start developing the methodology of the application of Accelerator Mass Spectrometry (AMS) to the characterization low and intermediate level nuclear residues. In this project, we proposed to optimise the originally developed methodology for environmental samples and to extend the application of the technique to new radionuclides of interest for their management that have not been studied before. These studies will be mostly focused on residues generated in the decommissioning of nuclear power plants for its implications in the ongoing activities carried out in Spain, as it is performed in collaboration with ENRESA, the company in charge of nuclear residues in Spain.

Some of the radionuclides present in this kind of residues are ^{129}I, ^{14}C, ^{36}Cl, ^{41}Ca, ^{239}Pu, ^{240}Pu, ^{236}U and ^{237}Np. Our project tries to evaluate the limits of AMS for the determination of these radionuclides in nuclear residues. For this, our efforts are put both on the optimization of the AMS measurement and the radiochemistry. Another important point is that low and intermediate nuclear residues can include a variety of materials that can be liquid or solid, coming from the daily processes carried out in normal operation or from decommissioning. Examples can include paper smears, resins, sludge, concrete, etc.

For many of the previously enumerated radionuclides, the expected levels will be high enough to be measured by AMS in similar conditions as environmental samples. More emphasis has to be put on the radiochemistry, as the isotopic ratios can be, in some cases, high. Sample preparation will then need to

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include carrier addition or isotopic dilution to reduce these ratios. Apart from this, radiochemical methods will need to be adapted to every kind of matrix.

The AMS facility at CNA is based on a 1 MV Tandetron and was installed in 2005. Its relatively low maximum terminal voltage makes it difficult to reach very low levels for some of the long-lived radionuclides that are traditionally detected by AMS, for example ^{36}Cl and ^{41}Ca. For them, we expect to evaluate the detection limits that the combination of radiochemical processes and machine set up can offer to reduce the detection limits that other techniques can offer.

In this talk we will present some of the results obtained up to now as well as the strategies and the experiments that are being currently performed in order to fulfil the described objectives.

IAEA ACTIVITIES IN SUPPORT OF SUSTAINABLE OPERATION OF ELECTROSTATIC ACCELERATOR-FACILITIES

Natko SKUKAN, Sotirios CHARISOPOULOS, Ian SWAINSON, Aliz SIMON, Kalliopi KANAKI, Danas RIDIKAS

Physics Section, IAEA, Vienna International Centre, PO Box 100, A-1400 Vienna, Austria

Promotion of nuclear applications for peaceful purposes and related capacity building is among the missions of the International Atomic Energy Agency (IAEA). Hereby, accelerator-based applications and nuclear instrumentation are among the thematic areas, where the IAEA supports its Member States in strengthening their capabilities to adopt and benefit from the usage of accelerators. The relevant activities are implemented by the Physics Section (PS) of the IAEA as will be briefly presented in this contribution.

More specifically, the IAEA supports electrostatic ion beam facilities through different modalities by organizing different forms of hands-on training courses; providing facilitated access to accelerator centres to the interested Member States without such facilities; offering assistance in planning of new facilities, design of beam lines, as well as giving expert advice in fault finding, repairs or O&M aspects of the accelerators and auxiliary instruments through expert missions on request from Member States. The IAEA also manages and maintains the Accelerator Knowledge Portal (AKP) as well as interactive maps of accelerator facilities world-wide. The IAEA Physics Section also has plans to establish an Ion Beam Facility (IBF) as part of its Nuclear Science and Instrumentation Laboratory (NSIL) in Seibersdorf.

The most recent examples of training activities include the Training Workshop on Ion Beam Analysis Techniques and Training Workshop on Operation & Maintenance of Electrostatic Accelerators. Only during the past year, three physical expert missions in status assessment and fault finding at accelerator facilities were to Algeria, Croatia and Greece. These and other activities in recent period will be presented.

A MONTE CARLO AND EXPERIMENTAL TOOL FOR ACTIVATION CALCULATIONS IN HIGH ENERGY X-RAYS IRRADIATION PROCESS

N. ARBOR[1], A. NOURREDDINE[1], J. RIFFAUD[1], F. KUNTZ[2], A. NASREDDINE[2], A. STRASSER[2]

[1] *Institut Pluridisciplinaire Hubert Curien, CNRS / University of Strasbourg, Strasbourg, France*

[2] *Aerial-CRT, Illkirch Graffenstaden, France*

X-ray photons produced by electron accelerator are increasingly used for industrial irradiation. More penetrating than electrons, easier to manage than radioactive sources, X-rays are very interesting for various processes such as sterilization. But the question of the maximum energy that can be used without risk has been open for many years and is currently being debated worldwide. Using energies higher than 5 MeV would certainly improve the DUR (Dose Uniformity Ratio) while reducing the cost of utilization. However, it is essential to take into account the risk of photonuclear activation, which can lead to the production of radioactive nuclei. These nuclear processes can occur both in the irradiation room (walls, supports), the accelerator components and the irradiated object. The issue of the maximum irradiation energy thus requires being able to assess with high precision the total quantity of radioactivity produced during a given industrial process, as well as the corresponding risks in terms of radiation protection of workers and populations.

In the context of food sterilization, most of the reference publications, including the IAEA report on "Natural and Induced Radioactivity in Food" (IAEA-TECDOC-1287), conclude that food irradiated with X-rays up to 7.5 MeV to a dose of 30 kGy has a radioactivity well below the natural radioactivity in non-irradiated food [1,2]. These very low levels of induced radioactivity highlight both the need and the complexity to develop a tool for easily and efficiently controlling the irradiation process in terms of activation. Experimental gamma spectrometry is a useful but insufficient solution because it does not detect the presence of pure beta or alpha emitting radioactive nuclei, which are much more difficult to measure. Monte Carlo (MC) simulation and analytical codes for radiation-matter interactions are considered to be more powerful and practical tools for quantifying the radioactivity potentially induced during the irradiation. These numerical tools must however be used with caution for radiation protection purposes, as it can lead to very significant errors on the type and number of calculated radioactive nuclei depending on the accuracy of the modelling (accelerator design, sample geometry, materials composition). A step-by-step validation of the calculation chain is thus essential to ensure the reliability of the results.

We present a hybrid Monte Carlo and experimental tool for activation calculations in high energy X-rays irradiation process. The purpose of this tool, and its associated methodology, is to establish the safety of high-energy X-ray irradiation installations by quantifying with a high precision the additional induced radioactivity for a given process (and compare it to the natural levels). This work is the direct continuation of the study carried out on the assessment of activation in foods product irradiated with high energy X-rays, within the framework of the IAEA DEXAFI (Development of Electron Beam and X-Ray Applications for Food Irradiation) coordinated research project. The first part of the work consisted in identifying the most critical steps in the simulation chain for the accuracy of the activation calculations. The impact of nuclear data (cross-section), X-ray spectrum and materials composition has been evaluated by benchmarking several calculation codes such as MCNP, Geant4 and FISPACT-II (Figure 1 – left).

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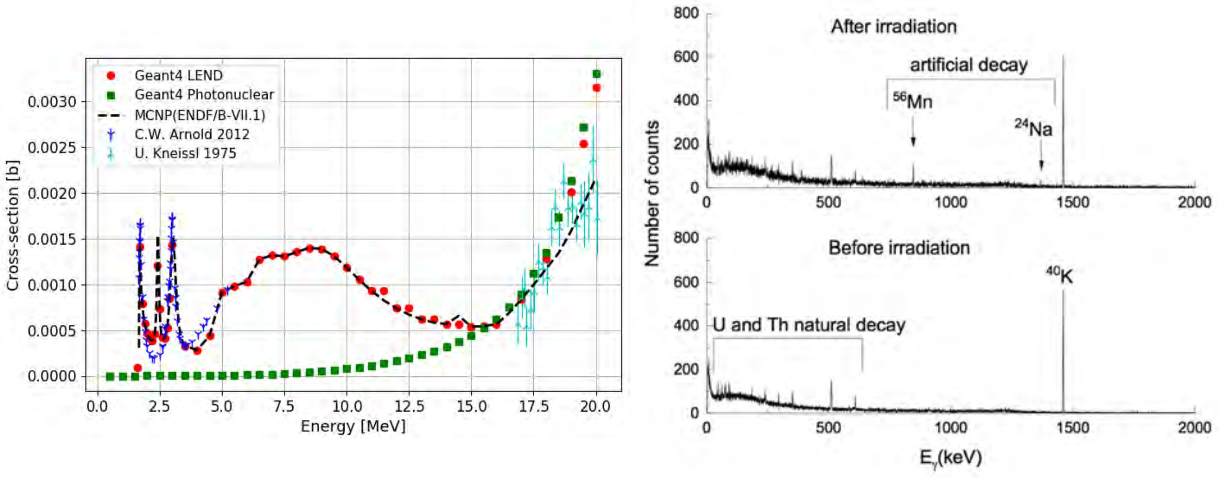

FIG. 1. Left: Comparison of Geant4 (G4Photonuclear and LEND models), MCNP (ENDF-BVII.1) and some experimental photonuclear cross-sections of ^{9}Be. Experimental data are available on the JANIS database; Right: Gamma emission spectrum of rabbit food before and after irradiation (total dose of 14 kGy with 7 MeV X-rays)

The second part is to test different experimental methods, such as dosimetry, neutron/gamma spectrometry (Figure 1 – right) or activation foils, that can be applied to verify calculations. A methodology, adapted to industrial constraints, has been defined to allow validation of both the Monte Carlo modelling of the irradiation setup and the activation calculations. The experimental measurement of photoneutrons, around and in the irradiated sample, appeared to be one of the most reliable means of control. Innovative neutrons instrumentation, developed at the IPHC laboratory [3,4], could be used for this purpose. Experimental measurements were carried out at the new Feerix® (Faisceau d'Electrons Et Rayonnement Ionisants X) facility of Aerial (Strasbourg-France). This facility, based on advanced IBA Rhodotron® technologies, constitutes a reference installation for the development of the proposed tool which aims to allow better control of X-ray irradiation processes.

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SURFACE TREATMENT OF SPECIAL HIGH-PROTEIN PRODUCTS USING LOW ENERGY BEAMS FROM MACHINE SOURCES

SLOBODAN B. MASIC, IVICA T. VUJCIC
Vinca Institute of Nuclear Sciences, Belgrade, Serbia

Recent developments in low energy electron beam (LEEB) technology have revolutionized aseptic packaging. Advancements in electron beam technology are shrinking the footprint of the devices used to generate ionizing radiation. With the relatively recent development of reliable, compact, cost-effective, LEEBs, a new class of in-line applications is now possible. The benefits of high-speed, high efficacy treatments, with no chemicals and at room temperature, are now realized across a variety of packaging applications. Such developments are also attractive to the food industry.

According to the Diabetes Registry, over 700,000 people in Serbia suffer from this disease. They need a special diet, with as few carbs as possible and more protein. It is well known that proper and healthy food is a prerequisite for good health. Protein nutrition seems to have become very popular in recent years, both among athletes and the general population. In creating such products, it is of great importance to extend the shelf life of the product. This can be achieved by treating the product with the use of ionizing radiation, during which all microorganisms in the product would be destroyed. However, it was found that this treatment is somewhat changing the nutritional value of the product. Irradiation of the product surface with a Low Energy E-beam (LEEB) appeared as a possible ideal solution. Such a treatment would neutralize the microorganisms that are on the surface of the product and are formed mainly during the handling of the product. On the other hand, the change of the nutritional values of the product under the influence of high-energy ionizing radiation would be avoided.

The aim of this research is to collect high-protein food products whose properties will be analyzed in detail. After that these products will be irradiated with LEEB in an external institution. Based on the analysis of microbiological parameters and nutritional values after irradiation, the potential application of this technology in the production of high-protein nutrients suitable for diabetics will be established.

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IMPLEMENTATION OF ION BEAM ANALYSIS FOR FORENSIC APPLICATIONS: THE WAY TO GLOBAL FORENSIC DATABASE THROUGH THE UNIFICATION OF DIFFERENT ANALYTICAL TECHNIQUES

Olga GIRSHEVITZ

Bar Ilan Institute for Nanotechnology and Advanced Materials (BINA), 52900, Ramat Gan, Israel

Forensic sciences are often key to obtaining a conviction in a trial. However, obtaining and analyzing evidence found during the investigation is not an easy task as evidence may be tiny and found in small quantities. Of the various forensic techniques used, elemental analysis of materials has become increasingly valuable for its ability to extract forensic insights from a few tiny specimens.

IBA techniques are a subfield in elemental analysis that is recognized for its sensitive and accurate measurements of a broad range of trace elements, thus being suitable to identify chemical fingerprints. Additionally, the non-destructive character of IBA methods, which permits to repeat and multiply measurements without destroying or spoiling evidence is valuable for small amounts of evidence. Combining various IBA techniques (PIXE, PIGE, NRA, RBS, ERDA, and recently, MeV-TOF-SIMS) into a unified database is extremely powerful for determining provenance markers of the different materials, their manufacturing processes and the alteration induced by the environment.

In this talk, the results of the studies from different labs will be presented, showing the types of samples, such as food and drug provenance or glass fragments, where IBA demonstrates considerable promise. The main focus of this talk will be concentrated on how the combination of PIXE with other IBA techniques (PIGE, PGAA) can be used to provide a unified database of glass fragments that were collected from various vehicles covering different manufacturers and years of production and received from Israeli Division of Identification and Forensic Sciences (DIFS). Moreover, we will demonstrate that the combination of elemental analysis using IBA and Machine Learning tools provided a reliable classification model with high (>87%) accuracy in identifying glass fragments origins, that can be potentially used by different laboratories around the world. We believe that using this methodology of combining various sources of measurements will both improve model performances and make the models accessible to law enforcement agencies that do not have access to IBA. Finally, the workflow presented in this talk can be extended to many other domains of forensics (e.g., gunshot residues, flammable liquids, substances of abuse, etc).

ACCELERATORS AND ION BEAMS FOR QUANTUM TECHNOLOGIES

Andrew A. BETTIOL

Centre for Ion Beam Applications, Department of Physics, National University of Singapore

Ion implantation is a key technology that has been successfully employed for decades in the semiconductor industry. For example, it is the method of choice for creating p and n type silicon, or the manufacture of silicon on insulator (SOI) wafers using the SIMOX process. We are now in the midst of the second quantum revolution where ion implantation continues to play a pivotal role in the development of the new quantum technologies such as quantum computers and quantum sensing devices. With the advent of these new quantum technologies, new scientific and engineering challenges have arisen that require unprecedented control over the position and fluence of the ion implantation process. The new generation of accelerators and ion implanters that are being developed for deterministic ion implantation require control over single ions with spatial and depth precision at the nanometre scale. In this presentation the current progress in the development of accelerators and ion implanters for deterministic ion implantation will be reviewed. In addition, applications and challenges associated with the generation of q-bits and colour centres using ion implantation will be explored.

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RADIOACTIVE ION BEAMS: FROM LARGE SCALE FACILITIES TO NUCLEAR MEDICINE APPLICATIONS

Thierry STORA
CERN, Switzerland

Large scale isotope mass separation facilities have been actively developed and operated across different countries for the scientific community active in the investigation of nuclear structures, nuclear physics and superheavy elements.

In parallel, Nuclear Medicine, and more particularly the so-called theranostics approach based on the combination of diagnostics and treatment drugs, has seen recent breakthroughs, originating from radionuclides made newly available notably for academic and industrial R&D medical scientists.

A striking example is the development and marketing of targeted radiopharmaceut-icals directed to the Prostate Specific Membrane Antigen (PSMA) and Somatostatin Receptor targeted therapy with ^{177}Lu beta-emitter.

Improved access to a portfolio of selected radionuclides, bioconjugates and radiopharmaceuticals is an important requirement for preclinical evaluations, clinical trials, and ultimately their translation as new drugs. The production of these radionuclides is complex and sometimes requires lengthy irradiations using powerful reactors, cyclotrons in combination with now dedicated isotope mass separation facilities.

During the presentation, I will introduce some of the recent challenges and developments that were witnessed over the past few years and show how the development of ion beam production techniques has allowed the production and test of new radiotherapeutics. Coordinated programs, like the National Isotope Development Center in USA, and more notably, PRISMAP-The European Medical Radionuclide Programme, involving major large-scale facilities will be described.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008571 (PRISMAP – The European medical radionuclides programme)

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REMOVAL OF HYDROXYCHLOROQUINE AND ACID RED 51 AQUEOUS SOLUTIONS BY THE ELECTRON BEAM PROCESS

A. ZAOUAK,

Research Laboratory on Energy and Matter for Nuclear Science Development, National Center for Nuclear Science and Technologies, Tunis, Tunisia.

H. JELASSI

Research Laboratory on Energy and Matter for Nuclear Science Development, National Center for Nuclear Science and Technologies, Tunis, Tunisia.

N. RAHMAN

Nuclear and Radiation Chemistry Division, Institute of Nuclear Science and Technology, Atomic Energy Research Establishment, Bangladesh Atomic Energy Commission, Dhaka, Bangladesh.

In this study, electron beam (EB) process was employed to remove two emerging pollutants: hydroxychloroquine (HYQ), and Acid Red 51 (AR) in aqueous solution. Change of absorption spectra, pH effect, Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC) were carried out and studied. It was found that all absorption bands decreased with increasing irradiation dose and disappear totally after 4 kGy and 7 kGy applied dose respectively for HYQ and AR. Unprecedented high removal rates of total organic carbon of the order of 98 % were achieved for both pollutants indicating quasi- total mineralization. Furthermore, based on spectrophotometric analysis, it was found that HYQ and AR degradation process follow a pseudo-first order kinetic. In addition, monitoring electron beam irradiation by CG/MS analysis, several by-products were identified indicating that HCQ degradation begins by the cleavage of the C-N bond in the aliphatic tertiary amine chain leading to 4-Amino-7-chloroquinoline and its hydroxylated derivatives. However, for AR degradation, the degradation process was started by hydroxyl radical's attack the chromophore group leading to 2- (2- formylphenyl)-2-carboxylate and 2-(2-(3,6- dihydro-2H-pyran-4-yl-phenyl)-2-carboxylate which are subsequently degrade onto 1,4-hydroquinone, oxalic and malonic acid before their mineralization into carbon dioxide and water. Based on identified intermediates, both degradation mechanistic schemas mediated by hydroxyl radicals have been proposed. Finally, it can be concluded that the electron beam process holds effective, great promise method as a treatment process of wastewater containing persistent organic pollutants.

Keywords: Electron beam process, DCO, TOC, Hydroxychloroquine, Acid Red 51, GC-MS.

ION BEAMS AND ION-ACCELERATORS FOR BIOLOGY-ORIENTATED APPLICATIONS AND RESEARCHES – CMU PRACTICES

L.D. YU[1,2]
[1] Plasma and Beam Physics Research Facility, Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
[2] Thailand Center of Excellence in Physics, Commission on Higher Education, 328 Si Ayutthaya Road, Bangkok 10400, Thailand

B. PHANCHAISRI[1,2,3], J. TECHARANG[1,2,3]
[1] Plasma and Beam Physics Research Facility, Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
[2] Thailand Center of Excellence in Physics, Commission on Higher Education, 328 Si Ayutthaya Road, Bangkok 10400, Thailand
[3] Science and Technology Research Institute, Chiang Mai University, Chiang Mai 50200, Thailand

U. TIPPAWAN[1]
[1] Plasma and Beam Physics Research Facility, Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand

S. ANUNTALABHOCHAI[4,5]
[4] Department of Biology, Faculty of Science, Chiang Mai University, Chiang Mai 50200, Thailand
[5] Biotechnology Unit, University of Phayao, Phayao 56000, Thailand

T. BOONYAWAN[6]
[6] PET/CT & Cyclotron Center, Center for Medical Excellence, Chiang Mai University, Chiang Mai 50200, Thailand

T. VILAITHONG[2]
[2] Thailand Center of Excellence in Physics, Commission on Higher Education, 328 Si Ayutthaya Road, Bangkok 10400, Thailand

Applications and researches of ion beams and ion-accelerators for the biology-orientated purposes have been rigorously developed at Chiang Mai University (CMU), Thailand, the national ion beam and accelerator research center, for more than two decades. The work is highly multiple, touching equipment development, genetic engineering, materials science, analytical technology, cell and molecular biology, biomedicine, and life science. The ion beam and ion-accelerator facilities for biology at CMU included in-house-developed 150-kV mass-analyzed and non-mass-analyzed horizontal and vertical ion implanters, respectively, 220-kV Varian ion implanter, 30-kV bioengineering-specialized vertical ion implanter, 25-kV plasma immersion ion implanter, 10-kV neutralized ion beam implanter, low-energy single ion implanter, low-energy Mark II broad-beam high-output ion source based ion implanter, 1.7-MV Tandetron tandem accelerator for ion beam analysis, and 20-MeV cyclotron for medical applications. Relevant applications involved ion-beam-assisted gene/DNA transfer in bacterial, plant and mammalian cells, ion beam induced mutations in rice, horticultural plants, vegetables and bacteria, ion-bombardment altered cell adhesion or attachment on material surfaces, ion beam analysis

of biological samples, ion beam lithography of biological microfluidic devices/patterns, and cyclotron-production of radiopharmaceuticals for diagnostic services. Researches concerned covered physical mechanisms of ion-beam-assisted gene/DNA transfer into cells and ion-beam-induced mutations of cells, low-energy ion bombardment effect on DNA strand breaks for fundamental understanding of ion beam effect on genetics including both experiments and computer program simulations of ultra-low energy ion impact on DNA, single-ion irradiation of cells for hyper low dose effect on cancer cell death, and cyclotron manufacture of radiopharmaceuticals for multi-purpose diagnostics. The presentation reviews all of these practices with the achievements such as hundreds of publications and presentations, some patents, tens of government-registered ion-beam-induced rice mutant lines, and a number of radiopharmaceuticals applied in clinics, etc., and highlights their socioeconomic impacts on the national developments. The programs have been supported not only by the governmental agencies but also by international cooperation particularly including the International Atomic Energy Agency (IAEA)'s supports.

POSSIBILITY OF USING SLUDGE FROM DRINKING WATER TREATMENT PLANT AS FERTILIZER IN AGRICULTURE AFTER E-BEAM TREATMENT: EFFECTS OF AGING

IVICA T. VUJCIC, SLOBODAN B. MASIC
Vinca Institute of Nuclear Sciences, Belgrade, Serbia

Using accelerators in treating waste sludge from a drinking water treatment plant is a well-known technique. Ionizing radiation is an effective method for neutralizing microorganisms from waste sludge [1]. Sludge treated in this way can be used as fertilizer in agriculture [2]. Sludge can increase the humus content of the soil [3], the physical condition of soils [4], can enrich the soil with micronutrients such as phosphorus, potassium, sulphur, calcium, magnesium, and micronutrients [5].

However, if it is not used as a fertilizer immediately, but after a storage period, the content of microorganisms and mold in the sludge can increase. It is also necessary to examine whether the polyacrylamide present in the sludge degrades.

In this paper, the effects of aging on the physicochemical characteristics (Table 1), the content of microorganisms and mold (Table 2), heavy metal concentration (Table 3), and total nutrient content (Table 4) in waste sludge treated with e-beam and were investigated.

TABLE 1. PHYSICOCHEMICAL CHARACTERISTICS OF SLUDGE SAMPLES COLLECTED FROM A DRINKING WATER TREATMENT PLANT

Parameter	Measured immediately after e-beam treatment	Measured after 15 months	Permitted values for sludge to be used as a soil improver*
pH	5.98	5.32	4-7
electrical conductivity	1486	1488	<3000
cation exchange capacity	108	107	>25
volatile solids	46	29	-

TABLE 2. TOTAL NUMBER OF MICROORGANISMS ANALYZED IMMEDIATELY AFTER IRRADIATION, AS WELL AS AFTER 15 MONTHS

Dose	0 kGy	1 kGy	3 kGy	5 kGy	10 kGy	25 kGy
Total number of microorganisms ($cfu \cdot ml^{-1}$)	24500	12500	1700	80	0	0
Total number of microorganisms ($cfu \cdot ml^{-1}$) After 15 mounts	5200	1000	500	0	0	0

TABLE 3. THE CONTENT OF HEAVY METALS BEFORE AND AFTER IRRADIATION WITH A DOSE OF 10 KGY

Heavy metal	Limit values, mg/kg dry matter	Irradiated with a dose of 10 kGy e-beam irradiation, measured after treatment mg/kg dry matter	Irradiated with a dose of 10 kGy e-beam irradiation, measured after 15 mounts mg/kg dry matter
Cadmium	20 to 40	19	19
Copper	1000 to 1750	388	390
Nickel	300 to 400	54.8	55.0
Lead	750 to 1200	123	120
Zinc	2500 to 4000	170	170
Mercury	16 to 25	8.20	8.19
Chromium	100	38.5	39.1
Arsenic	29	9.70	9.70
Selenium	0.7	0.0682	0.0672

TABLE 4. THE CONTENT OF TOTAL NUTRIENT IN SLUDGE IMMEDIATELY AFTER IRRADIATION WITH A DOSE OF 10 KGY AND 15 MONTHS AFTER IRRADIATION

Nutrient	Irradiated with a dose of 10 kGy e-beam irradiation, measured after treatment %	Irradiated with a dose of 10 kGy e-beam irradiation, measured after 15 mounts %
Nitrogen	1.9	2.0
Phosphorous	1.9	1.8
Potassium	0.19	0.18

The possibility of using treated sludge as a fertilizer in agriculture was evaluated. It has been shown that the content of acrylamide in treated sludge after 15 months of storage does not exceed the limits for sludge to be used as fertilizer. If the sludge is stored in closed bags in a dark place, aging does not increase total microorganisms and molds. The research also showed that the sludge's physicochemical characteristics treated in this way do not decrease under the influence of aging. Finally, it has been shown that aging does not change the concentration of heavy metals and total nutrients in sludge treated by ionizing irradiation. It can be concluded that waste sludge from drinking water treatment plants, treated with e-beam, has excellent potential to be used as fertilizer in agriculture

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LOW AND HIGH ENERGY ION IRRADIATION ON STRUCTURAL AND OTHER PROPERTIES OF CUBIC ZIRCONIA AND CERIA: FROM THE PERSPECTIVE OF NUCLEAR ENERGY MATERIAL

SANTANU GHOSH

Indian Institute of Technology Delhi, Hauz Khas, New Delhi-110016, India

The interaction of energetic ions/particles with matter results in the transfer of energy from the incident particle to the target material. This process, commonly referred to as 'irradiation', often results in defects creation and subsequent micro-structural changes in the material, e.g. deterioration of crystallinity, swelling, amorphization etc., eventually leading to a degradation of its properties. These effects, broadly termed/classified as 'radiation damage', have detrimental implications in vital fields of science and technology, e.g. nuclear, electronic & space industries, where the materials are subjected to severe irradiation with low energy and/or high energy particles during service. Radiation damage is thus an undesirable (and often unavoidable) consequence of ion matter interaction (i.e. ion energy loss in materials). Therefore, the search for ways to mitigate the radiation damage in materials is an area of research of immense technological significance. A common way to simulate the effects of such irradiations, within a limited time, is to use energetic ion beams from accelerators.

In the recent past, downsizing of materials to nano-dimension has received explosive attention and is being considered as an effective strategy in the context of reducing the radiation damage. This is due to the fact that grain boundaries (GBs) are defect 'sinks'; and therefore, GBs can lower the accumulation of irradiation induced defects and hence reduce the radiation damage. A query that emerges is whether the effect of grain size on the radiation tolerance the same in the high energy irradiation (HEI) regime i.e. dominated by electronic energy loss (S_e) as well.

Cubic zirconia and Ceria, potential materials for inert matrix fuels, with different grain sizes (tens of nanometers to few microns) was irradiated under different conditions (viz. single beam irradiation with high energy ($S_e>>S_n$) ions at 300 K and 1000 K& *simultaneous* dual beam irradiation with high and low energy ($S_n>>S_e$) ions at 300 K to investigate the effect of grain size, environmental temperature and electronic excitation (S_e)/ballistic processes (S_n) on the radiation damage. The irradiations at 1000 K and the *simultaneous* irradiations helped to better simulate typical nuclear reactor environment. In case of the single beam irradiations, (i) the nano-crystalline samples were more damaged compared to the micro-crystalline (i.e., bulk) ones irrespective of the irradiation temperature, and (ii) the damage for all grain sizes was found to be lower at 1000 K compared to that at 300 K - these observations being in contrast with results obtained previously with low energy irradiations. The nanocrystalline sample is however less damaged than its micro-crystalline counterpart upon the *simultaneous* low and high energy irradiations indicating better damage tolerance of the nano-crystalline state to simultaneous S_n and S_e deposition– this study provides the first realistic evidence towards the potential application of nano-materials over bulk in the nuclear industry.

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SHIELDING CONSIDERATIONS OF A BUNKER TO BE TAKEN INTO ACCOUNT BY THE REGULATORY BODY FOR AUTHORIZATION PURPOSES: CASE OF RADIOTHERAPY CENTER IN MALI

COULIBALY Adama, DICKO Aly Ag Mohamed, SAMAKE Tahirou, KONE Nagantié

Agence Malienne de Radioprotection (AMARAP)

Département Contrôle et Surveillance du Territoire (DCST)

1. Introduction

Structural shielding design in a bunker of accelerator's installations aims to limit radiation exposures to members of the public and employees to an acceptable level, i.e. to reduce the effective dose coming from accelerator to a point outside of bunker as low as reasonably achievable. Shielding design is particularly concerned with attenuation of primary beam and secondary radiations in the form of head leakage of accelerator, patient and wall scatter. Thus, finding the optimum barrier thickness is an essential requirement for the safety of facilities. For the building of any bunker able to hold an accelerator for medical or research activities, the owner of facility in collaboration with a qualify expert, medical physicist and architect must establish some detailed plans of the facility with the different thicknesses of bunker (in concrete or lead of primary and secondary barriers) and others areas close to this bunker.

The main objective of this work was to calculate the primary and secondary barrier thicknesses of bunker of the only radiotherapy center in MALI according to the NCRP report 151 methods for authorization purposes. The shielding of main door of bunker was not included in this paper because it was provided with the LINAC by manufacturer.

2. Materials and Methods

2.1. Basic considerations

For any practice related to the using of ionizing radiation, the main objective for shielding in term of radiation protection is to reduce $I_{(out)}$ to the authorized values for public or workers (see figure below).

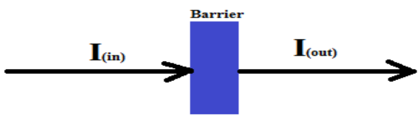

Figure: Basic considerations

$$\mathbf{B_{(x)}} = \frac{I_{(out)}}{I_{(in)}} \qquad 2.1$$

$\mathbf{B_{(x)}}$ is the barrier transmission factor to determine in order to know the thickness of specified barrier.

2.2. Calculation of $B_{(x)}$ and thickness for primary barriers

The transmission factor of the primary barrier (B_{pri}) that will reduce the radiation field to an acceptable level is given by Equation (2.2).

$$\mathbf{B_{(pri)}} = \frac{Pd_{pri}^2}{WUT} \qquad 2.2$$

P is the shielding design goal (expressed as dose equivalent) beyond the barrier and is usually given for a weekly time frame (Sv week^{-1}), $\mathbf{d_{pri}}$ is the distance from the x-ray target to the point protected(meters), **W** is the workload or photon absorbed dose delivered at 1 m from the x-ray target per week (Gy week^{-1}), **U** is the use factor or fraction of the workload that the primary beam is directed at the barrier in question, **T** is the occupancy factor for the protected location or fraction of the workweek that a person is present beyond the barrier.

2.3. Calculation of $B_{(x)}$ and thickness for secondary barriers

i. The barrier transmission for scattered radiation by the patient (B_{ps}) is given by:

$$B_{ps} = \frac{P}{a\,W\,T} d_{sca}^2 d_{sec}^2 \frac{400}{F} \qquad 2.3$$

ii. The barrier transmission for leakage radiation by the head of accelerator (B_L) is given by:

$$B_L = \frac{1000\,P\,d_L^2}{W\,T} \qquad 2.4$$

The thickness of the barrier can then be determined using tenth-value layers (TVL) based on the energy of the accelerator and type of shielding material. The required number (n) of TVLs is given by equation (2.5):

$$\mathbf{n = - \log (B)} \qquad 2.5$$

The primary barrier thickness and the secondary barrier thickness of leakage from the head of LINAC (6 MV) are given by equation (2.6).

$$t_{(barrier)} = TVL_1 + (n-1)TVL_e \qquad 2.6$$

The secondary barrier thickness of scattered radiation from patient and wall is calculated by equation 2.7.

$$t_{(barrier)} = n \times TVL_s \qquad 2.7$$

3. Results

In Mali, the regulated shielding design goals (dose equivalent) for public and workers from practice due to the ionizing radiation are respectively 1 $mSv.year^{-1}$ (which is $\mathbf{2.10^{-5}\ Sv.week^{-1}}$) and 20 $mSv.year^{-1}$ (this dose is optimized to 6 $mSv.year^{-1}$ which is $\mathbf{1.210^{-4}\ Sv.week^{-1}}$). The occupancy factor and the use factor were assumed to be 1 for all adjacent areas. According to the international calculation of radiation protection shielding requirements, a workload of $\mathbf{1000\ Gy.week^{-1}}$ was assumed. The field size of the collimator was $\mathbf{40 \times 40\ cm^2}$ at isocenter. The thickness of different barriers was expressed in centimeter of concrete.

The table below was the comparison between the obtained shielding results by AMARAP using NCRP report 151 methods and provided results by architect and qualified expert.

Thicknesses of Barrier in Concrete (cm)			
Location	**AMARAP Results using NCRP 151 Methods**	**Provided Results from experts of "Hôpital du MALI"**	**Obervations**
Primary Barriers			
F	224	235	Good thickness
I	200	235	Good thickness
Ceiling	223	235	Good thickness
Secondary Barriers			
A	110,87	141	Good thickness
B	93,81	60	Thickness should be completed by the shielding maze and door of bunker
C	83,78	60	Thickness should be completed by the shielding maze and door of bunker
D	85,46	117	Good thickness
E	108,73	141	Good thickness
G	113,6	140	Good thickness
H	89,41	141	Good thickness
Ceiling	137,95	141	Good thickness

4. Conclusion

The thicknesses of primary and secondary barriers for LINAC 6 MV Elekta-Compact bunker were calculated using NCRP report 151 by regulatory body (AMARAP) in order to check the provided thicknesses for authorization purposes. The results showed that, the provided thicknesses of different locations were bigger than the ones calculated except location B and C. But in the building plan, there is maze and the thickness of this maze must around **40 cm of concrete.** After building of the bunker, the regulatory controls or inspections revealed that the bunker protects efficiently workers and public around its vicinity against ionizing radiations.

CONCRETE AND STAINLESS STEEL ACTIVATION/DECAY HEAT DATA FOR THE IFMIF-DONES TEST CELL COMPONENTS

G. STANKUNAS
Lithuanian Energy Institute, Kaunas, Lithuania

Activity inventories and decay heat for waste evaluation and decommissioning are essential parameters for development of any nuclear device [1]. The activities in this field aim to provide the detailed calculation results and identify the needs for the IFMIF-DONES facility and components.

The main objective of the study is to perform activation/decay heat calculations for steel and concrete materials located in Target & Test Cell (TC) of the accelerator. This paper contains the data on updated activation, decay heat and dose rates calculations of TC liner and concrete inside biological shielding walls. On this basis new data was provided for the further DONES (one accelerator, 125 mA current, 5 MW beam power to the target) design, or the need for performing additional activation calculations cases not considered so far.

Test Facility consists mainly of two systems: 1) the Test Cell housing the nuclear reaction and 2) the set of hot cells allowing the replacement of the Target Assembly and the TMs, and also the preparation of new modules and the extraction of irradiated specimens. The Test Cell is the system where beams converge with the Li of the Target Assembly to generate high neutron and gamma radiation fields to irradiate Test Modules. Then, high quantity of radioactive materials will be in this cell, as well as liquid metal.

Test Modules inventory show variations from one to the others due to the different materials involved in the modules construction and in the irradiation experiments. Modules are cooled by gas (He) and contain materials such as Stainless Steel 316LN, EUROFER, INCONEL 600, Austenitic steel AISI 316L, sodium–potassium alloy (NaK), ceramic insulators and other.

Biological shielding surrounding the TC is composed of heavy concrete and inner liner. Inner layer is an independent closed framework which is covered with stainless steel (SS) liner from inside with a thickness of 8 mm. Between SS liner and inner shielding a set of water cooling pipes is designed for nuclear heating removal purpose. The thickness of the inner layer is 1 m in the beam direction and lateral direction, while 0.5 meter at the bottom.

The inventory analysis was carried out for the TC liner (Fig.1) The analysis was done by cell based; the liner part consists of 8 cells in the present calculation model (top, bottom, downstream, upstream, two lateral sides and two for TM supports) The average neutron spectrum was calculated for each cell and then passed to the FISPACT code.

Due to the activation of the liner and the concrete wall, the residual dose rate is still very high even if all the removable in-cell components are removed. Time evolution of activation and decay heat with identified dominant nuclides calculated for the TC concrete near TC liner are represented in Figures 2.

The specific activity for the TC liner are mainly influenced by isotopes produced by (n,g) reactions (neutron capture) with low energy neutrons with dominant nuclides that contribute to the decay heat - Co-60 together with Mn-56 and Fe-59. The calculated contact dose rate is 5E+05 µSv/h just after shut down of the beam. The main contributors for dose rate and decay heat of the irradiated TC material remains mostly the same as for activation. Specific activation and decay heat analysis of concrete exposed Mn-54 to be the biggest contributor to the total value.

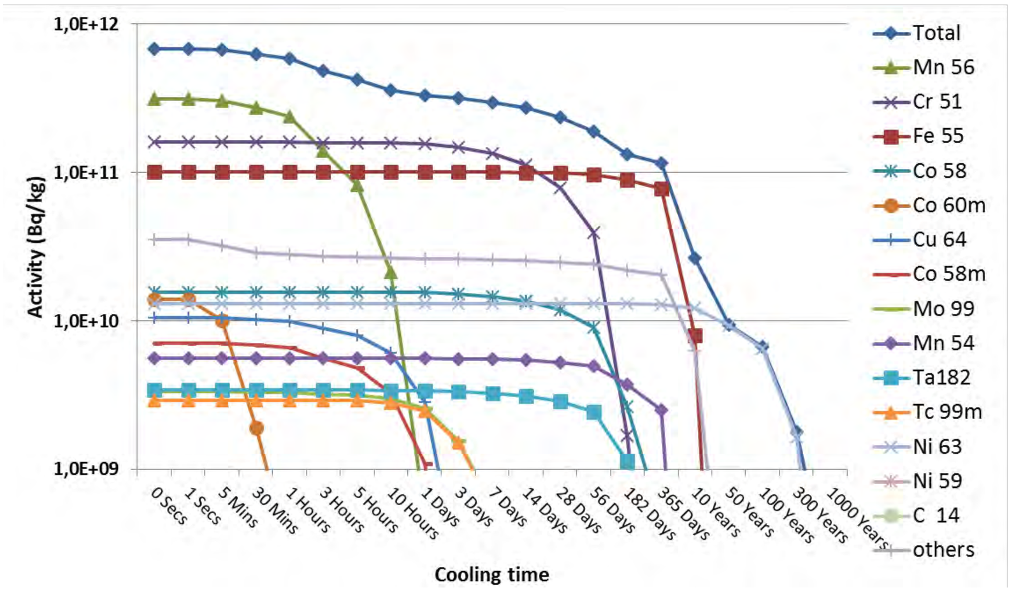

Figure 1. Time evolution of activity induced in the TC liner

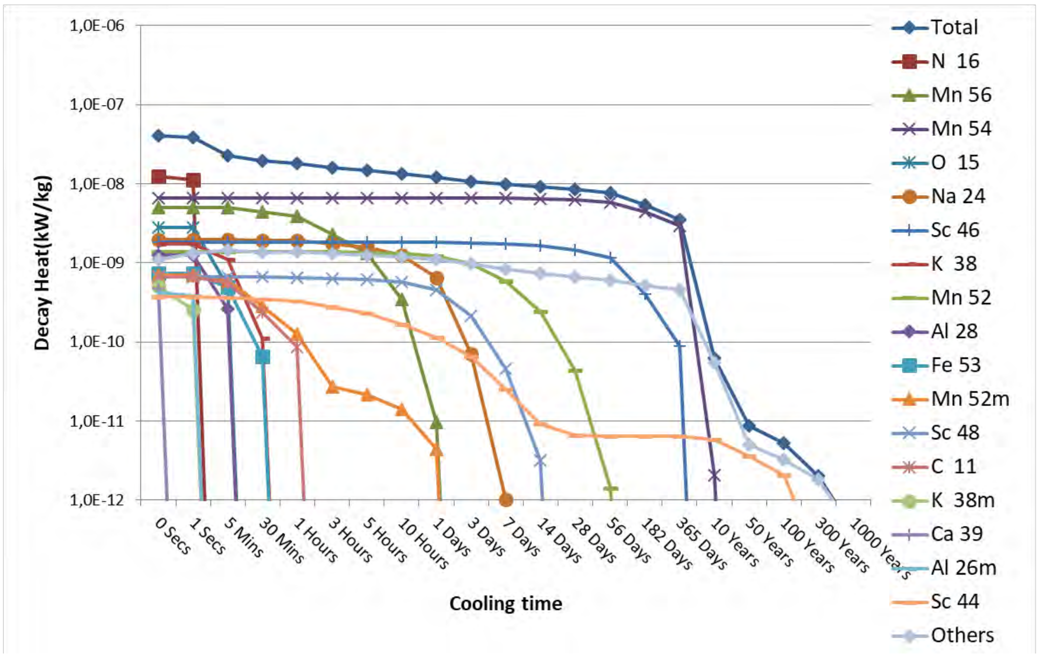

Figure 2. Time evolution of decay heat with dominant nuclides calculated for the TC concrete near TC liner.

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THE RIANBOW ION-SOLID INTERACTION POTENTIAL

S. PETROVIĆ, N. STARČEVIĆ, M. ĆOSIĆ

Laboratory of Physics, Vinča Institute of nuclear sciences, University of Belgrade, Belgrade, P. O. Box 522, Belgrade, Serbia

Recent rapid development of the nanoscience and the nanotechnology imposes new challenges with respect to the basic assumptions considering ion-solid collisions: the energy loss averaging over the impact parameters, the equilibrium charge state distribution and the use of ZBL universal ion-atom interaction potential.

Petrović et al. [1] presented the high-resolution transmission measurements of the angular distributions of medium energy protons (0.7 – 2 MeV) channeled through a 55 nm thick (001) silicon membrane. They showed that the universal ZBL proton-silicon interaction potential cannot accurately describe the experimental results. As a result, they obtained the rainbow interaction potential (RIP), which approximate ZBL potential for the small impact parameters and the Moliere potential for the large ones. The RIP was constructed by introducing the morphological method based on the crystal rainbow effect [1, 2]. Further, the rainbow morphological method was successfully applied for 27 cubic crystallographic crystals in the (001) and (111) orientations with the BCC crystallographic structure: vanadium, chromium, iron, niobium, molybdenum, barium, europium, tantalum and tungsten; with the FCC crystallographic structure: aluminum, calcium, nickel, copper, strontium, rhodium, palladium, silver, cerium, ytterbium, iridium, platinum, gold, lead and thorium; and the diamond type crystallographic structure: silicon, germanium and tin [3, 4]. For the (001) orientations RIP reds: $V_{001} = \frac{Z_1 Z_2 e^2}{R}\sum_{i=1}^{3}\gamma_i \exp\left(-\frac{\delta_i R}{a_F}\right)$, where the fitting parameters, γ_i = (0.10, 0.55, 0.35), δ_i = (${Z_2}^{1/3}(Z_1^{1/2}+Z_2^{1/2})^{-2/3}6.0$, 1.828, ${Z_2}^{1/3}(Z_1^{1/2}+Z_2^{1/2})^{-2/3}0.3$), while for the (111) orientations, $V_{111} = \frac{Z_1 Z_2 e^2}{R}\sum_{i=1}^{3}\gamma_i \exp\left(-\frac{\delta_i R}{a_F}\right)$, where δ_i = (${Z_2}^{1/3}(Z_1^{1/2}+Z_2^{1/2})^{-2/3}6.0$, 1.475, ${Z_2}^{1/3}(Z_1^{1/2}+Z_2^{1/2})^{-2/3}0.3$) and $a_F = \left(\frac{9\pi^3}{128}\right)^{1/3}(Z_1^{1/2}+Z_2^{1/2})^{-2/3}a_0$ is the Firsov's screening radius. One should note that the obtained potentials differ (for a small amount) for the value of the fitting parameter δ_2 only!

In this work we extend the rainbow morphological method to construct RIP for (110) Si oriented crystal and 6 MeV protons. The channel corresponding to (110) orientation in Si crystal is one of the largest in nature, with can be described by a 2D rhombic Brave crystallographic lattice with two atomic strings per the lattice node.

Figure 1a shows the rainbow lines in the impact parameter plane for RIP, ZBL and Moliere potentials designated by red, black and blue color, respectively. One can observe two separate regions, close to the atomic strings and in between them, corresponding to small and large impact parameters, respectively. It should be note that the rainbow lines in the impact parameter plane, according to the theory of crystal rainbows, are not observable [2, 3]. Figure 2b shows the rainbow lines in scattering angle plane, which has be experimentally established to be a skeleton of the corresponding angular distribution of transmitted channeled ions [1]. It is clear that the rainbow lines corresponding to RIP and ZBL potentials are clearly separate and consequently easily to distinguish in the corresponding experiment.

The analysis shows that for the considered case the fitting parameter δ_2 = 1.388 (the value close to the obtained δ_2 for the above-mentioned cases) and the thickness of the crystal is 50 nm. Therefore, one may hypothesize that an accurate interatomic potential should be the RIP with the average value δ_2 =1.564, for all major crystallographic directions!

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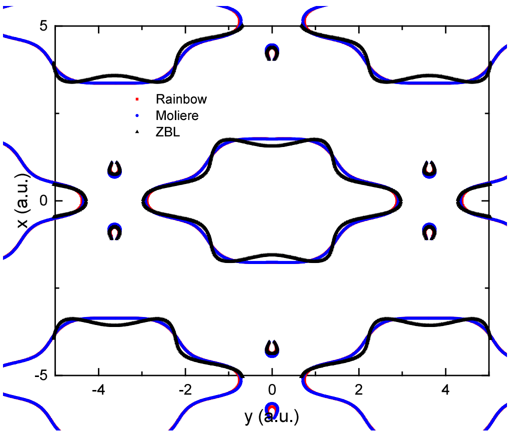

Fig. 1a *Rainbow lines in the impact parameter plane for the, ZBL - black lines, Moliere - blue lines and RIP potentials - red lines for 6 MeV protons and (011) Si crystal.*

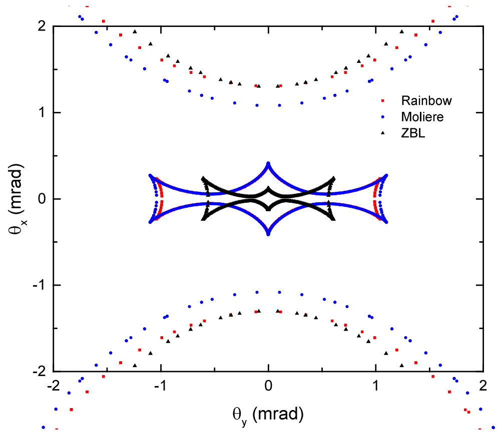

Fig. 1b *Rainbow lines in the scattering angle plane for the, ZBL - black lines, Moliere - blue lines and RIP potentials - red lines for 6 MeV protons and (011) Si crystal.*

DEVELOPING RADIATION TREATMENT METHODOLOGIES FOR DECONTAMINATION FOR FIRST USE OF PERSONAL PROTECTIVE EQUIPMENT (PPE) USING TUNISIAN ELECTRON BEAM ACCELERATOR

A. MEJRI, H. TRABELSI, J. CHATTI, Z. TRABELSI, M. KRAIEM
National Center for Nuclear Sciences and Technologies (CNSTN), Ariana/Sidi Thabet, Tunisia

Keywords: Dosimetry; E-beam accelerator; Personal Protective Equipment (PPE).

The Tunisian irradiation infrastructure was reinforced in end of 2009 by a high-energy electron beam accelerator with three energy levels (5, 7.5 and 10MeV). The electron beam facility represents the first semi-industrial scale in Tunisia and in North Africa. The facility is composed of RF linear accelerator of electrons, type CIRCE III, (Fig.1.) and an electromechanical conveyor system. The main characteristics of this Linac are three energy levels of the E-beam with a maximum power of 5 kW. The E-beam is pulsed (12.5µs). The conveyor is able to transport boxes from size 40 × 30 × 20 cm3 to size of 80 × 50 × 50 cm3 for a weight range of 1-35 kg for and a speed range of 15-500 cm/min. [1,2]

The productivity estimated of this new facility is 2.2 m3/h for medical products irradiated at 25 kGy and 360 kg/h for spices at 10 kGy, 3.15m3/h for surgical masks at 5kGy and 3.52 m3/h for Face Shields at 5kGy.

For (IQ), (OQ) and (PQ) Qualifications [3, 4], two dosimetry films were used for the dose measurements: CTA (type FTR-125, dose range: 0.1–100 kGy) film measured at 280 nm [4] using the Aerial Equipment [5] and GEX B3 dosimeters 1 to 80 kGy [6]. A medium size box (60×40×40 cm3) filed with rock wool, as reference materials, is used in the following experiment.

Tunisian Electron irradiation facility is used for decontamination and sterilization of Personal Protective Equipment (PPE), including surgical masks and Face Shields. Five sept of samples were selected from each received batch and treated with different electron irradiation doses (5, 10, 15, 20 and 25 kGy). A post irradiation inspection and evaluation of irradiated devices in relation to mechanical and Colorimetric change were carried out by the suplier in concordence with related regulations and standards. Microbiological characterization of the protective devices were carried out in CNSTN laboratories. The results showed that all treated samples are cleaned with 5 kGy dose and the survival rate of bacteria was significantly reduced function of the dose increases compared to non-treated samples. Results obtained by colorimetry show small change hardly discernible to the naked eye in the color properties of Face Shields after irradiation at 5kGy for higher doses the color becomes more and more dark a progressive loss in tensile strength was detected after irradiation especially for surgical Mask for dose up to 25kGy.

An appropriate methodology for the facility operating parameters (conveyor speed, beam current, scan width…) were developed for such kind of product.

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FIG.1. Tunisian E-Beam Accelerator

RADIOSENSITIVITY OF TWO *LENS CULINARIS MEDIKUS SUBSP. CULINARIS* VARIETIES TO ELECTRON BEAM IRRADIATION

S. MEJRI
Laboratory of Biotechnology and Nuclear Technologies, CNSTN, Ariana, Tunisia

I. HEMISSI
Institute of agronomic research of Tunisia, INRAT, Ariana, Tunisia,

C. BRINSI, A. ASMI, M. SAIDI, Y. MABROUK
Laboratory of Biotechnology and Nuclear Technologies, CNSTN, Ariana, Tunisia

Researchers are challenged to develop new crop adaptation strategies to withstand the climate changes; at the same time there is the need of sustainable alternatives to our current agricultural model, intending to reduce the environmental impact. Enhanced biotic-stress tolerance of lentil towards sustainable intensification of cropping systems for climate-change adaptation is the expected output of this project. However, nuclear techniques, in contrast to conventional breeding techniques, are widely applied in agriculture for improved genetic variability. Mutation breeding is quick, cost effective, robust and proven method to accelerate the process of developing and selecting novel agronomic traits.

The first step in our breeding program using gamma irradiation and electron beam accelerator as source of physic mutagens for resistance to *Stemphylium botryosum* is the assessment of treatment dose known as radiosensitivity test. The present work will be limited to the comparison of radiosensitivity of two lentil (*L. culinaris)* varieties to electron beam irradiation in M1 generation. Growth and development, as well as on the content of photosynthetic pigments in 28 days lentil leaf were recorded.

The present study was carried out to compare effect of electron beam on two Tunisian lentil varieties, KEF and BOULIFA [1]. Dried seeds of both the varieties were treated with electron beam accelerator (7.5Mev) at the Tunisian National Center for Nuclear Sciences and Technology (CNSTN) with different doses, 200Gy, 300Gy, 400Gy, 500Gy, 600Gy, 700Gy, 850Gy and 1kGy with the control. Initially LD50 dose is determined, which is used as an optimal dose for mutation induction. By ignoring this step, mutagen dose can either be high or low resulting mutation frequency. The radiosensitivity test for the two treated varieties were done and counts of germinated seeds were made daily for 7 days to determine both the final germination percentage and germination index. The photosynthetic pigment content was determined spectrophotometrically [2].

The lethal dose was determined by probit analysis [3]. LD50 dose for KEF and BOULIFA was 400Gy and 250Gy respectively. Results showed that germination, shoot length, root length, seedling height on 28th day, in M1 generation reduced steadily with the increasing doses of mutagen. Chlorophyll contents of *M1* KEF and BOULIFA lentil leafs analyzed at 28 days after planting were found to be significantly ($P \leq 0.05$) affected by various levels of electron beam irradiation doses. The biometric measurements of roots emerged from irradiated seeds showed a significant decrease of root length after two weeks from the start of the experiment. The decrease of root length was confirmed by the increased doses in electron beam treated KEF and BOULIFA. Higher reduction of root length was observed at higher dose of electron beam. Seedling height is widely used as an index in determining the biological effects of various physical mutagens in M1. The present study exhibited that the seedling height measured at 28 days after planting was decreased with the proportion of increase in dose in both the varieties of KEF and BOULIFA. Based on the overall consideration of M1 effects, the variety BOULIFA was more sensitive to mutagen than KEF variety.

Results of this study reveal that higher doses of e-beam irradiation exhibited strong detrimental effects on chlorophyll contents and growth parameters of lentil two varieties. The overall study on the effect of electron beam on germination index, survival, shoot length, root length, seedling height and chlorophyll contents at 28th day in M1 generation of two lentil varieties concluded that, BOULIFA was highly sensitive to electron beam than KEF. These optimum mutagen doses determined for the two lentil genotypes could be useful while formulating lentil mutation breeding program for improvement of specific traits (Stemphylium Blight resistance) in lentil.

Key words: breeding program, lentil, biotic stress, e-beam accelerator.

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ELECTRON BEAM CROSSLINKING OF PE/NG NANOCOMPOSITE FOR SOLAR COLLECTOR APPLICATIONS

A. AKHAVAN, H. KAZEMINEJAD

Radiation Applications Research School, Nuclear Science and Technology Research Institute, Tehran, Iran

Commodity plastics like polyethylene (PE) offer a cost reduction potential for use in solar thermal systems, however their application in thermal collectors, especially as absorber materials, is still rather limited [1]. The use of PE as a thermal conductive material is limited due to its low melting temperature, below 140 °C, and its poor dimension stability at high temperatures. Crosslinking reactions can probably compensate disadvantages of PE. Because it is well known that the three-dimensional network structure formed in PE via the crosslinking process is responsible for improved mechanical properties, such as tensile strength, hardness and the dimension stability. Among the current crosslinking ways, radiation crosslinking could be an efficient way to get crosslinked PE without any additives and chemical pollutions [2]. On the other hand, due to the excellent properties of the nanographite pigment, it may fulfil the requirements of high absorbance in the solar absorber materials [3]. The main emphasis of this work is to study the thermal and aging behaviours of the radiation-crosslinked polyethylene containing nanosized graphite under stagnation conditions related to solar thermal applications.

For this purpose, PE/NG composites containing 2.25% nanographite was prepared through masterbatch preparation and then melt extrusion process. SEM images of the PE/NG 2.25% sample proved a good dispersion of NG in polymer matrix (Fig. 1).

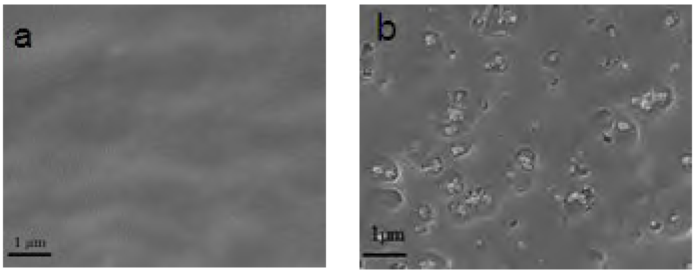

FIG.1. SEM images of (a) PE (b) PE/NG composite.

The results of hot creep and hot set measurements for PE/NG 2.25% are depicted in Table 1. As observed, the unirradiated sample melts rapidly at 150 °C, so that fail immediately. For irradiated samples by increasing of the irradiation dose to 200 kGy, hot creep decreases, indicating that high amount of crosslink density formed with increasing dose. The higher concentration of crosslinks leads to a longer resistant time in the hot creep condition, indicating improved thermal stability of the samples. In addition, hot set results show that after cooling, irradiated sample at 200 kGy has the lowest extension. This means that even if the irradiated nanocomposite exposed to 150°C in the stagnation condition, after cooling it nearly goes back to its original form which is important property in the solar thermal absorber applications.

TABLE 1. HOT SET RESULTS OF IRRADIATED PE/NG

Dose (kGy)	0	100	150	200
Hot creep (%)	-	72	56	44
Hot set (%)	-	5.2	4.8	2

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Differential Scanning Calorimetry (DSC) analysis of 100 kGy irradiated sample in hot air at 140 °C for 100, 200 and 400 h are shown in Fig. 2. It is found that thermal aging causes a prominent increase in melting point and degree of crystallinity during initial 100 h, followed by a slower increase at longer aging times. This increase in crystallinity could be due to additional crystallization and formation of new crystals in the interface between NG nanoparticles and polymer matrix by thermal aging [4].

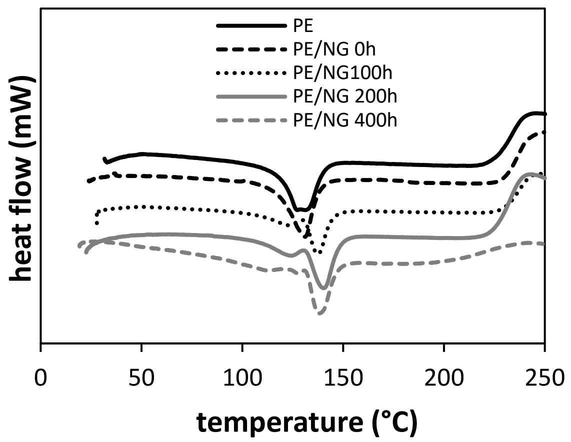

FIG. 2. DSC thermograms of irradiated PE/NG composites after exposing to air at 140 °C.

Altogether, radiation crosslinked PE/NG containing 2.25% NG at 100 kGy appears to be a promising candidate for application as a black absorber material for solar thermal collectors.

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ESTABLISHMENT OF THE FIRST ACCELERATOR-BASED INFRARED FREE-ELECTRON LASER FACILITY IN SOUTHEAST ASIA

S. RIMJAEM
PBP-CMU Electron Linac Laboratory (PCELL), Plasma and Beam Physics Research Facility, Department of Physics and Materials Science, Chiang Mai University, Chiang Mai, Thailand

An accelerator-based mid-infrared (MIR) and terahertz (THz) free-electron laser facility is recently established at the PBP-CMU Electron Linac Laboratory (PCELL) of the Plasma and Beam Physics Research Facility in Chiang Mai University, Thailand. This project was officially launched in 2019 and planned to be ready for applications in late of 2022. This new facility will be the first of its kind in Thailand and Southeast Asia. The major parts of the 25-MeV electron accelerator and the free-electron laser beamlines have been designed and developed in-house by our group. The system consists of a thermionic radio-frequency radio-frequency (RF) electron gun, a pre-bunch compressor in a form of alpha magnet, an S-band RF linear accelerator, two magnetic bunch compressors, and two undulator magnets for generation of the MIR oscillator free-electron laser and the coherent THz radiation. Development of experimental stations using THz time-domain spectroscopy and pump-probe experiment is proceeded. The ultimate goal of this facility is to become the first user infrared free-electron laser facility in Southeast Asia that opens for all researchers from Thailand and Asian. It will provide experimental stations and advanced tools for frontier researches and applications in material science, biotechnology and medicine. With environment of research university like Chiang Mai University, this facility will also excellently become an academic training centre for students and interested researchers on the fields of electron accelerator and accelerator-based light source. Introduction to the facility and progress report in terms of the facility performance and its experimental stations will be presented in this contribution.

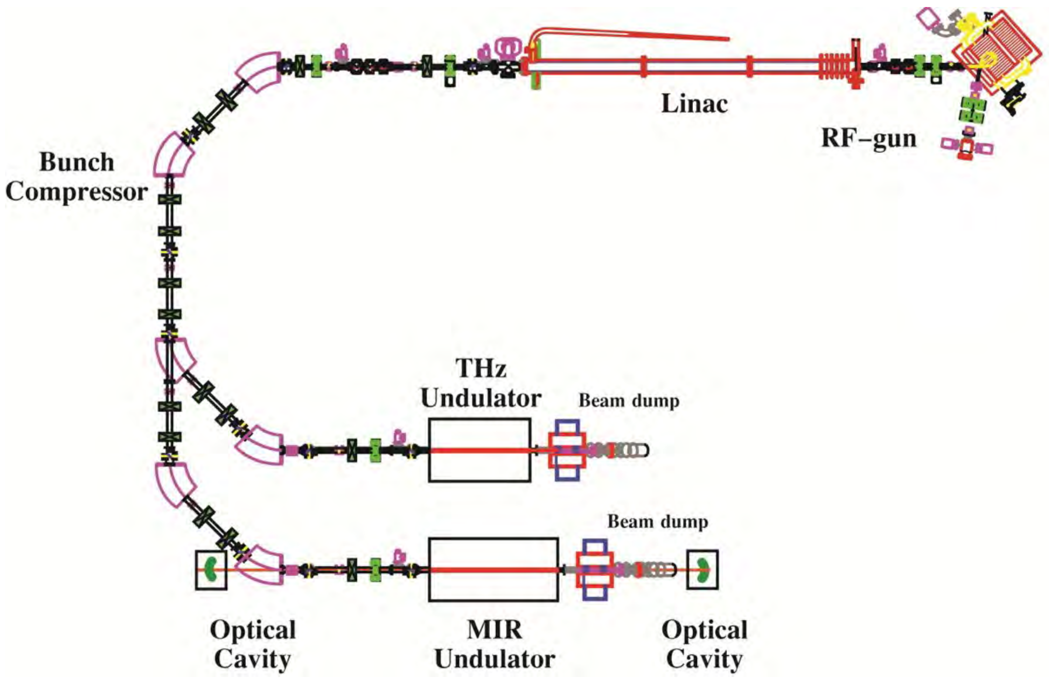

FIG. 1. Schematic layout of the 25-MeV electron accelerator system and MIR-THz free electron laser beamlines at Chiang Mai University in Thailand.

SOCIOECONOMIC IMPACT OF CYCLOTRONS IN KING FAISAL SPECIALIST HOSPITALS & RESEARCH CENTRE IN SAUDI ARABIA

Ibrahim ALJAMMAZ
King Faisal Specialist Hospital & Research Centre, Saudi Arabia

Cyclotron and Radiopharmaceuticals Department (C&RD) is a state-of-the art facility for two primary activities: Radiopharmaceuticals production and Precision Radiopharmaceuticals research. Since late 1970s, the mission of C&RD is to provide diagnostic and therapeutic radiopharmaceutical products that are manufactured by employing the highest quality standards, and to make the Kingdom of Saudi Arabia self-sufficient in all its radiopharmaceutical requirements. At the C&RD facility, three cyclotrons (particle accelerators) are dedicated to producing several essential radioisotopes, which are transformed into radiopharmaceuticals, and subsequently qualified as suitable for human use through rigorous testing and quality assurance. Radiopharmaceuticals manufacturing program is not only quite unique even for a major medical center, but also an essential component of King Faisal Specialist Hospital & Research Centre (KFSH&RC) in providing the specialty services and quality patient care for the population of the Kingdom. On-demand and reliable availability of radiopharmaceuticals are essential components of viable nuclear medicine practice. C&RD manufactures a wide range of radiopharmaceuticals used in diagnostic medical imaging, as well as for radiotherapy.

Over 30 high quality products are manufactured in state-of-the-art cleanroom facilities and supplied to more than 50 nuclear medicine centers throughout the Kingdom. To-date, well over 600,000 patient doses of radiopharmaceuticals have been supplied for clinical investigations throughout the Kingdom and abroad. Products are manufactured according to the international and Saudi Food and Drug Authority (SFDA) standards of Good Manufacturing Practices (GMP), as well as in adherence to the ISO 9001 Quality Management System (QMS). Research activities of the C&RD are focused on developing new radioisotopes and radioactive molecular probes with potential usefulness as precision radiopharmaceuticals for imaging and therapy. The facility comprises of appropriate equipment, including a micro-PET/CT for *in vivo* studies of the new radiotracers for achieving translational research from bench to bed-side. C&RD's multi-disciplinary staff is a blend of engineers, chemists, radiochemists, radiopharmacists, and quality control chemists all working toward KFSH&RC's goal of providing the specialty services in patient care. The Department is committed to the policy of *Quality in Performance and Pride in Achievement.* Our commitment to future growth is amply supported by R&D activities ensuring continuous influx of new technology and products, and also continuous quality improvements. Furthermore, our scientists are sharing with upcoming new cyclotron/PET facilities worldwide their vast experience and expertise, in form of valuable advice and consultations in manufacturing radiopharmaceuticals. Finally, these efforts have resulted in delivering precision medicine, reducing dependency on imported sources, generating quality job opportunities for qualified Saudi youth and generating considerable revenue and financial self-sustainability.

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DETERMINATION OF THE EFFECTIVENESS AND CONTROL OF FOOD IRRADIATION PROCESS WITH A LOW-ENERGY ELECTRON BEAM

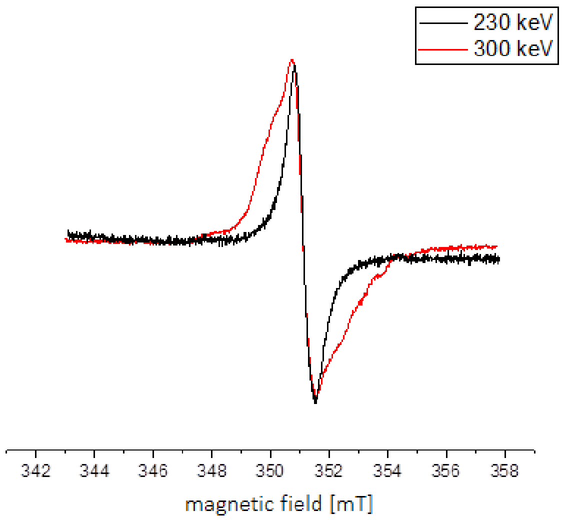
U. GRYCZKA, S. BUŁKA, W. MIGDAŁ, J. SADŁO
Institute of Nuclear Chemistry and Technology, Warsaw, Poland

Currently, for food irradiation highly penetration ionizing radiation sources are used. A new approach to irradiation processing of food and agricultural products is related to the limited penetration of low energy electrons (LEEB), which can effectively reduce the number of microorganisms in food products [1]. The advantage of such a solution is that low energy electrons do not penetrate the whole volume of food products thus interacting less with food components. However, to ensure that microorganisms are effectively inactivated in food products it is necessary to determine all parameters which may influence the effectiveness of LEEB microbial decontamination process. Due to the limited penetration of electrons in treated material, it is important to define which food categories can be treated with the low energy electron beam.

In the presented study the work focused on the determination of the thickness of the layer which electrons can penetrate in different types of food products depending on the energy of electrons. Since microorganisms may inhabit different thicknesses of food [2], for the high LEEB process effectiveness it is important to select process paraments that ensure that the whole sub-surface layer inhabited by microorganisms is reachable by the electrons.

The results obtained for the selected classes of food products are supported by dosimetric data, EPR spectroscopy, analysis of the internal structure using a USB camera and density measurements. The dose measurements were performed using B3 dosimetric foil to determine the range of electrons in water which in experimental conditions ranged from 100 µm for the beam of energy 200 keV up to about 350 µm for the beam of energy 300 keV. EPR spectroscopy was used to determine the type of radicals formed as an effect of ionising radiation interaction with food components. The range of electrons in food was correlated with the EPR signal, which for heterogenous in chemical composition food samples changes with the energy of electrons, as shown for pepper sample in Fig.1. The radicals localised in cellulosic components, starch or sugars of food result in a different signal, thus giving information on the thickness of the irradiated layer.

FIG. 1. Changes of EPR signal measured for white pepper grains irradiated with the electron beam of energy 230 and 300 keV



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MEASUREMENT OF EXCITATION FUNCTIONS OF PROTON-INDUCED NUCLEAR REACTIONS ON ^{NAT}DY

Jaroslav ČERVENÁK, Ondřej LEBEDA
Nuclear Physics Institute, CAS, Prague, Czech republic

Background

Radionuclide ^{161}Tb (6.89 d) is a promising alternative to the established therapeutic ^{177}Lu. It emits low energy β^- particles with mean energy of 154 keV and maximum energy of 593 keV. Moreover, it provides more conversion and Auger electrons that may enhance its therapeutic efficacy compared to ^{177}Lu.

Terbium-161 is usually produced in nuclear reactors via neutron capture on highly enriched ^{160}Gd targets, followed by a β^- decay of short-lived ^{161}Gd (3.66 min). While the production in nuclear reactors is already well established, its potential production by charged particles accelerators has not been entirely investigated. In principle, there are two possible reactions leading to ^{161}Tb – ^{160}Gd(d,n) and ^{164}Dy(p,α). The excitation function of the latter has been measured only once on natural dysprosium target and the results were published in 2013. We decided to re-measure in detail proton-induced excitation functions on ^{nat}Dy for all the radionuclides detected in the target.

Methodology

The excitation functions were measured using the stacked foil technique on the cyclotron U-120M of the Czech Academy of Sciences in the energy interval of 7.1–36.0 MeV. After the irradiation, the stacks were immediately disassembled and foils repeatedly measured using off-line high resolution γ-ray spectrometry. Cross-sections and their uncertainties were calculated from the activities of each particular radionuclide and other measurement parameters.

Results and Discussion

The cross-sections for the nuclear reactions ^{nat}Dy(p,x)$^{159m+g}$Ho, ^{160m}Ho, ^{160g}Ho, $^{161m+g}$Ho, ^{162m}Ho, ^{162g}Ho, ^{155}Dy, $^{157m+g}$Dy, ^{159}Dy, ^{155}Tb, $^{156m+g}$Tb, ^{160}Tb, ^{161}Tb and ^{159}Gd in the energy range of 7.1–36.0 MeV were measured and compared with both the previously published experimental data and with the theoretical prediction of the nuclear reaction model code TALYS (library TENDL2019). Thick target yields were deduced from the experimental data. If possible, activities of the ground-state isomers were corrected for the contribution of the metastable isomeric nuclei.

Conclusion

We provided a detailed cross-section data for the nuclear reactions ^{nat}Dy(p,x)$^{159m+g}$Ho, ^{160m}Ho, ^{160g}Ho, $^{161m+g}$Ho, ^{162m}Ho, ^{162g}Ho, ^{155}Dy, $^{157m+g}$Dy, ^{159}Dy, ^{155}Tb, $^{156m+g}$Tb, ^{160}Tb, ^{161}Tb and ^{159}Gd covering the energy range of 7.1–36.0 MeV. The thick target yields based on the experimental data allow for calculation of both the ^{161}Tb activity and the content of major radionuclidic impurity, ^{160}Tb, in the target as a function of energy, bombardment and cooling times.

Key words: Excitation functions, cross-section, proton activation, stacked-foil technique, Tb-161, Tb-160

LOW ENERGY S–BAND ELECTRON LINEAR ACCELERATOR(S) DEVELOPMENT FOR RESEARCH AND APPLICATIONS HAVING SOCIO–ECONOMIC IMPACT

MUHAMMAD ASIF KHAN
PINSTECH, PAEC, Islamabad, Pakistan

Abstract: It is to report on the design & development of low energy RF based linear accelerator(s) for radiography, medical, cargo scanning and food irradiation applications. These applications are chosen considering high demand and direct socioeconomic impact in one of the most populated country (Pakistan) of the world. In the first phase, a 6 MeV standing–wave side–coupled linear accelerator structure has been designed and manufactured. The developed accelerator was then transformed into a Non–Destructive Testing (NDT) Radiography system, which shall be discussed at the conference. An in house accelerator test facility has been established, which comprises of 10 MW klystron powered by solid state modulator and the compatible RF transmission system. The research and development on various aspects of accelerator technology including electron gun, HV pulsed modulators, accelerator cavity design & manufacturing, e^-beam dynamics and diagnostics, X–rays target, vacuum brazing, RF conditioning, accelerator operation and control systems shall be presented. The progress on transformation of the developed accelerators into radiography, medical, cargo scanning and food irradiation systems shall also be presented.

Introduction: Small–to–medium energy electron linear accelerator systems (ELAS) encompass the technological domain that has multifaceted applications. This has potential to substantially impact the import–export imbalance and social well–being of a developing country.

Establishment of Accelerator Setup/ Facility: Considering the huge socioeconomic impact (need based) and training of young scientists/ engineers, an accelerator research and development setup has been established and is being extended to a full grown facility for design and development of low–to–medium energy commercial accelerators.

6 MeV Linac Design, Development and Testing: Initially, during phase–I of the project, design, manufacturing and testing of the maiden 6 MeV Linac was established. Table 1 below, lists the operational parameters of the developed Linac that coincides very well with the similar developments reported in literature [1].

Table 1. 6 MeV Linac Operational Parameters

S. No.	Parameter	Measured Value
i.	RF Injected Power	2.5 MW
ii.	Operating Frequency (f_o)	2997.7 MHz (@ 37°C)
iii.	RF Pulse Width (PW)	4 μsec
iv.	Pulse Repetition Frequency (PRF)	50 Hz
v.	Vacuum: Base Pressure	1E–9 mbar
vi.	Vacuum: Pressure with Beam	1E–7 mbar
vii.	E-Gun Filament Power	7.67 W
viii.	E-Gun Extraction Voltage	–29.6 KV
ix.	Beam Current (@ Target)	~ 120 mA (peak)
x.	Dose Rate (@ 100 cm)	110 cGy/min

6 MeV Radiography/ NDT Linac: The developed/ tested 6 MeV Linac was gradually transformed to Radiography (NDT) system. Following experiments were conducted to characterize the NDT Linac:

- Beam Profile Measurement;
- Penetration Measurement;
- Contrast Sensitivity;
- Exposure Chart;
- Spatial Resolution.

Other Linacs: Besides 6 MeV Radiography Linac, other single–energy deliverable systems being considered, as per country requirements are:

- 6 MeV Radiotherapy Linac;
- 6 MeV Cargo scanner Linac;
- 9 MeV Radiography Linac;
- 6–9 MeV Food irradiation Linac.

Conclusion: Pakistan being a developing country, could breakthrough in economy to offset the heavy export–import imbalance through technological developments in accelerators domain especially for medical, radiography, cargo scanning and food irradiation. These accelerator applications directly impact wellbeing of the large population. The developments in early phase of the project/ program shall be presented at the conference to seek collaboration with potential international partners.

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CURRENT DEVELOPMENT STATUS OF THE LINAC-BASED BNCT DEVICE OF THE IBNCT TSUKUBA PROJECT

Hiroaki KUMADA,

Tsukuba University, 1-1-1, Tennodai, Tsukuba, Ibaraki, 305-8575, Japan

Boron neutron capture therapy (BNCT) is the next generation of radiation therapy that combines neutrons and boron drugs. iBNCT project headed by the University of Tsukuba is being currently developed iBNCT001, a demonstration device for the compact linac-base neutron source based BNCT device. The accelerator of the iBNCT001 has adopted an RFQ and a DLT type linac. Fig.1 shows the linac of iBNCT001. The linac had been designed to be able to accelerator protons of the average current of 5 mA or more to 8 MeV. Regarding a neutron target material, beryllium has been adopted. At present, the device has succeeded to drive in the condition of an average proton current of 2 mA and generate epithermal neutron beam from the beam aperture.

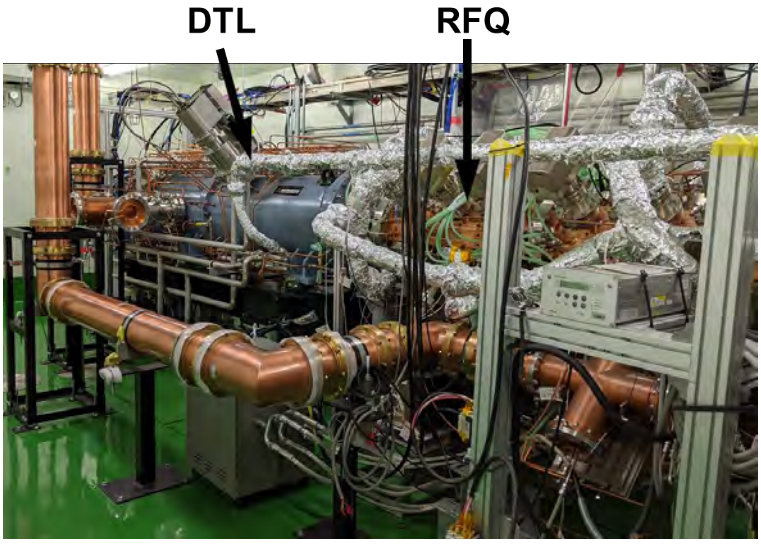

Fig.1 The RFQ and the DTL of Linac of iBNCT001

To confirm the applicability of the beam of iBNCT001 to the treatment, we are conducting several characteristic measurements of the neutron beam generating from the device. In the experiment with a rectangular water phantom, two dimensional distributions for thermal neutron flux and gamma-ray dose rate that are important factors to determine the dose in BNCT, has been measured in the phantom. In the measurement of the thermal neutron flux, some gold wires were set inside the phantom where was set in front of the beam aperture. In the measurement of the gamma-ray dose rate, many TLDs were located irradiation field in the phantom. The phantom for both measurements was irradiated the epithermal neutron beams and then the distributions for thermal neutron flux and gamma-ray dose rate were measured by using each detector. The measurement results demonstrated that the maximum thermal neutron flux in the phantom was approximately 1.4×10^9 (n/cm^2/s) in the phantom. The neutron intensity has sufficient performance to complete irradiation within 30 minutes with BNCT for malignant brain tumors and for head-and-neck cancer. One of the features of the device is capable an extended beam collimator to the beam aperture. The extended collimator works to avoid the interference of the patient's shoulder to a wall during the irradiation in the head and neck cancer and a patient can be received the irradiation in a more comfortable posture. In the case that the extended collimator is used to BNCT, neutron flux at the beam aperture drops to about half compared with the conventional collimator. Thus, it is impossible to apply the extended collimator to treatment unless the neutron source can generate the neutron beam with the higher intensity. Fig. 2 shows a scene of the phantom experiment that was measured the beam performance of the extended collimator. The measurement results for the extended collimator with a water phantom had proven that the irradiation with the collimator can be completed within one hour and the collimator can be applied to treatment. iBNCT001 is currently the only accelerator-based BNCT device that can be combined practically the extended collimator.

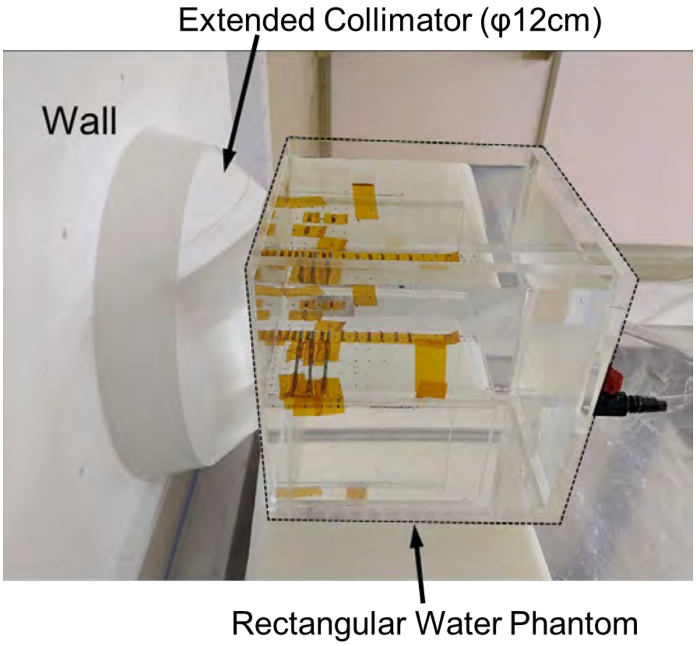

Fig.2 Scene of an irradiation experiment with a water phantom for the measurement of the performance of the extended collimator

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VENTILATION AIR SYSTEM ISSUE AT THE UNIVERSITY OF COSTA RICA'S CYCLOTRON FACILITY

MORA-RAMIREZ, E., CORRALES-CORRALES, E.
Atomic, Nuclear and Molecular Science Research Center, University of Costa Rica
San Jose, Costa Rica

Background: The first Cyclotron in Costa Rica was installed in 2020 at the Atomic, Nuclear and Molecular Science Research Center (CICANUM), at the University of Costa Rica. The layout of the building was initially accepted by the CICANUM and it was approved by IBA. The layout considers all different areas and systems of the facility. During the first acceptance tests of the Cyclotron, 18F isotope was produced, sent to the hot-cells and eventually dumped through the building ventilation exhaust pipe, where were released outside the building but then detected by the environmental detectors into the production floor, therefore outside the hot-cells, which represents a radiation incident that needs to be corrected. The analysis of the incident showed an issue with the vial which received the activity produced from the cyclotron. After a building gas flow analysis, the CICANUM personnel concludes that there was a recirculation of the dumped gas from the hot-cells and it should be fixed by changing the configuration of exhaust pipe of the HVAC system of the building.

Aims: The goal of this work was to develop a proposal for the practical geometric change of that exhaust, to avoid recirculation events of potentially radioactive gaseous waste through the building ventilation system, which could trigger radiation incidents into the production floor.

Methods: An analysis of the geometric configuration of the inlet and outlet of the HVAC system was faced with a geographic air trajectory study using mainly HYSPLIT model by the NOAA Air resources laboratory. An anemometer was placed between the main HVAC inlet and outlet of the building to evaluate the wind direction at that point in order to sustain the wind direction arguments based on the analysis with the modelers and propose a practical option to reconfigure the exhaust pipe. Along with that study, hot-cell intermediate artefacts were proposed to contain its dumped gases enough time to reduce its activity before being released to the main exhaust pipe.

Results: As a result of the analysis and discussion of possibilities, one rotation of nearly 100° at the elbow of the exhaust pipe along with an extension of its length of 20 meters, was performed over the roof of the building beside with a "delay line" system to reduce the evacuation speed of the hot-cell dumped gases.

FIG. 1. A. Inlet and outlet pipe HVAC system initial arrangement installed in the building and radioactive gas trajectory entering production main floor. B. Final placement of the outlet pipe.

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Conclusion: The incident analysis gave us the opportunity to understand where the problem was and solve it. HVAC system configuration requires a meticulous analysis for these types of installations to prevent recirculation of radioactive gases. Our solution considered wind speed and direction using HYSPLIT model. Incident analysis gave a solution to prevent this type of events within our hot – cells.

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PRELIMINARY DESIGN FOR A CYCLOTRON EXTRACTION BEAM LINE AND EXTERNAL TARGET FOR PRODUCING GALLIUM-68 & TECHNETIUM-99M ISOTOPES: A DEVELOPING COUNTRIES SCENARIO

L.F. SALAS-TAPIA & T. ZHANG,
Harbin Engineering University, Harbin, China

L.F. ECHEVERRI-ECHEVERRI
Universidad del Cauca, Popayán, Colombia

Currently, over 1500 cyclotrons around the world are being used for isotope production [1]. From that amount, more than a half of those machines have particle exiting energies below 20 MeV. These low and medium energy range cyclotrons are mainly located in developing countries. Cyclotron-based solutions for developing countries can contribute in some extent to foster the accessibility of radiopharmaceuticals to more human beings requiring these substances [2]. When analyzing the figures [1], low to medium energy machines are mainly designed to hold an internal target for their irradiation routines. However, this kind of configuration does not allow to test and analyze easily new targets for producing a wide variety of radioisotopes commonly used in the medical and industrial environment. Moreover, cyclotrons with internal targets are more susceptible to undergo periodic maintenance procedures leading to a lost of pressure in the main Dees cavities [3].

Nowadays Technetium-99m (Tc-99m) represents the most used nuclear medicine isotope around the globe [4]. Many daily procedures rely on its physical properties to offer a diagnostic service for patients inside health care facilities. In the same way, recently Gallium-68 (Ga-68) has contributed in the advancing of the PET-CT technique due to its proper half-life time and ability to form new ligands [5]. These two previous isotopes can indeed be produced in low to medium energy cyclotrons. This is due to the energy range of these machines belongs to the nucleon cross section for both Tc-99m and Ga-68 when bombarding a target with protons [6][7]. Achieving a practical way to produce both Ga-68 & Tc-99m using an accelerator-based approach could decrease the high dependency on both ${}^{68}_{32}Ge/{}^{68}_{31}Ga$ & ${}^{99}_{42}Mo/{}^{99m}_{43}Tc$ generators [8].

In this work, a preliminary design of the external beam line for a general small and medium-sized cyclotron is designed using theoretical accelerator physics concepts and computational tools & codes. Using an extraction beam line will also allow us to have a better understanding on the proton beam shape—useful for the production yield calculations. The H^- ions that were accelerated inside the cyclotron are stripped off in order to get protons. As from the cyclotron the exiting energy of the protons considered here is around 17 MeV, the main idea of the beam line is to hold this energy across the linear trajectory till the particles reach the target—the calculated length of the beam line is supposed to be from one to two meters. This beam line behaves, in some extent, as a proton linear accelerator. When particles are impacting the external target main structure for producing our desirable isotopes (Tc-99m & Ga-68), many secondary particles are created such as neutrons and photons. Thus, in this work we also considered the required shielding for protecting the surroundings of the machine from ionizing radiation. The target whole structure which fits into the beam line is supposed to be self-shielded, therefore a practical design is proposed in this investigation with the objective of containing hazardous radiation as much as possible. Regarding the isotope production yield, two generic external targets are designed which incorporate the proper integrated energy degrader thickness for achieving the adequate nucleon cross section for two particular reactions of interest using a solid target: ${}^{68}_{30}Zn(p,n){}^{68}_{31}Ga$ & ${}^{100}_{42}Mo(p,2n){}^{99m}_{43}Tc$.

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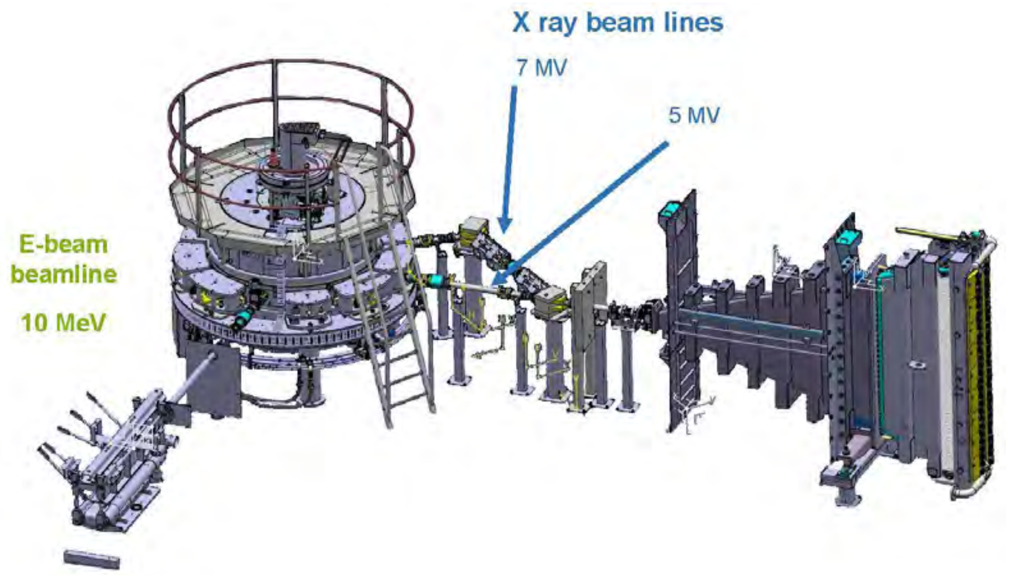
FEERIX, A NOVEL IRRADIATION PLATFORM FOR R&D, EDUCATION AND TRAINING

Florent KUNTZ [1], **Abbas NASREDDINE** [1*], **Nicolas LUDWIG**[1], **Alain STRASSER** [1]
[1] *Aerial, 250 Rue Laurent Fries, 67400 ILLKIRCH GRAFFENSTADEN (France)*

Nowadays, a clear growth in switching from industrial radioactive source based (^{60}Co) irradiators to X-ray and Electron Beam irradiators is observed in the field of industrial radiation processing as well as for health or research applications needing smaller irradiators. This switch is driven by the difficulty to purchase, transport and reload radioactive sources as well as dealing with potential radioactive wastes. Electron beam or X-ray irradiation is a cold, and residue-free physical treatment that has been used for several decades. Among the desired effects on irradiated products one can mention, the microbiological decontamination or sterilization, the modification of the physico-chemical properties of materials, the radical degradation of molecules of interest or the radiochemical creation of neoformed molecules.

The feerix facility, setup in 2019, is an industrial like, novel and unique high energy and high power irradiation plant with its multiple beam lines producing 10 MeV electrons and 5 and 7 MV X-rays.

It is a complementary tool to Aerial's existing platform of irradiation facilities based on electron accelerators. Low, medium and high energy electron and X-ray beams are now available at Aerial for R&D, education and training purposes on radiation applications, innovative approaches of irradiation process control and more over on high dose dosimetry.



Absorbed dose and dose measurement is indeed of prime importance for the control of all the above listed applications. The absorbed dose, which is not only process parameters dependent but also product dependent, is the primary factor to master while processing a specific product. It can be assessed through complementary approaches, practical measurement and in silico with Monte Carlo simulation tools.

There is clearly a growing demand from the industry and researchers for accessing fully qualified training and R&D facilities and capabilities.

Education and training as proposed at Aerial in the field of radiation processing is based on three pillars, know, understand and execute.

It is therefore clear that both a theoretical and a practical approach are used to address, during the proposed training sessions, the importance of process control and traceable dosimetry measurements.

The education and training program is dedicated and customized to each of the key positions of the radiation processing activity i.e. irradiation plant operators, plant managers, quality assurance managers, dosimetrists, auditors, regulation bodies.

With its unique platform of Electron Beam and X ray facilities covering low, medium and high energy radiation fields and "industrial like" innovative irradiation configurations, associated to an accredited dosimetry laboratory with state-of-the-art equipment, Aerial, as IAEA Collaborating Centre, is open for international collaborative research and training.

SIBERIAN CIRCULAR SOURCE OF PHOTONS – MODERN "GREEN" SYNCHROTRON RADIATION SOURCE IN GREEN SIBERIA

CHURKIN, Igor

Budker Institute of Nuclear Physics

BUKHTIYAROV Valeriy, KRASNIKOV Nikolay; LOGACHEV Pavel, LEVICHEV Eugeniy

Boreskov Institute of Catalysis

Budker Institute of Nuclear Physics of Siberian Branch of Russian Academy of Sciences, which is creating the accelerator complex, participates in the implementation of the project on the basic of Boreskov Institute of Catalysis. The accelerator complex consists of Linac (up to 200 MeV), booster synchrotron (up to 3 GeV), booster-storage transport channel (200 meters), Storage Ring (3 GeV) with wigglers and undulators.

The Siberian circular source of photons (SKIF) is creating as a synchrotron radiation source with improved parameters (energy - 3 GeV, storage perimeter - 476 meters, emittance - 75 pm.mrad, current - 400 mA) in Siberia, near Novosibirsk city.

SKIF will have six SR- stations (the first phase) with subsequent development – up to 30 stations. Some of the stations are remote due to the peculiarities of the experiments conducted at stations. Therefore, in the first phase there are such stations as "fast-flowing processes" (15-100 keV and) "diagnostics in the high energy range (25-200 keV). In addition, the first stations will include: "microfocus" (5-47 keV), "structural diagnostics" (5-40 keV), "XAFS spectroscopy and magnetic dichroism" (2.5-35 keV), "electronic structure" (0.01-2 keV).

A special place in the research will take by the virological station. Next to «SKIF» there is State Research Center of Virology and Biotechnology "VECTOR ", which will investigate viruses and other objects in order to create antiviral drugs, including anti-COVID-2019 drugs and vaccines.

The center for collective use of the «SKIF" is located on a plot of land with an area of almost 30 hectares in the "center" of Russia. As part of the "SKIF": main buildings (injector, storage, remote stations) and auxiliary buildings (power corps, engineering support, laboratory). It is planned to carry out assembly and commissioning work on the equipment of the Storage Ring and SR-stations in the building of the stands. Besides, there is the center for work with nonresident/foreign researchers in the Administrative Building.

The power supply capacity will be 12.5 MW when the Center will reach full power (30 SR- stations). The main requirements for the Center's infrastructure that ensure reliable operation in the project parameters of the Center are in the tables:

Area	Air Temperature Stability
Storage Ring tunnel	± 0,1 ^{0}C (1 hour)
Experimental Hall	± 1 ^{0}C
Booster – SR transfer line	± 1 ^{0}C
Booster tunnel	± 1 ^{0}C
Linac	± 1 ^{0}C

Equipments in Areas	Water Temperature Stability
Storage Ring tunnel	± 0,1 ^{0}C
Experimental Hall	± 1 ^{0}C
Booster – SR transfer line	± 1 ^{0}C
Booster tunnel	± 1 ^{0}C
Linac	± 1 ^{0}C

To create comfortable working and living conditions for researchers, visitors and locals, a town with its own unique infrastructure (SKIF-City) is creating.

It is supposed to provide transport accessibility for visiting researchers by creating additional roads and forming a wide network of highways and trails.

After the modernization of transport networks, the travel time to the airport will not exceed 30-40 minutes.

In addition to research groups from research centers, active work is underway to attract specialists from industry.

In cooperation of leading Siberian universities, a lot of work is being done to train personnel. Specialized seminars and conferences are being organized by schools of young scientists.

AN OPTIMIZED PERIODIC MAINTENANCE PLANNER FOR A COMMERCIAL MEDICAL CYCLOTRON FACILITY

ANEES MUHAMMED, DILSHAD KOTTUPARAMBAN
Molecular Cyclotrons Pvt. Ltd., Kochi, India

T.K. SREEDEV
Siemens Healthcare Pvt. Ltd., Kochi, India

RAVITEJA NANABALA, K.N. SUDHAKARAN NAIR, M.R.A. PILLAI, AJITH JOY
Molecular Cyclotrons Pvt. Ltd., Kochi, India

Implementation of scheduled preventive maintenance at regular intervals is mandatory in order to ensure the reliable supply of radiopharmaceuticals from medical cyclotron center to hospitals. The unplanned downtime of the cyclotron interrupts radiopharmaceutical supply which has a compounding impact on the hospital staff, patients, and bystanders. Unplanned production failure of a single day in our facility could affect more than five hundred people which includes about 200 patients expecting imaging. This is a huge economic loss to the cyclotron centre but a much higher revenue loss to the hospitals and mental agony/indirect cost to the patients. The purpose of this study was to develop an effective maintenance protocol to reduce unexpected failures of cyclotron operation in a commercial radiopharmaceuticals production facility.

Siemens Eclipse HP self-shielded medical cyclotron with 11 MeV proton beam installed in our facility at Kochi, India was used for this study. It has four tantalum F-18 targets with dual irradiation capability of up to 120 µA total beam current. As the best practice, we followed manufacturer's operating guidelines from the time of cyclotron's commissioning itself. The operational parameters are kept at optimum reference value to produce maximum isotope yield which also helps in improvement of lifespan of the cyclotron parts. Based on our operation experience, we felt that the pre-default guidelines from the manufacturer are not sufficient to reduce the downtime of the cyclotron. Initially, we experienced three to four weeks of downtimes annually.

Major maintenance issues observed in the last six years were failure of RF and ion source, vacuum leakage, target foil rupture, extraction foil rupture, failure of valves in the activity transfer line, and cyclotron network communication error. Sometimes they were not standalone issues, instead were observed as sequential. Though, the manufacturer's guidelines provide the detailed troubleshoot actions, it did not give information to prevent or minimize such issues. In this scenario, we developed a periodic maintenance protocol to minimize the major and minor troubles in the cyclotron based on our past experience. This protocol includes a daily check list of different parameters in addition to monthly, quarterly, semiannual, and annual maintenance.

We followed the policy that prevention is always better than cure. In such a way, we periodically assessed the performance of each cyclotron parts and replaced whenever found it has underperformed. The parts such as targets, ion source and extraction foils are rebuilt when it reached 80% of its recommended consumption. Keeping detailed record of all the parameter readings of cyclotron is a good practice to find out any sudden change in those values. The gradual increase of the ion source current each day predicts its performance and time to rebuild. More attention is required for the service of the radioactive parts as sufficient time must be allowed for decay of radioactivity to workable limits. Having four water targets allowed us to cool the target for an extended period thereby reducing radiation exposure. Availability of most of the parts at the facility or somewhere near to the facility was also ensured for faster replacement of the parts.

Application of the developed protocol in the two years resulted in smooth operation of the cyclotron with very little downtimes. Talking in figures, the annual downtime reduced to 1 – 2% from previous 5 – 8% which resulted in significant socioeconomic benefit not only to the cyclotron center but also to the hospitals and patients.

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DEVELOPMENT AND APPLICATION OF INDICATORS FOR THE ASSESSMENT OF RADIATION SAFETY SYSTEMS IN RADIOPHARMACEUTICALS PRODUCTION FACILITIES WITH CYCLOTRON

MAGGIOLO Ayelén, RABI Germán, ESPÓSITO Mauro
Autoridad Regulatoria Nuclear, Buenos Aires, Argentina

Radiopharmaceuticals production facilities with cyclotron have to implement radiation safety systems in order to control and mitigate not only external exposure risks due to gamma and neutron fields generated during the cyclotron operation and the radioisotope production, but also internal exposure and surface contamination that may occur while working with unsealed sources.

Safety systems have to be prioritized in the features planned in the design of the facility and can be complemented with operational procedures with the purpose of ensuring the protection of workers, the public and the environment.

The design of these systems depend on the type of facility; the equipment, for example, whether the cyclotron is self-shielded or not; and the production processes that are carried out, among others. In addition, normal operational situations as well as incidents and accidents need to be considered.

The "Class I Particle Accelerators Control Department" of the Nuclear Regulatory Authority detected the need of a tool that helps perform safety assessments, particularly for the evaluation of safety systems implementation at the facilities under regulatory control and for monitoring the application of radiation safety standards in facilities that are currently operating.

For its development, it was used as a reference the document "Criterios para el licenciamiento y requisitos de inspección en instalaciones con ciclotrones para producción de radioisótopos utilizados en aplicaciones e investigaciones médicas" (2013) from Foro Iberoamericano de Organismos Reguladores Radiológicos y Nucleares as, considering the guidelines presented there for interlocks, alarms, manual safety systems, plans and records. This document was chosen because it was considered the most representative of the state of the art concerning radiation safety in this type of facilities when the tool was developed.

Afterwards, the conditions at cyclotron facilities in operation stage from Argentina were analyzed and indicators were developed by the "Class I Particle Accelerators Control Department". These indicators are intended to measure the level of adequacy of each facility compared to what is recommended in the referenced document. The indicators were collected and presented in an organized way using a spreadsheet and graphics which makes easier its display and allows its interpretation depending on different criteria such as the type of safety system or type of facility.

Finally, the follow up of these indicators was done from 2018 to 2021 and a tendency to improvement was detected as a consequence of the update of procedures and also due to the implementation of new safety systems. Moreover, through this tool, the Nuclear Regulatory Authority could monitor indirectly the success of the regulatory functions in the increase of the level of intrinsic safety at cyclotron facilities.

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REGULATORY FRAMEWORK ADOPTED BY THE NUCLEAR REGULATORY AUTHORITY OF ARGENTINA FOR THE LICENSING OF THE ARGENTINE CENTER OF PROTON THERAPY AND PROGRESS ACHIEVED.

RABI Germán, MARTIRI Lucas

Autoridad Regulatoria Nuclear, Buenos Aires, Argentina

The Argentine public health system is currently carrying out the project of the Argentine Proton Therapy Center (CeArP), being the first in the region to incorporate high-energy proton beams for cancer treatment. This represents a challenge for the regulatory body, the Nuclear Regulatory Authority of Argentina (ARN), as it does not have a specific regulatory framework or staff with prior experience in this technology. This paper summarizes the activities conducted by the ARN during the CeArP licensing process, describes the regulatory approach adopted and the implemented steps to strengthen its capacities.

The ARN is facing this challenge by strengthening its regulatory framework for licensing and processes oversight, to ensure that national and international standards are met. The licensing process is being implemented in stages, with construction, commissioning, operation and closure licenses. Facility personnel will be authorized through a mixed licensing scheme, combining the staff licensing applicable to Class I facilities with the one for obtaining individual permits that applies to Class II facilities. Emphasis will be placed on ensuring adequate education and training for all positions in the organization chart, as well as the application of an Integrated Safety Management System that includes a program for the promotion of a strong safety culture.

To carry out these regulatory endeavors, a multidisciplinary working group was formed, with strategic personnel with background in regulatory affairs in an attempt to leverage prior experience. Moreover, efforts are being made by the ARN to further develop the technical capabilities of the human resources. Finally, the milestones achieved so far, the lessons learned, and future plans are presented.

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THE POTENTIAL USE OF ELECTRON BEAM IRRADIATION TO PRESERVE MICRO-BIOLOGICALLY INFECTED EGYPTIAN PAPYRUS

Hassan ABDELREHIM
National Center For Radiation Research and Technology – NCRRT, Cairo, Egypt

The work was aimed to use electron beam for preserving some cellulosic natural heritage made from papyri. A comparative study on the effect of gamma, and e-beam, on papyri properties was investigated. Irradiation conditions as total dose, dose rate, and surrounding environment conditions during irradiation (air or oxygen-free) were taken in consideration. The physical and chemical analysis, colour change, mechanical properties, ageing studies and radical stability of irradiated samples were evaluated. Limited post oxidation and degradation effects on papyri samples exposed to EB irradiation were recorded. Mechanical properties of 6 months stored samples showed that the electron beam irradiation has limited degraded effect on papyrus. It could be concluded that the electron beam irradiation can be applied for decontamination of microbiologically infected and damaged papyrus.

CONCEPTS AND METHODOLOGY OF THE PARTICLE THERAPY MASTERCLASS (PTMC) FOR CAPACITY BUILDING – PTMC IN GREECE AS A CASE STUDY

A. MAMARAS, A. IOANNIDOU
Aristotle University of Thessaloniki, School of Physics Thessaloniki, Greece

P. FOKA
GSI Helmholtz Centre for Heavy Ion Research & CERN Geneva, Switzerland

With the aim to highlight the impact of fundamental research on the broader society, the new Particle Therapy MasterClass [1] (PTMC) package was developed and recently integrated into the International MasterClass 2021 (IMC) online programme, attracting 37 institutes from 20 countries and more than 1500 high-school students [2].

Focusing on the particular sensitive topic of cancer treatment, the main idea is to show that fundamental properties of particle interactions with matter, which are the basics for detecting them in physics experiments, are also the basis for treating cancer tumours; and that the accelerator technology, used in research laboratories, is also used at particle therapy centres.

The School of Physics at Aristotle University of Thessaloniki (AUTH), playing an important role within the PTMC core team, participated in the 6th of March PTMC2021 session [3]. The PTMC2021 in Greece was organized, in online mode, with the participation of AUTH, National Center for Scientific Research "Demokritos", Papageorgiou Hospital and Public Central Library of Veroia.

It was given a broad publicity in press and social media by the Public Central Library of Veroia, which also organized the registration and participation to the online session. It attracted a large number of participants, from whole Greece and registrations reached the maximum capacity.

The morning lectures were complemented by hands-on sessions in the afternoon.

For the hands-on sessions, the open-source professional Treatment Planning software matRad [4] was used, developed for research and training by DKFZ, the German cancer research institute, in Heidelberg [5].

The PTMC was successfully conducted thanks to the dedication and creativity of the tutors and moderators. The lectures included speakers from Greece (AUTH, Demokritos, Papageorgiou) but also from abroad, graduates from AUTH, now researchers at institutes such as CERN in Switzerland, GSI and TUM in Germany.

In the same day, another four institutes from Germany (DKFZ, GSI), N. Macedonia and Portugal performed the PTMC, and joined a common videoconference [6] to discuss their results at the end of the day.

In total, during the PTMC 2021 season, 6 PTMC common videoconferences took place, each one with about 6 institutes performing the PTMC locally in each of its 6 sessions.

The aim of the PTMC is to motivate high-school students for STEM studies, to highlight the importance of fundamental research and its direct impact on society, developing on the theme of using the acquired knowledge on particles and their interaction with matter in medical applications. Through the overall process, students are shown "what physics has to do with medicine" and what are the various possibilities that physics, and STEM studies may open up for job opportunities in fields that there is lack of expert personnel.

These events support capacity building in preparation for the future ion research and therapy facility planned by the South-East European Institute for Sustainable Technologies, SEEIIST, where Greece also actively participates as a full member with contributions from AUTH.

For the PTMC 2022 AUTH is taking leading role for organizing a special PTMC to celebrate the "International women's day in STEM" on the 11th of February with support from the PTMC core team. This presentation will describe experiences from both, the PTMC2021 and PTMC2022 and the response of participants, also outlining further possible improvements and developments.

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MULTIPURPOSE ELECTRON BEAM FACILITY IN SLOVAKIA FOR RESEARCH AND INDUSTRIAL APPLICATIONS

A. SAGATOVA
Slovak University of Technology in Bratislava, Faculty of Electrical Engineering and Information Technology, Institute of Nuclear and Physical Engineering, Bratislava, Slovakia

M. FULOP
ABRS Ltd., Samorin, Slovakia

M. PAVLOVIC, S. KOTOROVA
Slovak University of Technology in Bratislava, Faculty of Electrical Engineering and Information Technology, Institute of Nuclear and Physical Engineering, Bratislava, Slovakia

Radiation processing had not been well-developed technology in Slovakia before 2011. It included one cyclotron for positron radioisotope production and two electron beam (EB) accelerators as parts of production lines for sterilization and tyre crosslinking, those in private companies of foreign ownership. Accelerator utilization for research purposes was minimal. Situation changed during last decade. Since 2011 more ion accelerators have been installed, 3MV Pelletron tandem accelerator for material research and dating at Comenius University in Bratislava, 6 MV tandem accelerator and 500 kV ion implanter of Slovak University of Technology for material research in Trnava as well as 2 MV tandem accelerator of Slovak Academy of Sciences in Piestany.

Research possibilities were widened also by a new electron accelerator in Trencin, designed for research and also industrial purposes. This multipurpose facility started its operation in 2012 with one main goal, to introduce the radiation treatment technology into practise in Slovakia. The facility runs one 5 MeV electron accelerator (LINAC) with 1 kW maximum power and with adjustable electron energy in the range 3.6 – 6.2 MeV. The electron beam can scan in various widths or to work in a pulse mode and together with variable velocity of conveyor, transporting the objects for irradiation beneath scanning beam, it offers wide range of irradiation dose rates (10 – 5600 kGy/h) for electrons. Moreover, the accelerator is equipped with tungsten target conversing electrons to X-rays, which spreads its fields of application and research possibilities. Due to low efficiency of conversion, the dose rates for X-ray treatment are in different but also wide range (26 – 1400 Gy/h).

During a decade since the multipurpose EB facility in Trencin has started its operation, wide range of research experiments was realized with many promising socioeconomic impacts. The research activities are in the field of radiation aging, medicine, environment and cultural heritage. The radiation aging includes research of radiation hardness of detectors of ionizing radiation, electronics for space applications and accelerator and nuclear power plant components [1, 2]. In medicine we collaborated on research of radiation treatment of hydrogels, skin, corneas and in the research aimed on radiotherapy of oncology patients [3]. Our research is aimed also to the serious environmental problematics in Slovakia, the contamination of soil and ground water by PCB (PolyChlorinated Biphenyls), were we use the accelerator to decontaminate environment [4, 5]. We collaborated with Serbian colleagues in research on radiation treatment of waste sludge from drinking-water-treatment plant [6]. Big impact might also have our successful story of preservation of a late-gothic wooden altar with help of radiation [7], which will open the gates for utilization the radiation technologies in the field of cultural heritage in Slovakia.

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SESAME, A SYNCHROTRON RADIATION FACILITY IN THE CRADLE OF HISTORY

A. LAUSI, M. ATTAL, A.A. ELKADIME
SESAME (Synchrotron-light for Experimental Science and Applications in the Middle East)
Allan, Jordan

The Synchrotron-light for Experimental Science and Applications in the Middle East SESAME is a third-generation 2.5 GeV synchrotron radiation (SR) source in Allan, Jordan. It is the first major international research centre in the Middle East and neighbouring countries. SESAME is a widely available 'user facility'. Scientists, including graduate students, from universities and research institutes, from the region and beyond, typically visit the Centre to carry out experiments for periods that can span from a few days to one or two weeks, frequently in collaboration with scientists from other centres/countries, and then return home to analyze the data they have obtained. In other words, SESAME is not a source of brain drain; quite the contrary, not only do the scientists who visit SESAME take back scientific expertise and knowledge, which they will share with their colleagues and students, but it also creates a motivating scientific environment that encourages the region's best scientists and technologists to stay in the region or to return if they have moved elsewhere.

Synchrotron radiation (SR) beamlines provide one of the most powerful and advanced tools available in modern science for research, covering a wide range of disciplines ranging from materials science and engineering to medicine, cultural heritage, healthcare and the environment, as well as fundamental understanding in physics and chemistry.

The high photon flux, small source size, and low divergence available at SR sources allow for advanced spectroscopy and imaging techniques, well suited for studying ancient and historical materials, which often present very complex and heterogeneous structures. Moreover, SR techniques are non-destructive, and as an SR facility gathers several beamlines around its accelerator, samples can easily be transferred and reanalysed using complementary techniques. At SESAME, a series of accelerators raise the energy of electrons up to the 2.5 GeV used in the storage ring to provide the high brilliance sources for the Infrared Microspectroscopy, the Powder Diffraction and the X-ray Absorption Spectroscopy beamlines, all three already open to users. In 2022 an X-ray Imaging and a Soft X-ray Spectroscopy beamline will come on stream, and Turkey will start constructing a soft X-ray photoelectron spectroscopy beamline, the first to be built by one of the Members. Altogether, the suite of beamlines available at SESAME can address the challenge of supporting research on ancient and historical objects from the region. The geographical position of the facility allows for reducing travel-related risks and establishing research programmes in close cooperation with surrounding institutions devoted to the reseach, preservation, restoration of materials of archaeological, palaeontological, palaeo-environmental and cultural heritage interest. Because of these multiple applications, it will be necessary to establish a working group involving a multi-disciplinary team and develop and share expertise on various factors such as handling, packaging, customs' paperwork, shipping and insurance.

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METHOD FOR DETECTION OF ILLEGAL CIGARETTE BOXES IN IRON ORE CARGO

M. FULOP
ABRS Ltd., Samorin, Slovakia

A. RUZICKA
Faculty of Mathematics, Physics and Informatics Comenius University in Bratislava, Bratislava, Slovakia

P. RAGAN
ABRS Ltd., Samorin, Slovakia

A. SAGATOVA
Slovak University of Technology in Bratislava, Faculty of Electrical Engineering and Information Technology, Institute of Nuclear and Physical Engineering, Bratislava, Slovakia

Braking radiation, obtained by converting electron beams accelerated by linear accelerators (hereinafter referred to as x-scanner) to energies of 5 to 9 MeV is used to detect illegal hiding of goods in container transport by the non-destructive method of X-radiography. These scanning systems can penetrate a load thickness equivalent to a layer of iron 30 to 40 cm thick. With larger cargo thicknesses, such as iron ore in shipping or rail, x-scanners are inefficient, and customs control of loads is often performed manually. Manual customs control of iron ore on railway wagons is a lengthy and physically demanding activity, so it is rarely applied to more than 20% of wagons. This problem of customs control with wagons loaded with iron ore is solved by a scanner, which is based on a neutron generator T (d, n).

In the proposed project the Monte Carlo code MCNPX was used for:

- Determination of the vertical neutron transition factor of the generator T(d, n)) through different layers of a selected type of iron ore loaded on a wagon.
- Optimization of irradiation geometry of iron ore cargo and neutron beam collimation.
- Design and verification of a neutron detection system after their passage through an iron ore cargo in order to detect the presence of cigarettes hidden in different positions of the iron ore cargo.
- Control of the influence of cosmic neutrons and muons on the determination of the neutron emission size of the generator T (d, n).
- Checking the efficiency of the neutron generator with regard to radiation protection of workers and protection of the environment

According to a survey carried out on the basis of a patent application, similar devices are not yet manufactured in Europe, the USA and China.

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RADIATION ISODOSE MEASUREMENTS INSIDE INTERACTION CHAMBER DURING THE COMMISSIONING EXPERIMENTS OF THE CETAL FACILITY. GAS TARGET CASE.

E. STANCU, C. DIPLASU, G. GIUBEGA, M. SERBANESCU, A. MARCU, R. UNGUREANU, G. COJOCARU, M. ZAMFIRESCU

National Institute for Laser, Plasma and Radiation Physics (INFLPR), Magurele, Romania

Nowadays there are more than 50 high power laser systems in use or in development throughout the world [1]. A part of them is able to accelerate particle beams in relativistic regime and generate high energy ion beam. Two of these high-power lasers are developed in Romania: first developed is from INFLPR, CETAL, and second one ELI-NP [2]. INFLPR during the commission of the CETAL-PW laser demonstrated the ability to accelerate ion beam to considerable high energies. One of the type of experiments performed during the commissioning activities were interaction of ultra-intense laser with gas target in order to accelerate high energy electron beam. For these experiments the laser wake field acceleration (LWFA) mechanism was considered [3]. The interaction take place in interaction chamber in vacuum. The laser pulses generated by the CETAL-PW laser system focused on a gaseous target can produce accelerated electron beams. To achieve this, a valve was used to properly synchronize the gas jet with the laser beam. He (99%) + N (1%) gas targets were used in these experiments. For each experiment inside interaction chamber the radiation isodose measurements were performed using EBT3 gafchromic films. Figure 1 shows the distribution of detectors in order to measure radiation isodoses.

FIG. 1. Position of EBT3 detectors inside the interaction chamber for radiation isodose measurements

During the experiments, the gafchromic films were screened at optical radiation with Al foil. Due to the experimental conditions, which involve vacuuming and unwinding the interaction chamber, it is not possible to perform isodose measurements for each laser pulse. The detectors were read after the accumulation of a noticeable degree of blackening of exposure to ionizing radiation following the laser-target interaction. The radiation isodose measurements were normalized at a distance of 30 cm from the target. Table 1 shows the maximum measured values of radiation dose measurements, normed at a distance of 30 cm from the target. The high energy accelerated electrons on forward the laser beam were measured outside interaction chamber. Radiation doses measured in high energy electron beam axis are not included presented.

TABLE 1. MEASURED VALUES FOR RADIATION ISODOSE MEASUREMENTS, GY, INSIDE THE INTERACTION CHAMBER FOR DIFFERENT EXPERIMENT PERIOD

Measurement point	27.08-17.10.2019	28.10.2019	29.10-10.12.2019	11.02-19.04.2021	19.04-03.06.2021	03.06-02.09.2021
1 (340º)	12	13,4	5,1	0,18	0,20	0,07
2 (51º)	5,7	4,5	8,9	1,30	3,66	0,13
3 (78º)	2,4	1,7	2,5	0,75	14,52	0,38
4 (102º)	1,3	1,3	2,3	0,89	1,20	0,42
5 (135º)	7,2	4,4	1,5	0,78	5,79	0,16
6 (226º)	13,8	13,9	3,1	0,31	0,29	0,10

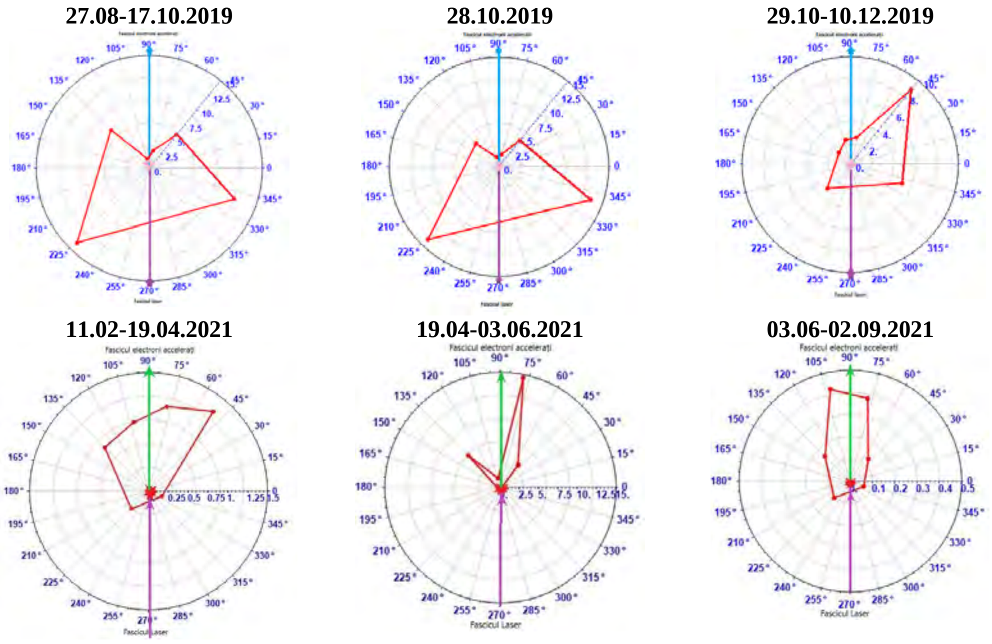

FIG. 2. Radiation isodose measurements during high power laser target interaction.

In this paper there are presented measured values for radiation isodoses obtained during the high-power laser gas target interaction. The measured values suggest the necessity to be considered for experimental data assessment and radiation protection purposes.

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HOW INDUCED ACTIVATED ACCELERATOR PARTS HAVE AN IMPACT ON THE RADIATION SAFETY OF A PROTON THERAPY FACILITY

AUGUSTYNS V[1], AESSELOOS C[2], DRIESEN R[2], BERGANS N[3]
[1]*Radiation protection, University Hospitals KULeuven*
[2]*KULeuven, faculty of medicine*
[3]*KULeuven, lab of experimental radiotherapy, department of oncology, KULeuven and Radiation protection, University Hospitals KULeuven*

I. Introduction

Residual activity induced in particle accelerators is a radiation safety concern as the long-lived radionuclides produced by fast or moderated neutrons and impact protons can cause problems of radiation exposure. Staff involved in maintenance of the proton therapy installation or in the quality control measurements done for evaluation of the beam output need to be aware of this.

This study presents dose rate and energy spectrum-based measurements done on 1) phantoms used during quality control measurements; 2) on the accelerator components that become activated due to the backscattered neutrons from the target and also due to the direct proton interactions and their secondaries. As a part of this study, a correlation is made between de continuously monitored neutron and gamma dose rate measurements in the cyclotron vault and the registered beam-on time. In this way we can evaluate how quickly the dose rate, measured at contact of these activated parts, goes down to a safe level after irradiation.

These measurements are used to assess operator exposure and to evaluate the need for specific radiation safety measures during maintenance and regular quality control.

II. Material and methods

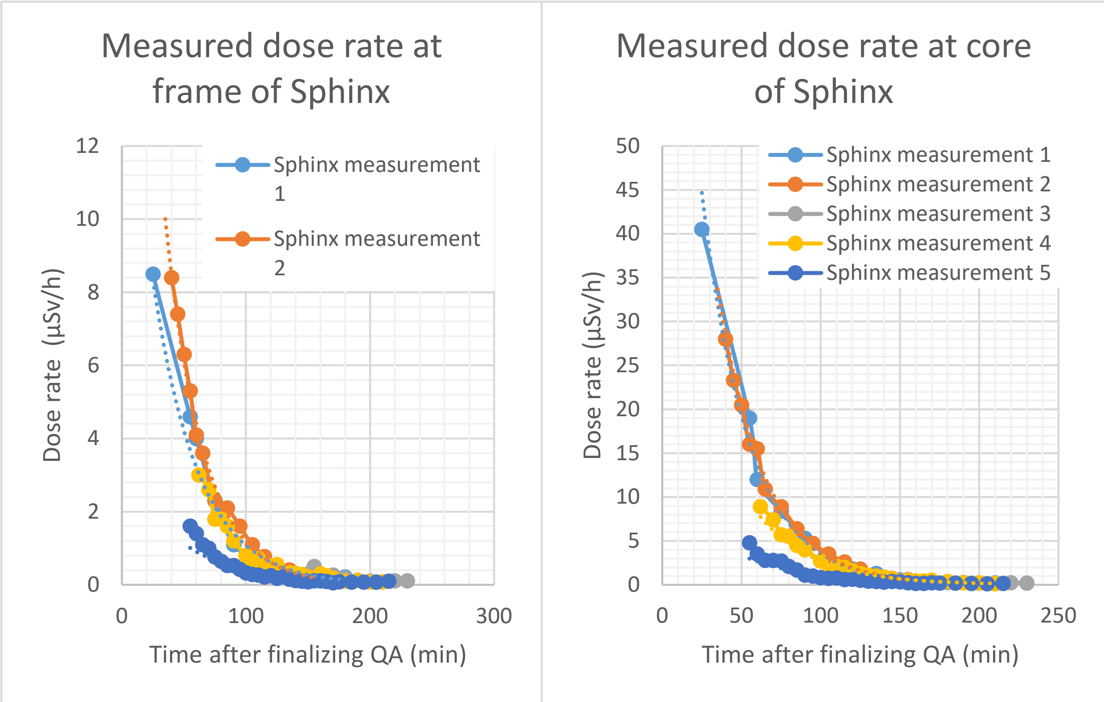
Measurements were carried out at ParTICLe, the proton therapy facility of UZ Leuven, which consists of a Proteus®ONE (IBA) compact proton therapy system using the latest generation Pencil Beam Scanning.

2 IBA Dosimetry products (Sphinx and Lynx) used for quality control and removed metallic parts during maintenance (cooling cylinders, beam flanges,…) were selected for this activation study. Dose rate measurements were done using the LB134 (Berthold) and Babyline 81A (Mirion) dose rate meters. Hot spots were detected by using a LB124 scintillation monitor (Berthold).

III. Results and discussion

Measurements performed at contact on the grid of the detector for 2D-dosimetry, i.e. Lynx, showed no significant increase in dose rate measured 30 minutes after finalizing the QA measurements. However, at the end of life of these devices it is necessary to investigate if cumulated activation over time is still below legal release limits.

Irradiations on the Sphinx resulted in elevated dose rates inside the core of the Sphinx, but these dose rates are also significant at the positions where the Sphinx is held during manipulations. Based on the exponential extrapolation of these performed measurements a dose rate above 100 μSv/h can be expected at the core of the Sphinx immediately after finalizing the QA measurements. The cumulated dose for staff related only to the daily manipulation of the Sphinx immediately after the morning QA during one year is estimated to be 2% of the Belgian public yearly dose limit.



Spectrum-based measurements performed on activated metallic parts of the accelerator show the presence of Co-57 and Co-60. Dose rates at contact can vary significantly, from a few µSv/h up to 1 mSv/h for the most activated components.

IV. Conclusions

Activation was significant after long irradiation sessions, resulting in instantaneous dose rates up to 1 mSv/h at contact of accelerator components where the highest beam losses are expected. Therefore specific radiation safety measures are necessary during maintenance operations.

Some of the investigated quality control devices may also cumulate activity in time, depending on the scenario of periodic irradiation in routine clinical practice.

Results of this study will help to determine which specific radiation protection measures need to be taken during maintenance and quality control measurements.

THE DEVELOPMENT OF AN EXTERNAL BEAM IRRADIATION SYSTEM FOR MATERIAL ANALYSIS AT THE CYCLOTRON FACILITY IN THAILAND

P. THONGJERM, S. WONGLEE, W. PORNROONGRUENGCHOK, A. NGAMLAMIAD, and K. BOONSIRICHAI
Thailand Institute of Nuclear Technology, Nakhon Nayok, Thailand

The cyclotron (MCC-30/15) at Thailand Institute of Nuclear Technology (TINT, Nakhon Nayok, Thailand) accelerates protons and deuterons up to 30 MeV and 15 MeV, respectively. The maximum beam current of proton is 200 µA. It is primarily designed for radioisotopes production. The system consists of three beamlines transporting the beam to three target halls. Apart from irradiating solid targets for daily radioisotopes production, the beam is then guided to the R&D irradiation vault. The beam transport system equipped with a five-port switching magnet allows performing multi-purpose research and ion beam applications. Fig. 1 shows the current setup of the research beamline. It is under installation and due to commission by the end of 2021. The first irradiation station is devoted for proton-induced x- ray and gamma-ray emission (PIXE and PIGE) applications in the early phase of this research project. The other beam ports will be eventually extended and developed for research experiments. As reported in the studies, the proton beam energy and current extracted from cyclotron would be unsuitable for material analysis and research applications such as radiobiology[1, 2]. Therefore, the additional instruments, including beam degrader and sample holder, are designed to achieve appropriate beam parameters and produce homogenized beams over the sample. In addition to adjusting beam energy and current, the proton beam can be substantially scattered as it is extracted in air, causing impaired beam quality. Beam collimator and exit window foil need to be properly designed to improve the beam quality.

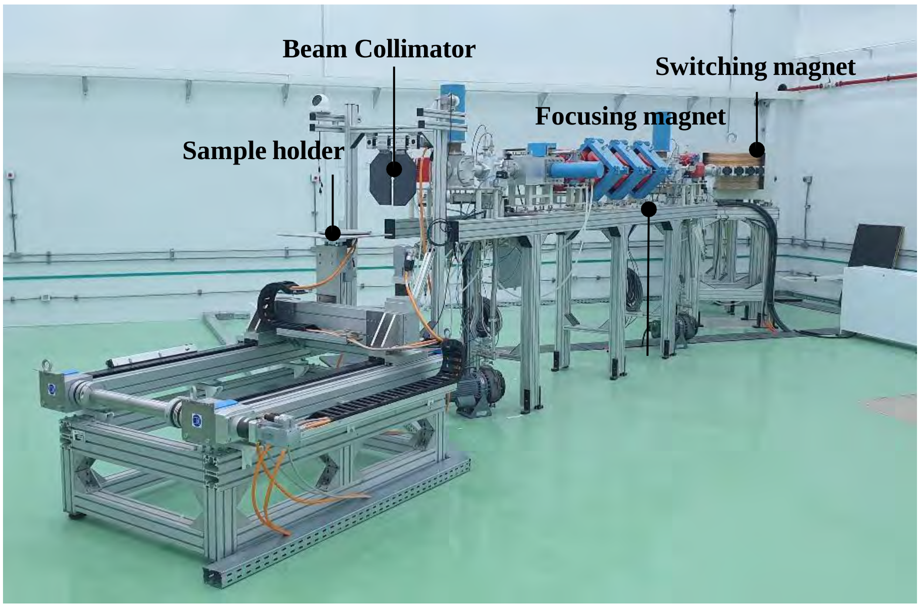


FIG. 1. The current setup of R&D beam line consists of a five-port switching magnet, a set of quadrupole magnets and a graphite collimator mounted at the end of the horizontal beam line.

A Monte Carlo simulation of the beamline was developed with Geant4[3] to design additional systems, optimize proton beam energy, and maintain a low current beam. We investigated the effect of different materials and thickness configuration of the beam collimator to achieve minimal losses and less secondary radiation. A detailed description of the irradiation system with the corresponding simulation results is presented. Further, the simulation results is validated with experimental measurements.

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DEGRADATION OF AMINO ACIDS BY MEV IONS

<u>C.A.P. DA COSTA</u>, E.F. DA SILVEIRA

Pontifical Catholic University Rio de Janeiro, Rio de Janeiro, Brazil

Outside Earth, amino acids have been detected in the dust traces left by the Comet 81P/Wild 2 and collected by the Stardust spacecraft [1] and [2]. Similar astrophysical materials, present in comets and meteorites rich in complex molecules, could have fallen on early Earth; thereby, organic extraterrestrial molecules could have stimulated pre-biological processes and forming nucleobases and other molecular building blocks of life [3]. Knowledge on the dissociation rates of amino acids by galactic cosmic rays is relevant to the study of the radioresistance of these materials in space.

Radiolysis and sputtering of the amino acids glycine, valine and phenylalanine by 0.5 – 2 MeV H^+, He^+ and N^+ ion beams were studied. The material degradation as a function of beam fluence was monitored by infrared spectroscopy and their destruction cross sections determined. Present results show that apparent destruction cross sections (which include sputtering), σ_d^{ap}, vary proportionally with electronic stopping power, S_e, ($\sigma_d^{ap} \approx$ a S_e), where 1/a is ≈ 120, 100 and 65 eV/nm³ for glycine, valine and phenylalanine, respectively (Fig. 1). Such values correspond to the average absorbed energy density necessary to dissociate (or eject) those molecular species and similar organic compounds from a solid sample. Assuming the relationship $\sigma_d^{ap} \approx$ a S_e, half-lives are predicted to be ~10 million years in the interstellar medium.

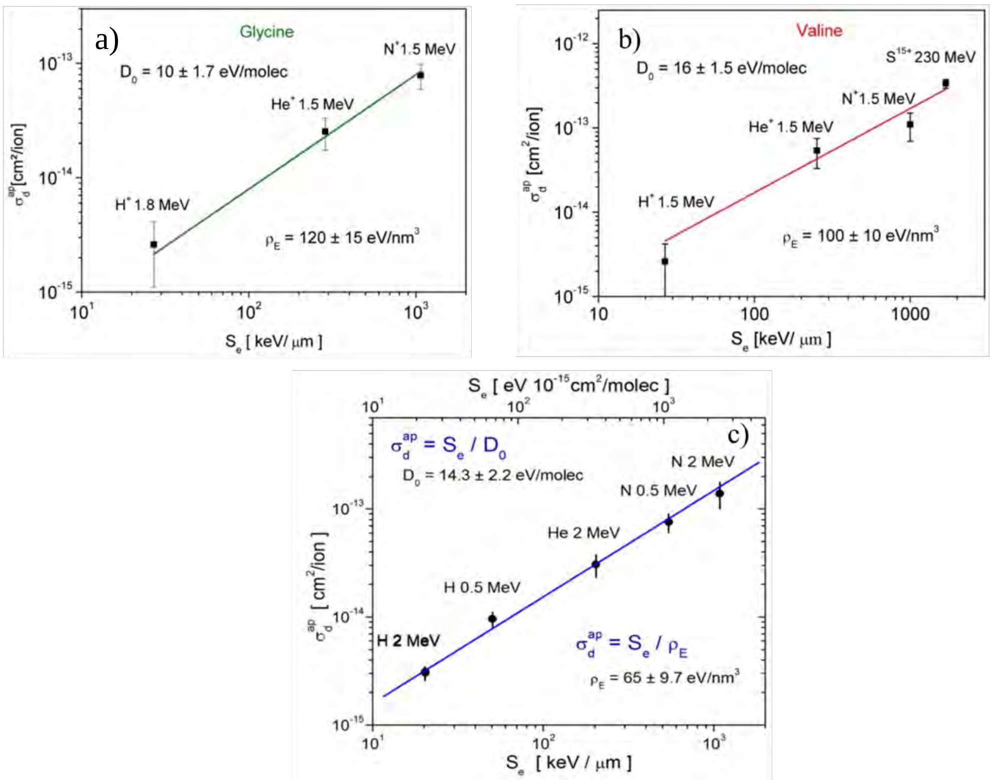

FIG. 1. Apparent destruction cross section dependence on electronic stopping power for (a) glycine, (b) valine and (c) phenylalanine. The straight line represents the power law $y = a x^n$, where n =1. For each amino acid, the respective energy density ρ_E and dose D_0 values are extracted directly from the linear fittings with equation $\sigma_d^{ap} = S_e/\rho_E$.

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IMPACT PATHWAYS FOR RESEARCH INFRASTRUCTURES: THE CASE OF CMAM-UAM

G. GARCÍA
CMAM-UAM, Madrid, Spain

Research infrastructures (RI) are hubs where sophisticated instruments, expert staff and a proper organization are made available to a wide scientific community. The ultimate motivation for funding RIs is to contribute in a multiplicative way to the generation of impacts benefiting society. CMAM-UAM is an ion beam facility equipped with a 5 MV tandem accelerator and six BLs implementing different techniques for analysis and modification of materials at the nanoscale. The pathways for impact production will be analyzed based on the outcomes of the recently finished H2020 project RI pathways. A recent study in collaboration with ALBA synchrotron and CSIL will be used as an example on how difficult to detect impacts may be made to arise.

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ESTABLISHMENT OF THE CYCLOTRON FACILITIES IN BANGLADESH – PRESENT STATUS AND EXPERIENCES

Md. Nahid HOSSAIN and **Md. Nurul ISLAM**

National Institute of Nuclear Medicine & Allied Sciences (NINMAS) Bangladesh Atomic Energy Commission (BAEC), Block-D, BSMMU Campus, Shahbag, Dhaka, Bangladesh

Cyclotron is a device that accelerates charged atomic or subatomic particles in a constant magnetic field. This type of particle accelerator was very first developed in the early 1930s by two American physicists Ernest Orlando Lawrence and M. Stanley Livingston at the University of California, Berkeley.

In Bangladesh, the first medical cyclotron was installed in a private hospital named United Hospital, Dhaka at 2011. This one is the only cyclotron (9.6 MeV energy from GE) which was supplied the PET tracers to all PET-CT establishments since 2011 to 2020. United Hospital operated the cyclotron only two days per week. This cyclotron managed the demands of PET tracers in the country at that period.

Considering the necessity of a cyclotron, the government took the initiative to establish a cyclotron facility under a government ADP project at the National institute of Nuclear Medicine & Allied Sciences (NINMAS), Bangladesh Atomic Energy Commission (BAEC). Selection of the type of cyclotron to set up was crucial. Accumulating the information regarding expenditure and time required, expert opinions from IAEA were sought, then the decision was finalized to have a cyclotron of around 16-20 MeV within our budget. Following completion of the tender procedure, it was decided to install a 18/9 MeV cyclotron from IBA. IBA Cyclone 18/9 is a dual particle accelerator/cyclotron whose proton energy is 18 MeV and deuteron energy is 9 MeV.

After reaching the main equipment of cyclotron and radiochemistry, enormous hurdles and challenges were faced with the placement of a 100 tons crane during the rigging of the cyclotron in the cyclotron bunker due to narrow space in front of the building. Another big challenge was to slide the 27 tons cyclotron in the appropriate place of the cyclotron bunker. Solving these undue and uncalculated issues were time consuming and at last it was possible to rig the cyclotron on designated bunker at the basement of the building. The cyclotron was commissioned and simultaneously the installation of two chillers, four air handling units (AHU), clean room, radiochemistry unit, quality control equipment and radiation safety equipment were completed during that period.

The main objective of this cyclotron establishment is to produce conventional ^{18}F, ^{11}C, ^{13}N and ^{15}O PET radionuclides. This cyclotron has eight target ports. Primarily four target ports have been chosen for the ^{18}F, one for ^{11}C, one for ^{13}N, one for ^{15}O and one for solid target. Presently the cyclotron has been exclusively used for the production of ^{18}F for ^{18}F-FDG PET imaging. ^{18}F- FDG is supplied to four government and two private PET-CT facilities regularly twice in a week.

Establishment of Cyclotron facility at NINMAS was aimed to develop modern services and innovative in both diagnostic and therapeutic service to patients and physical and biomedical research. Regarding human resource development in this filed, IAEA accepted a TC project title: “Developing Human and Infrastructure for Cyclotron Based Diagnostic Positron Emission Tomography Radiopharmaceutical Production and Radiation Treatment Facilities for Cancer Patients (BGD/6028)” for the year 2020-21. The main objective of this project is that the skilled and dedicated multidisciplinary professionals with a strong technical knowledge of cyclotron-based PET

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Radioisotope production as well as synthesis and quality control of various PET radiopharmaceuticals are developed in Bangladesh.

Both two Cyclotron facilities so far were established in Dhaka, the capital city of Bangladesh. Considering the demand of PET-CT scan and the necessity to expand the facilities outside of Dhaka, the government has taken the initiative to establish another three cyclotron facilities at different area of the country. It is expected that within two years these facilities will be established.

DEVELOPMENTAL WORK ON ECONOMIC PRODUCTION OF HIGH AND LOW SPECIFIC ACTIVITY ^{64}CU – SUITABLE FOR PRECLINICAL STUDIES USING ACCELERATOR NEUTRONS

A. GOPALAKRISHNA[1], Amit KUMAR[1], P. MALETHA[2], KAMALDEEP[2] , S.V.SURYANARAYANA[2], H. NAIK[2], B.K. NAYAK[2], S.P. KULKARNI[2], P. MUKHERJEE[1]

[1] *Board of Radiation and Isotope Technology, Mumbai, India*

[2] *Bhabha Atomic Research Centre, Mumbai, India*

Introduction: ^{64}Cu is unique as it decays by three different routes, namely, electron capture and β− and β+ decays. Hence, this radioisotope holds promise toward development of PET imaging probes for noninvasive visualization of diseases and can also be used in targeted radiotherapy. Its half-life of 12.8 h makes it versatile – short enough to be useful for tracers with rapid pharmacokinetics such as small molecules and peptides, yet long enough to be useful for tracers with slow pharmacokinetics. However the utilization of ^{64}Cu is mostly limited to studies, sourcing no carrier added ^{64}Cu, produced via irradiation of expensive ^{64}Ni ^{64}Ni(p, n)^{64}Cu reaction in a medical cyclotron. This study investigates the potential of producing low specific activity ^{64}Cu via ^{65}Cu(n,2n) + ^{63}Cu(n,g) ^{64}Cu and high specific activity ^{64}Cu via ^{64}Zn(n,p) ^{64}Cu, in an economic way utilizing accelerator neutrons.

Irradiation parameters: Natural foils of Cu and Zn were irradiated in the neutron field (slow + fast neutrons) produced during the irradiation of ^{18}O, in the routine production of ^{18}F via ^{18}O(p,n)^{18}F. 2.4 mL of 98% ^{18}O water was loaded onto a standard silver cavity target and irradiated at 55 µA in the 16.5 MeV PETtrace cyclotron at Radiation Medicine Centre, Mumbai India.

Table 1: Irradiation parameters and activity of ^{64}Cu at end of bombardment

Irradiation time (h)	Target and weight (g)	^{64}Cu (Bq/g)	^{64}Cu(Bq/g*µA*h)
1.1	Cu (0.02)	29218	483
1.2	Cu (0.022)	28475	431
1.1	Zn (0.026)	53179	879
1.2	Zn (2.1)	56246	851

Off-line gamma-ray spectrometry: Radioactivity levels of ^{64}Cu and other radioisotopes co- produced were determined by the quantification of photo-peaks by off-line gamma -ray spectrometry. The γ-ray counting of radionuclides was performed using a pre-calibrated HPGe detector coupled to a PC based 4K channel analyzer. The energy resolution of the detector system was 1.8 keV FWHM at the 1332.5 keV γ-ray peak of ^{60}Co. The energy and efficiency calibration of the detector system was done by using a standard ^{152}Eu source. Spectroscopy software, Interwinner 7 was used for the analysis. Radioactivity levels were determined by the quantification of the following photo-peak counts of the γ-lines: ^{65}Zn (1115.5keV), ^{69m}Zn (438.6 keV), ^{67}Cu (184.6keV) and ^{64}Cu (1345.8 keV).

Separation of ^{64}Cu from irradiated zinc: No carrier added 64Cu was separated from the irradiated zinc by solvent extraction [1]. The solvent extraction method is based on (a) selective extraction of Cu dithizonate into organic solvent from a dilute acidic solution of the bulk Zn target and (b) back extraction of Cu into aqueous phase.

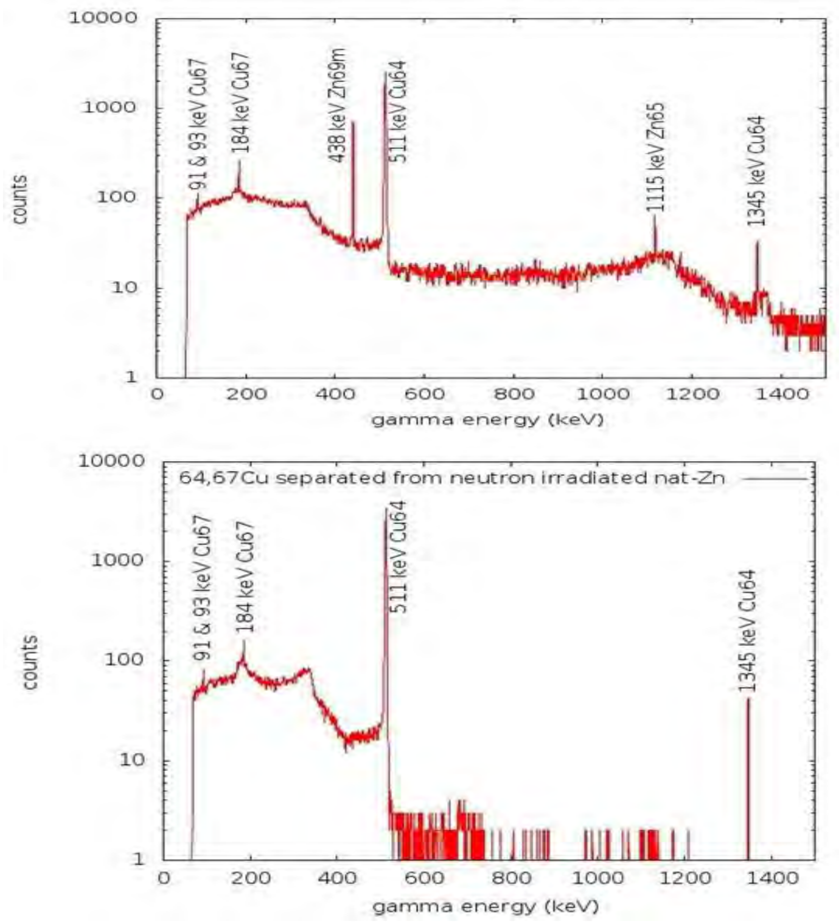

Fig 1: Gamma ray spectra of irradiated ^{nat}Zn before and after the radiochemical separation

Results and conclusion: High separation yields of > 90%, with high radionuclidic purity and good reproducibility was achieved. Radionuclide impurities ^{65}Zn and ^{69m}Zn are not detected in the final product, indicating achievement of high radionuclidic purity. This method demonstrates an economical method of obtaining ^{64}Cu with activity levels suitable for radiochemical experiments, aiding in development of new radiopharmaceuticals / preclinical studies.

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ACCELERATOR-BASED QUANTIFICATION AND DEPTH PROFILING OF HYDROGEN ISOTOPES AND IMPURITY ATOMS IN WALL MATERIALS FROM CONTROLLED FUSION DEVICES

L. DITTRICH, P. PETERSSON, S. MOON, M. RUBEL
KTH Royal Institute of Technology, Fusion Plasma Physics Stockholm, Sweden

A. WIDDOWSON
UK Atomic Energy Authority, Culham Science Centre Abingdon, UK

JET Contributors
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The fusion reactor ITER, which is under construction in France, will be a milestone on the way towards fusion energy, generating (as currently planned) for the first time conditions in which 10 times more fusion power output is expected than power input for plasma heating. Currently, the largest device is the Joint European Torus (JET), located in Great Britain. Since August 2011 it has been operated with a full metal first wall with beryllium (Be) limiters in the main chamber and tungsten (W, coatings and bulk metal) in the so-called divertor [1]; JET with the ITER-like wall (JET-ILW). Plasma-material interactions constitute an important part of the research programme. The understanding of fuel retention and material migration belong to the top missions of JET-ILW.

This work is focused on the determination of erosion, re-deposition/co-deposition of eroded species with fuel atoms and, on resultant retention of hydrogen isotopes on the JET-ILW wall components. Samples of the components retrieved from the torus after the three consecutive ILW campaigns (ILW-1, ILW-2 and ILW-3) were examined with accelerator-based ion beam analysis (IBA) techniques. This powerful set of methods is one of the crucial tools for surface/sub-surface studies of wall materials from controlled fusion devices [2].

The JET-ILW samples were analysed by the 5 MV NEC Pelletron accelerator at Uppsala University: By means of ^{3}He-based nuclear reaction analysis (NRA) using a standard and micro-beam and, by time-of-flight heavy ion elastic recoil detection analysis (HI-ERDA) with a gas detector [3] using bromine (32 MeV $^{82}Br^{7+}$) and iodine (36 MeV $^{127}I^{8+}$ and 44 MeV $^{127}I^{10+}$) beams. Additionally, microscopy techniques were applied. The major objectives were to determine: (i) Hydrogen (H, D) content and distribution on Be and W after experimental campaigns with different fuelling; (ii) co-deposition of Be, C, O, W and seeded gases on plasma-facing surfaces (PFS) and, in shadowed regions, e.g. gaps between the tiles and grooves of the castellation. The main results are summarized below.

(a) The ratio of H-to-D on surfaces depends on plasma fuelling in the last phase of campaigns. The sum of isotopes contents (H+D) on W lamellae remains similar thus indicating isotope exchange, see Fig. 1.

(b) The content of impurities on Be limiter tiles changes with the position. On the surface of the inner wall guard limiter wings, the impurities amount to 20 atomic %, mainly O (10%), C, N, H isotopes and Inconel components. Inside the castellation C could be determined with HI- ERDA to be around 1%.

(c) Deposits on sides of the bulk W tiles contain Be and C of a ratio around 1, as measured by µ-NRA. Their content decreases with depth. The D concentration varies strongly: the maximum at 6×10^{17} cm^{-2}.

(d) On the PFS of the bulk W module the Be content reaches the level of 11.2×10^{17} cm^{-2}, C at 8.7×10^{17} cm^{-2}, and D at 4.8×10^{15} cm^{-2}, as measured by µ-NRA.

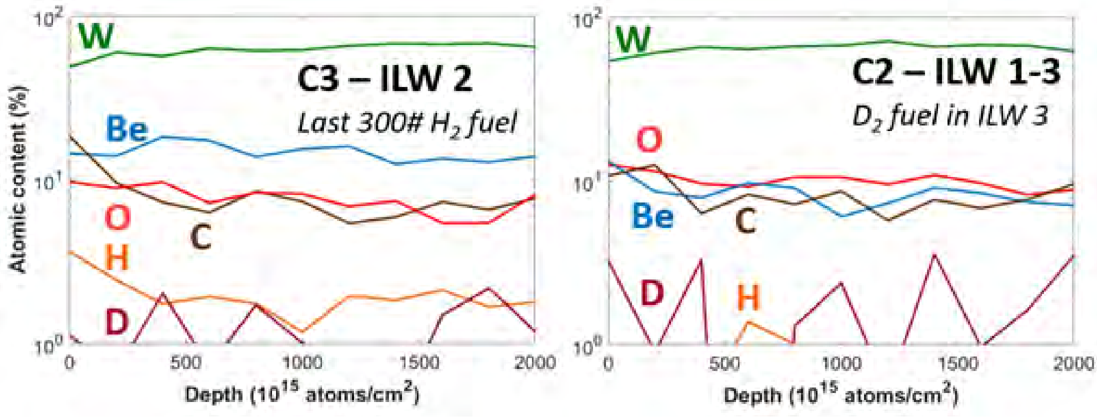

FIG. 1. HI-ERDA depth profiles of elemental composition on W samples from neighbouring positions C3 and C2, retrieved after ILW-2, which finished off with 300 shots of H_2, and ILW-3, which finished with D_2 fuelling. The total hydrogen isotope retention is 6.7×10^{16} and 5.3×10^{16} cm^{-2}, respectively.

Critical assessment of accelerator-based analysis methods and results will be presented.

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CLUSTER ION EMISSION FROM C_2H_2 AND C_2H_6 ICES INDUCED BY ^{252}CF FISSION FRAGMENTS

P.R.B. OLIVEIRA
Pontifical Catholic University, Rio de Janeiro/Rio de Janeiro, Brazil

R. MARTINEZ
Federal University of Amapá, Macapá/Amapá, Brazil

E.F. DA SILVEIRA
Pontifical Catholic University , Rio de Janeiro/Rio de Janeiro, Brazil

Surfaces covered with astrophysical ices are the predominant materials of many solar system bodies, such as comets and trans-Neptunian objects. They are constantly subjected to ion bombardment by solar wind ions and cosmic rays, which induces: i) chemical reactions in the ice and ii) sputtering, supplying the exosphere with neutral and ionic radicals or clusters. Energetic processing of these materials at low temperature have been investigated through laboratory studies, aiming to analyze the processes of astrophysical ion desorption and new molecular species synthesis [1][2]. C_2H_2 and C_2H_6 were observed in molecular clouds, comae of comets, the hydrocarbon-rich atmosphere of planets and their moons (like Jupiter and Saturn), and on the surfaces of Titan, Triton and Pluto [1][3].

In the current work, pure C_2H_2 and C_2H_6 ices at 10 K were irradiated by energetic (MeV/u) multicharged heavy ions (e.g., ^{105}Rh and ^{140}Ba). The positive and negative secondary ions were analyzed by the ^{252}Cf – PDMS – TOF technique (Time-of-Flight Plasma Desorption Mass Spectrometry). This system is also connected to a Van de Graaff accelerator, that can be used for the same purpose (e.g., expose the astrophysical ices to ionizing radiation in the MeV range), but for the aim of this work, only the fission fragments from a ^{252}Californium ionization source was used.

A large number of ionic species were identified during the bombardment, indicating strong molecular synthesis. They are classified into several ion series: C_nH_{2n+2}, C_nH_{2n}, C_nH_{2n-2}, C_nH_{2n-4}, C_nH_{2n-6}, C_nH_{2n-8} and C_nH_{2n-10}. As illustrated in Fig 1, their yield distributions are described by the sum of two decreasing exponentials, one fast (-*F*) and another slow (-*S*) decaying, suggesting a two-regime formation, see Eq. (1) below:

$$Y = Y_0^F e^{(-k_F m/z)} + Y_0^S e^{(-k_S m/z)} \quad (1)$$

where *m/z* is the mass-to-charge ratio, k_F and k_S are the exponential decay constants representing the two-regime formation. Zigzag yields are due to their chemical molecular structures. The new ionic species and their relative yields are provided, contributing to the understanding of the processes by which, in space, neutral and ionized molecular species are delivered to the gas phase.

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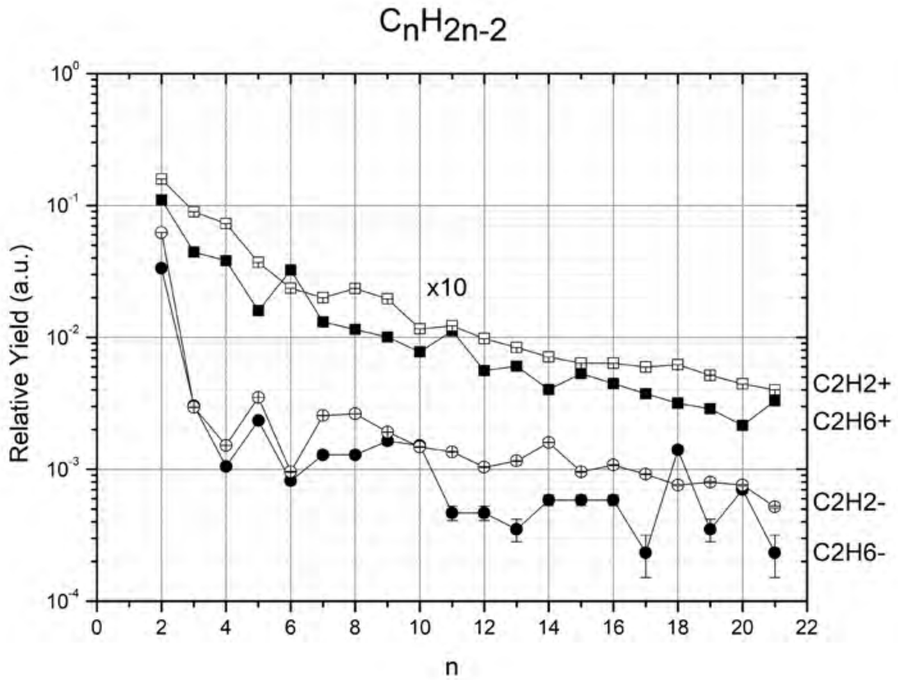

FIG. 1. Positive and negative ion yields of molecular species with C_nH2_{n-2} stoichiometry, emitted from C_2H_2 and C_2H_6 ices bombarded by MeV projectiles. Data were obtained by Time-of-Flight Mass Spectrometry.

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GLYCINE BOMBARDMENT BY ALPHA PARTICLE – DESTRUCTION CROSS SECTION DEPENDENCE WITH keV ENERGY AND TEMPERATURE

R. MARTINEZ
Federal University of Amapá (UNIFAP), Macapá/Amapá, Brazil

I. ULRICHSEN, E.F. DA SILVEIRA
Pontifical Catholic University (PUC-Rio), Rio de Janeiro/Rio de Janeiro, Brazil

Life may have originated on Earth from prebiotic molecules that arrived brought by extraterrestrial bodies. Fragments' analysis of Murchison meteorite suggests that it is made of Solar System (SS) primitive material before the beginning of nowadays terrestrial life. In the interior, 17 primary amino acids and 13 sugars were found [1]. Alternatively, space probes are launched periodically to collect samples looking for prebiotic material. Knowing that amino acids, building blocks of proteins, are fundamental in the composition of all organisms, the academic community suggests the possibility of an evolution theory with exogen principles. A major question is how the prebiotic material could survive billions of years in the interplanetary medium.

Considering that α particles with energy of about 1 keV are very abundant in the SS, this research aims to determine experimentally the glycine radioresistance, that is, its half-life under solar wind irradiation. Thus, the different radiation effects due to this interaction, like sputtering and radiolysis, will be studied.

Experiments were performed at the Van de Graaff Laboratory of PUC-Rio, Rio de Janeiro, Brazil, using a He^+ beam produced by a keV accelerator. Glycine films were prepared and irradiated by the He^+ beam ions, with energies of 0.5, 1.0, 1.5 and 2.0 keV. Infrared spectroscopy (FTIR) was used to analyze the irradiation effects. Experimental data show that Glycine destruction cross section depends on the beam energy and on sample temperature [2]. Fig. 1 shows the former dependence, indicating that at low energies, glycine absorbance decay faster that at lowers energies. Additionally, this research intends to find out if daughter molecules arise after Glycine irradiation with α keV particles.

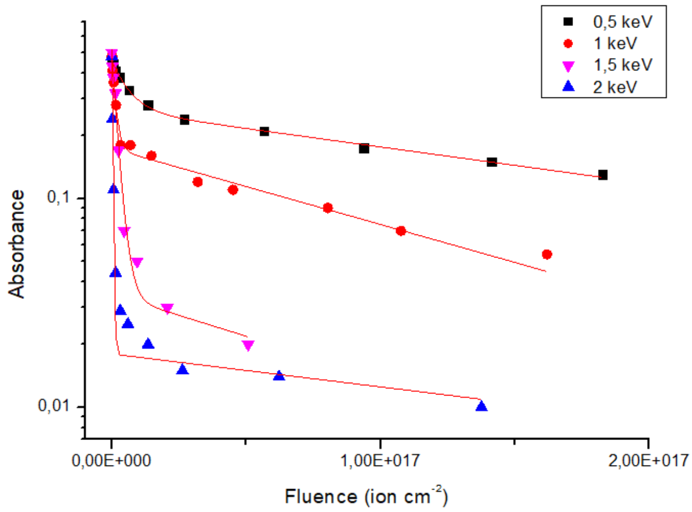

FIG. 1.Typical results of the normalized absorbance as a function of the fluence, for four different He^+ beam energies: 0.5, 1.0, 1.5 and 2.0 keV.

Keywords: Glycine, Irradiation, Destruction cross section, Origin of life

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SYNTHESIS AND IRRADIATION EFFECTS ON CRNBTAVW$_X$ HIGH ENTROPY ALLOYS

M. DIAS
Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

J.B. CORREIA
LNEG, Laboratório Nacional de Energia e Geologia, Lisboa, Portugal

R.C. DA SILVA
Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa Lisboa, Portugal

A.P GONÇALVES
C^{2}TN, Instituto Superior Técnico, Universidade de Lisboa, Campus Tecnológico e Nuclear Other-Bobadela, Portugal

U.V. MARDOLCAR
Departamento de Física, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa Portugal e Centro de Ciência Moleculares e Materiais, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

E. ALVES
Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa Lisboa, Portugal

During operation of a nuclear fusion reactor the divertor region stands high heat fluxes making the thermal compatibility between the low-working temperature heat sink material (CuCrZr) - which embrittles under irradiation - and the plasma-facing W tiles a major problem. An appropriate solution to address this discrepancy and to sustain irradiation damage is the introduction of a thermal barrier interlayer.

In this work CrNbTaVW$_x$ high entropy alloys have been devised for thermal barriers. Alloys with 20 at.% and 30 at.% of W have been prepared by ball milling and consolidation by Upgrade Field Assisted Sintering Technology (U-FAST) at temperature of 1600 ºC under a pressure of 90 MPa. Irradiation of the equiatomic CrNbTaVW sample was carried out at room temperature with Ar^+ (300 keV) beams with a fluence of 3 x 10^{20} at/m^2 at 25ºC, 200ºC and 400ºC. Structural changes prior and after irradiation were investigated by scanning electron microscopy, coupled with energy dispersive X-ray spectroscopy and X-ray diffraction and thermal stability was evaluated. The diffractogram of the raw powder mixture shows peaks of the individual elements in the alloy. After 2 hours of milling the X-ray pattern changed drastically, indicating the formation of a BCC structure with a minor fraction of WC. Moreover, after consolidation the diffractograms for both compositions evidence two BCC structures together with minor phases identified as Ta-Cr and Ta-V rich. In addition, no significant phase transformation was observed in these samples in the range from 25 ºC to 1500 ºC range which is a good indication of thermal stability of the materials in this temperature range. No severe superficial modifications were observed, after irradiation.

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MEASUREMENT OF ^{9}BE(^{3}HE,P$_{I}$)11B NUCLEAR REACTION CROSS SECTIONS AT ENERGY RANGE 0.5–2.35 MEV

N. CATARINO[a], E. ALVES[a], R. MATEUS[a], J. CRUZ[b]

[a]*IPFN, Instituto Superior Técnico, U. Lisboa, 1049-001 Lisboa, Portugal*

[b]*LIBPhys- UNL, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Monte da Caparica, 2892-516 Caparica, Portugal*

The interaction between the plasma and the wall materials in a fusion reactor is the key factor in determining the useful life of the wall components. This interaction includes the erosion and redeposition of material in the plasma-facing wall, accompanied by the formation of alloys from the different materials present. These processes are critical for the retention of hydrogen isotopes by the wall materials. Determining the amount and the depth profile of Be and other elements is crucial for understanding those phenomena making the knowledge of its cross sections essential for ion beam analysis of these systems.

The discrepancies and lack of knowledge on fundamental parameters required for ion beam techniques, raised the need to fill the gaps in the experimental data base of the nuclear differential cross-section reactions induced by ^{3}He in ^{9}Be. In this work we determined the ^{9} For ^{9}Be(^{3}He,p$_{x}$)^{11}B ($i = 0 - 9$) cross-sections, obtained using a thin beryllium film target at the backscattering angles between 110° and 165° with a 5° step and in the energy range between 1.0 and 2.5 MeV, which is the relevant energy range for the ion beam tchniques. The results were compared with the two previous studies in the same energy range. The results are in very good agreement with one of these studies and were benchmarked with the measurement of thick target reaction yields from a pure beryllium target at 2.0 MeV for 115°, 135° and 155°.

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EFFECT OF SWIFT HEAVY ION IRRADIATION ON THE OPTICAL PROPERTIES OF ION IMPLANTED POLYETHYLENE TEREPHTHALATE

J.J. MBOUKAM[ab]
[a]*Physics Department, Tshwane University of Technology, Pretoria, South Africa*
[b]*iThemba LABS TAMS, National Research Foundation, Johannesburg, South Africa*

M. MADHUKU[b]
[b]*iThemba LABS TAMS, National Research Foundation, Johannesburg, South Africa*

M. MSIMANGA[ab]
[a]*Physics Department, Tshwane University of Technology, Pretoria, South Africa*
[b]*iThemba LABS TAMS, National Research Foundation, Johannesburg, South Africa*

The surface modification of polymer thin films with heavy ion beams irradiation always induces irreversible changes of the materials through cross-linking, chain scission, mass losses, and irreversible bond cleavages for specific customizations. We report here on structural and optical characteristics of ion implanted polyethylene terephthalate (PET) films measured through ion beam elemental depth profiling and UV-Vis optical spectroscopy measurements, respectively. The samples were implanted with 150 keV Ag^+ ions to different ion fluences of 1.00 x 10^{16}, 5.00 x 10^{16} and 1.00 x 10^{17}ions/cm^2, and thereafter irradiated with 30 MeV Au^{7+}-ions for fluences ranging between 7.00 x 10^{13} to 2.50 x 10^{14} ions/cm^2. The immediately observable effect of the implantation was the darkening of the initially transparent PET films, with the degree of darkening increasing with implantation ion fluence. The elemental depth profiles showed considerable atomic depletion of hydrogen from 36% down to below 1%, and oxygen from 18% to about 6% for the highest implantation ion fluence, whereas the proportion of carbon increased from 46% up to over 90% with increasing ion fluence. Optical characterisation results showed notable changes in the UV-Vis absorption spectra of the implanted, as well as the implanted-and-irradiated samples. The optical band-gap was found to decrease with increasing implantation ion fluence, and decreased even further on irradiation after implantation. Consequently, the number of carbon atoms in beam induced carbon clusters is also seen to increase with the implantation ion fluence, and as well after irradiation. These results suggest that the same materials modification effects in polymers that are normally only achievable through high fluence implantation, can still be realized through a combination of low fluence implantation followed by low fluence swift heavy ion irradiation.

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FORMATION OF Au NANOPARTICLES IN TIO2 BY ION IMPLANTATION

N. CATARINO, A. RIBEIRO, M. DIAS, M. PERES, E. ALVES
Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001, Lisboa, Portugal,

J. BORGES, F. VAZ
Centro de Física, Universidade do Minho, Campus de Gualtar, 4710-057 Braga, Portugal Campus de Gualtar, 4710-057 Braga, Portugal

The potential of Gold nanoparticles (NPs) as biosensors is being widely explored in several fields like biology, medicine, chemistry and physics. The applications in chemical and bio- sensing, phototherapy of tumours, nanoscopy and optical imaging are among the most relevant. In this work, we use ion implantation technology to produce Au-nanoparticles in TiO2 dielectric layers in a controlled way. Ion implantation is ideal to control size and depth distribution of the nanoparticles.

Titanium Dioxide films with different thicknesses were deposited by direct current magnetron sputtering method on silicon and glass (for optical studies) substrates. The Au ions with multiple energies were implanted with different fluences to produce a box like profile. The energies used were 50 keV and 150 keV with fluences in the range 1×10^{16} to 2×10^{17} ions/cm^2. After implantation the samples were submitted to annealing in air at 500 ºC for 15 min to induce the precipitation of the Au ions.

The depth profiles were studied with Rutherford Backscattering Spectrometry (RBS) using a $^4He^+$ beam of 1.5 MeV, before and after annealing. The results do not show significant changes on the Au profile at this temperature. XRD analysis show the presence of the (111)Au diffraction peak confirming the formation of Au particles for the films as deposited in Si while for the films on glass the nanoparticles are only observed after annealing. The samples were also analysed using scanning electron microscopy (SEM) to get a better understanding of the size and distribution of the formed NPs. The microstructures were observed in backscattered electron imaging (BSE) and secondary electron imaging (SE) modes using a JEOL JSM-7001F field emission gun scanning electron microscope equipped with an Oxford Instruments X-ray EDS system with an energy of 25 kV. The results show an increase of the density of the particles with the annealing and an average size of 15 nm, Fig. 1.

The optical characteristics of the films was studied using optical absorption spectroscopy in the films deposited in glass. The presence of a band centred at 570 nm, corresponding to the plasmon resonance of Au nanoparticles, was observed.

The possibility to use the technique to develop of platforms to explore optical Transmission Localized Surface Plasmon Resonance (TLSPR)-biosensing systems will be discussed.

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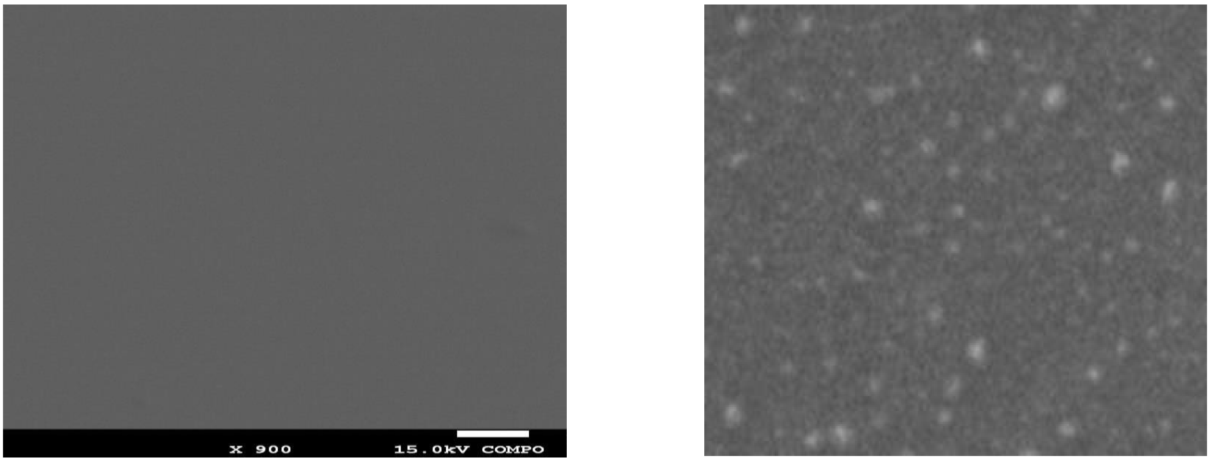

FIG.1. SEM images of a implanted TiO2 film before (left) and after annealing (right) at 500 ^{o}C, 15 min.

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UTILIZATION OF 30MEV DAE MEDICAL CYCLOTRON FOR PRODUCTION OF MEDICALLY USEFUL RADIOISOTOPES AND CORRESPONDING RADIOPHARMACEUTICALS

Pradip MUKHERJEE
BRIT, Mumbai, India

Sankha CHATTOPADHYAY
BRIT, Kolkata, India

Cyclotrons are extensively used to produce radioisotopes for diagnostic and therapeutic use for cancer care. In India, the IBA Cyclone-30, 30MeV, 350µA proton cyclotron has been commissioned and made operational in September 2018 for the production of radioisotopes/radio pharmaceuticals for medical application. This cyclotron has the potential to produce SPECT (Single-Photon Emission Computed Tomography) Isotopes (^{67}Ga, ^{111}In, ^{123}I, ^{201}Tl etc.), PET (Positron Emission Tomography) isotopes (F-18, Ge-68/Ga-68 generator for in situ production of Ga-68, Ga-68, Cu-64, Zr-89, I-124 etc.) and therapeutic isotope like Pd-103. Here, we report the production of ^{18}F-FDG, ^{68}Ga-PSMA, ^{68}Ga-DOTATATE and ^{201}TlCl radiopharmaceuticals using Cyclone-30. The specification of the radiopharmaceuticals complies with norms of the regulatory bodies in India. Presently, India is importing long lived SPECT Isotopes. Indigenous production of RI is going to be a boon to make the treatment cost more affordable.

The production of ^{18}F was achieved by irradiating $H_2{}^{18}O$ using IBA niobium target assembly (1.8ml in 2.4ml Nb target cavity) with 18 MeV, 35-40µA average proton beam current for 1 to 2 hrs. and subsequent production of ^{18}F-FDG has been carried out in hotcells (Comecer, Italy) using IFP (integrated fluid processor) cartridge in IBA synthera module. The production yield of ^{18}F-FDG varies from 65-70 % (without decay correction). The radiochemical purity of the ^{18}F-FDG has been found to be 99.9% by using TLC method. The radionuclidic purity was greater than 99.99% (determined by HPGe). Regular production and supply to hospitals have been started after obtaining necessary regulatory clearances. Supply logistics for the short-lived isotopes are usually challenging and the same was resolved through meticulous transport planning and optimizing the procedures and resources.

The SPECT isotope ^{201}Tl ($t_{1/2}$= 73.06 hours) in the form of ^{201}TlCl is a diagnostic myocardial flow tracer to detect coronary artery disease and to assess myocardial viability, with an accuracy comparable to that of positron emission tomography. ^{201}Tl was produced in 30 MeV cyclotron using electroplated enriched ^{203}Tl target via ^{203}Tl(p,3n)^{201}Pb→^{201}Tl (^{201}Pb decayed for ~32h to ^{201}Tl) nuclear reaction utilizing 28MeV proton beam energy and 50µA beam current for up to 6-8h. The production of ^{201}TlCl has been carried out in hot cells and automated radiochemistry module.

At present, the supply of Ga-68 for medical imaging is primarily based on the imported [^{68}Ge]Ge/[^{68}Ga]Ga generator ($t_{1/2}$ of Ge-68 : 271 days; $t_{1/2}$ of Ga-68 : 68 min). Since these commercial generators can deliver only a limited amount of activity and the demand for Ga-68 is high, an effort has been made to produce Ga-68 directly from the cyclotron and supply to the nearby hospitals at a much affordable price. We have produced Ga-68 directly from electroplated enriched ^{68}Zn target via ^{68}Zn(p,n)^{68}Ga nuclear reaction. The enriched ^{68}Zn electroplated on the copper base material were irradiated with 15 MeV proton beam energy and current 40-60 µA in the Cyclone-30 cyclotron for 30-60 minutes. The irradiated target was transferred to the processing hotcell (100 mm lead shield) from the irradiation station by remote-controlled rabbit transport system to complete radiochemical

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processing in 30-45 minutes. The Ga-68 chloride produced was labelled with PSMA-11& DOTA-TATE ligands. The R.N. Purity of ^{68}Ga-chloride was found to be 99.90-99.99%. The R.C. Purity of ^{68}Ga-PSMA & ^{68}Ga-DOTA-TATE was >95%.

Potential of the 30 MeV cyclotron is immense. The complete utilization of this Cyclotron is going to bring a paradigm shift in the use nuclear medicines in the country to offer a more affordable cancer care.

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ION BEAM STUDIES OF DEUTERIUM RETENTION IN HIGH ENTROPY ALLOYS AND W TARGETS IN THE PF-1000U FACILITY

R. MATEUS, R. MARTINS, M. DIAS, A. MALAQUIAS, E. ALVES
IPFN, Instituto Superior Técnico, Estrada Nacional 10, km 139.7, 2695-066 Bobadela, Portugal

P. CZARKOWSKI, S. A. ARKUSZEWSKI, A. SZYMASZEK, R. MIKLASZEWSKI
IFPiLM, Institute of Plasma Physics and Laser Microfusion, 23 Hery Str., 01-497 Warsaw, Poland

The demands of materials proposed for nuclear fusion applications are based on high radiation hardness and low activation. Actually, W is being used as plasma facing material [1] and High Entropy Alloys (HEAs) were proposed as thermal barriers interlayers between W and heat sink parts [2]. It is a demand to study the chemical and morphological modifications induced by plasma discharges in fusion grade materials to evaluate their behaviour under operational or accidental scenarios. In the IAEA research contract with IST under the frame of the CRP F13020 project [3], target samples with mirror quality surfaces are being irradiated in the plasma focus PF-1000 U at the IFPiLM institute in Warsaw, Poland [4], with intense deuterium plasma stream discharges. Virgin and as-irradiated samples are characterized before and after exposition by electron microscopy, namely by scanning electron microscopy (SEM) and, particularly, by ion beam analysis (IBA) at IST, Bobadela, Portugal [5], involving proton induced X-ray emission (PIXE) to investigate any possible heavy or semi-heavy elemental contamination apart the plasma species, elastic backscattering spectrometry (EBS) for other light elemental inspection, and a simultaneous Rutherford backscattering spectrometry (EBS) and nuclear reaction analysis (NRA) to quantify the retained deuterium contents from the NRA protons yields induced by the $^{2}H(^{3}He,p)^{4}He$ reaction [6].

The first irradiation campaign was carried out with two batches of $W_{30}Ta_{17.5}Cr_{17.5}Nb_{17.5}V_{17.5}$ and $W_{20}Ta_{20}Cr_{20}Nb_{20}V_{20}$ HEA alloys produced at IST. Three pairs of samples with mirror quality surfaces (0.8 mm thick, ~1 cm^2) were irradiated simultaneously with 1, 3 and 5 deuterium plasmas discharges of similar power densities and plasma parameters. After five discharges the $W_{20}Ta_{20}Cr_{20}Nb_{20}V_{20}$ target collapsed. The remaining irradiated targets were analysed by SEM, by EBS with a 1750 keV $^{1}H^{+}$ ion beam, and simultaneously by RBS-NRA with 1000 keV and 2300 keV $^{3}He^{+}$ ion beams. SEM images evidenced some blisters, most of them detached from the fully cracked surface in the $W_{20}Ta_{20}Cr_{20}Nb_{20}V_{20}$ alloy after 1 and 3 discharges, with no visible morphological evolution. The $W_{30}Ta_{17.5}Cr_{17.5}Nb_{17.5}V_{17.5}$ surfaces present blistering and superficial swelling after 1 discharge with additional fracture and zoned melting afterwards (see Fig. 1). In opposition to SEM, RBS-NRA quantifications evidenced an extremely low deuterium retention in the irradiated surfaces (see the example of NRA $^{2}H(^{3}He,p)$ yields with corresponding fit lines achieved from quantification in Fig. 2a and 2b). Despite a huge increment of deuterium after successive discharges, maximum superficial deuterium areal amounts are similar and lower than 9.0 x 10^{15} at/cm^2 in both alloys along a depth range of ~1.5 µm. Other elemental contaminations were not quantified in the same surfaces by PIXE and EBS. The results point to a low retention behaviour in the bulk of the HEA alloys under extreme deuterium plasma exposure.

A second irradiation campaign on 8 W plates with mirror quality surfaces (99.95 at.%, 10x10x2 mm^2) is being carried out at PF-1000U comprising: (a) 3 plates exposed to 1, 3 and 5 deuterium plasma discharges at the same power density used for the HEA alloys, (b) 3 plates exposed to 1, 3 and 5 deuterium plasma discharges at a distinct power density, and (c) 2 plates exposed to 1 and 3 discharges at the same power density used for the HEA alloys using a mixture of deuterium and helium gases (75 % ^{2}H + 25 % ^{4}He). The results will signalize the role of the individual plasma discharges in the W irradiated surfaces.

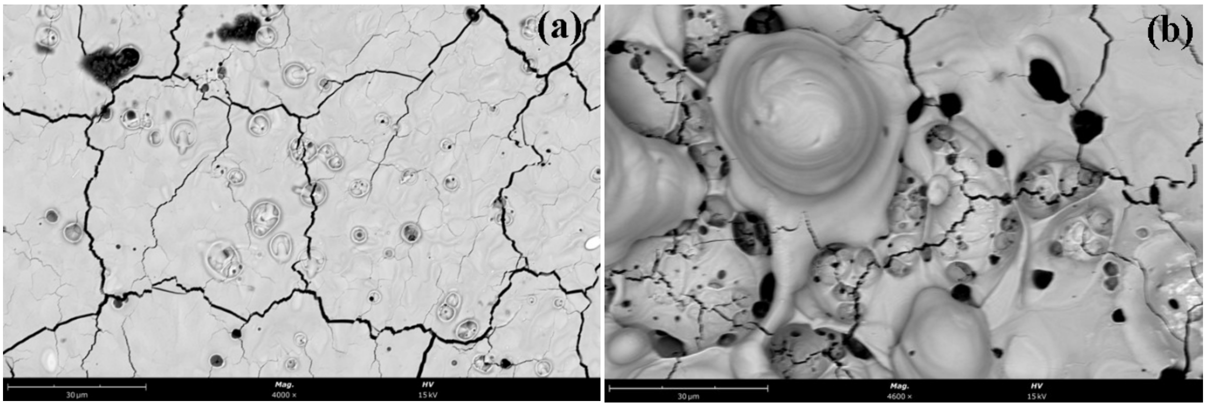

FIG. 1: SEM images of (a) $W_{20}Ta_{20}Cr_{20}Nb_{20}V_{20}$ and (b) $W_{30}Ta_{17.5}Cr_{17.5}Nb_{17.5}V_{17.5}$ after 3 discharges.

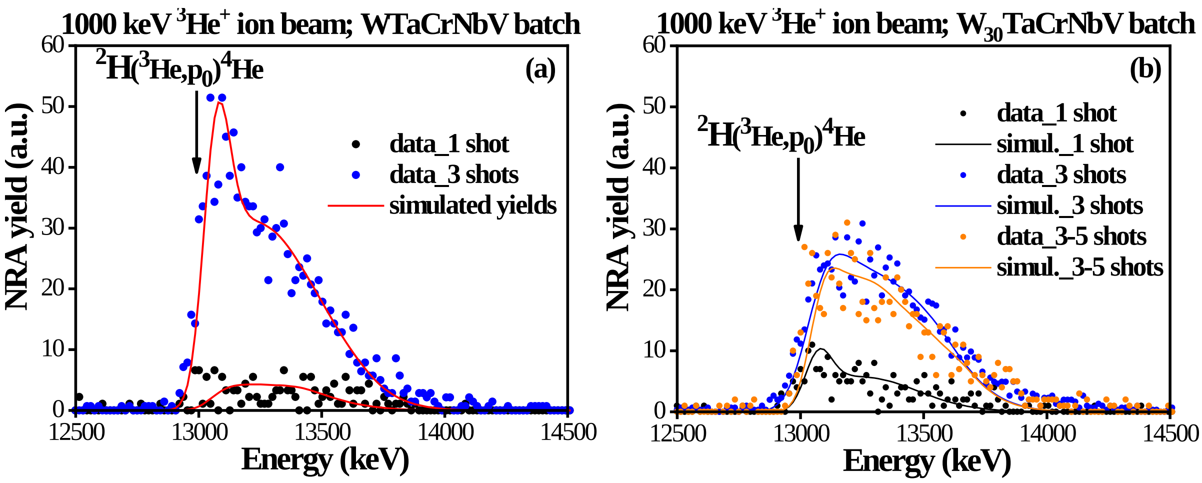

FIG. 2: NRA spectra and corresponding fit lines achieved from the elemental quantification using the NDF code [6]: (a) $W_{20}Ta_{20}Cr_{20}Nb_{20}V_{20}$ and (b) $W_{30}Ta_{17.5}Cr_{17.5}Nb_{17.5}V_{17.5}$ alloy.

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DEVELOPMENT AND APPLICATIONS OF THE DUAL-BEAM ION IRRADIATION FACILITY FOR FUSION MATERIALS (DIFU) AT RBI, ZAGREB

T. DUNATOV, T. TADIĆ, S. FAZINIĆ, M. JAKŠIĆ, Z. SIKETIĆ, M. VIĆENTIJEVIĆ, D. COSIC, Z. KOLAR
Ruđer Bošković Institute, Zagreb, Croatia

M. CAPOR, R. GRACIN
Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia

C. HARDIE
Culham Centre for Fusion Energy, Abingdon, UK

We present the Dual-beam ion irradiation facility for FUsion materials (DiFU) developed at Ruđer Bošković Institute in Zagreb, Croatia. It has a versatile setup which allows irradiation of fusion materials samples by one or two ion beams as well as other similar experiments. Two beamlines come to the DiFU chamber at an angle of 17^0 between them, from 6 MV HVE Tandem VDG and 1 MV HVE Tandetron accelerator. Ion beam handling and scanning systems enable fast electrostatic scanning of the beams over the sample at kHz frequencies, and irradiation of areas up to 30x30 mm^2. The sample holder enables XYZ positioning of heated, cooled or room temperature samples. Ion fluxes are measured indirectly by insertion of two large Faraday cups in ion beams and the ion flux is also monitored continuously by two sets of XY slits. Conditions during irradiation are monitored by a set of thermocouples, an IR camera, a high-sensitive video-camera, and a residual gas analyser. The DiFU facility has been developed according to ASTM standard E521-16 [1] with support from EUROfusion, the IAEA and the Croatian Science Foundation.

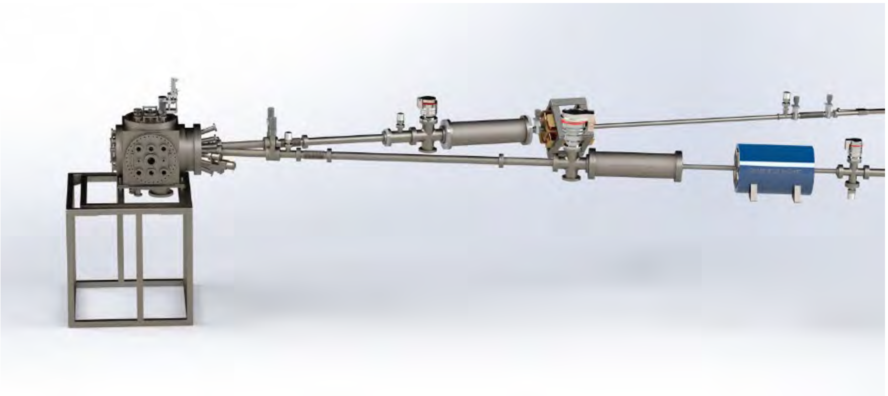

FIG. 1. Drawing of the DiFU chamber along with both beamlines

Ion beam irradiation can be used to emulate neutron irradiation effects in reactors [2]. Dual-beam facilities such as this are especially important for applications in fusion materials due to their ability to simultaneously reproduce the effects of radiation damage and helium or hydrogen formation inside a fusion power plant. The Tandetron accelerator can be used for light ion implantation, while the VDG damages the material with heavy ions. Particular care has been dedicated to mitigating carbon contamination during irradiation [3], an issue which has been shown to significantly affect the results of post-irradiation characterizations of materials [4]. Research into this effect is still ongoing.

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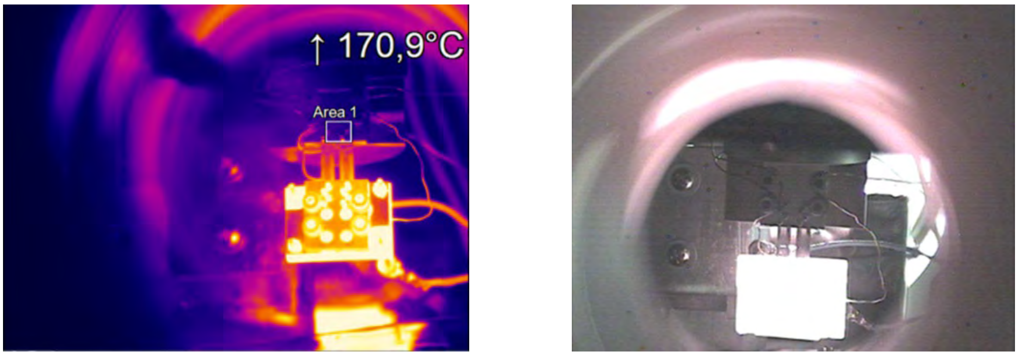

FIG. 2. IR and ordinary camera captures of a high-temperature irradiation

Material irradiation experiments conducted include a novel method of creating a temperature gradient in the material [5], as well as continuous irradiations of more than 24h to achieve a high doses in the range of 10 dpa [6]. The setup is also used in other irradiation or implantation experiments where the precise determination of fluence and a broad beam are needed.

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ARTIFICIAL NEURAL NETWORKS AND ION BEAMS FOR 3D IMAGING

V. CORREGIDOR, L.C. ALVES, T. PINHEIRO, R.C. DA SILVA
DECN, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

M. FURTADO
MEFT, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

The nuclear microprobe (NM) together with Ion Beam Analysis (IBA) techniques allows obtaining 2D elemental distribution maps, providing also elemental depth profile along the ion path, with lateral micrometric precision and depth precision down to the tens of nanometer scale. Traditionally, Rutherford backscattering spectrometry (RBS) and particle induced X-ray emission (PIXE) are simultaneously used for sample characterization.

Typically, each scanned area by the NM is acquired as a 256x256 pixel map, each pixel containing all the IBA spectra recorded during the experiment. To analyse each spectrum individually would be tedious and time consuming. To solve this problem the use of artificial neural networks (ANNs), once trained, can be very important because they can handle the analysis of large data sets instantaneously [1-3]. From results obtained, it is possible to visualize in a 3D environment the sample composition variations.

Examples obtained from biological and archaeological samples will be presented, showing the versatility of the neural networks used. Their use can open the path for automated and/or real-time data analysis together with 3D reconstruction of sample elemental distribution and content.

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CNA: USER-ORIENTED ACCELERATOR FACILITY DEDICATED TO INTERDISCIPLINARY RESEARCH IN SPAIN

J. M. LOPEZ-GUTIERREZ
Centro Nacional de Aceleradores, Avenida Tomas Alva Edison, 7. 41092-Sevilla. Spain

The Centro Nacional de Aceleradores (CNA) is a joint-research centre of the University of Seville, the regional government of Andalucía and the Spanish National Research Centre (CSIC). It is recognized by the Spanish government as a Singular Scientific Technical Facility (ICTS) dedicated to interdisciplinary research and open to external users. It has six major facilities: A Van der Graaf 3 MV Tandem Accelerator, a 18/9 MeV Cyclotron Accelerator, an accelerator 1 MV Mass Spectrometer, a radiocarbon dating system called Micadas, a ^{60}Co irradiator and a PET/CT scanner.

The research lines applied with these set of facilities are numerous and cover fields as diverse as material sciences, environmental impact, nuclear and particle physics, nuclear instrumentation, medical imaging, biomedical research, ^{14}C dating and irradiation samples of technological and biological interest, between others.

In this contribution, some research lines more related with sustainable development and with important socioeconomical impact will be summarized.

- The CNA neutron beam line associated to a charged pulsed beam in the Tandem (HISPANoS) allows for time-of-flight measurements which determine the neutron energy, opening research application related to astrophysics, detector characterization and electrical devices irradiation for aerospace purposes, between others.
- The use of an adequate stripper gas in the AMS Tandetron allows to measure heavy radionuclides with very low detection levels, allowing to perform environmental studies using these radionuclides as tracers. In fact, CNA is an active IAEA Collaborating Centre in the topic “Accelerator-based analytical techniques for the study of radionuclides in marine samples”,
- The use of a microbeam line in the Tandem accelerator allows to apply the ion-beam-induced current technique (IBIC) to investigate the spectroscopic properties and radiation hardness of different semiconductor detectors. We are a member of the international CERN RD50 collaboration “Radiation hard scintillaor devices for hgh luminosity devces”.
- The combined use of the 18/9 MeV Cyclotron and the PET/CT scanner located in the same building, allow to external users to perform in an optimized way clinical study using radiopharmaceuticals of very short life.
- In addition to conventional ^{14}C dating application in archaeological, geological studies, forensic applications are being carried out in CNA by the measurement of ^{14}C in the Micadas system, such as the dating of ivory samples against poaching and ivory smuggling.
- Unique irradiation studies are being performed in the Centre by combining the proton and heavy ion irradiation research lines associated to the 3 MV Tandem and 18/9 MeV Cyclotron accelerator, with the photon irradiation (^{60}Co) facility which generates in air and at 100 cm distance a maximum kerma rate of 100 Gy./h.

EFFECTS OF IONS IRRADIATION ON TIO_2 NANOPARTICLES: A REVIEW

I. AHMAD
National Centre for Physics, Islamabad 44000, Pakistan

S. O. AISIDA
Department of Physics and Astronomy, University of Nigeria, Nsukka, Nigeria

Z. TINGKAI
School of Materials Science & Engineering, Northwestern Polytechnical University, Xi'an, China

It is obvious that the physical properties of nanomaterials could be tuned to induced defects or phase transformation using physical or chemical methods. In this review, a physical method of ions irradiation induced tuning the physical properties of TiO_2 nanoparticles (NPs) is presented. Effects of different ions species on TiO_2 NPs at different fluences and substrate temperature were fully reviewed. Ion irradiation induced two phenomena; ions-induced-defects production and ion-induced-phase transformation were fully investigated. Moreover, ion-beam-induced-mixing of TiO_2 NPs at contact points which cause coalescence of TiO_2 NPs were also illustrated in this review. Finally, results were summarised and fully investigated the irradiation issues on latest ion irradiation research on TiO_2 NPs and future way forward to solve these issues are highlighted in this review paper.

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REVIEW OF 20 YEARS OF INDUSTRIAL APPLICATIONS OF ION BEAM AND RADIATION TECHNIQUES

L. POPA-SIMIL

LAAS – Los Alamos Academy of Sciences, Los Alamos, USA

The present work summarizes the applicative researches performed during 1980s and1990s in Romania using Ion beam based technologies, radiation based technologies and many other measurement techniques to characterize various technological objects as engines, gear boxes, pumps, tools and materials as shown in Fig.1. Tribology studies were performed together with material studies, and assembly performances using a large variety of measurement methods and devices. In order to improve speed and accuracy of tribology thin and Ultra-Thin Layer Activation (UTLA) method have been used producing a radioactive layer on a selected surface of a technological part, measured for quality assurance with auto-radiography and spectroscopy. The part was mounted in the installation and its radioactivity decrease faster than the natural decay was considered to be due to material loss by wear, corrosion or abrasion.

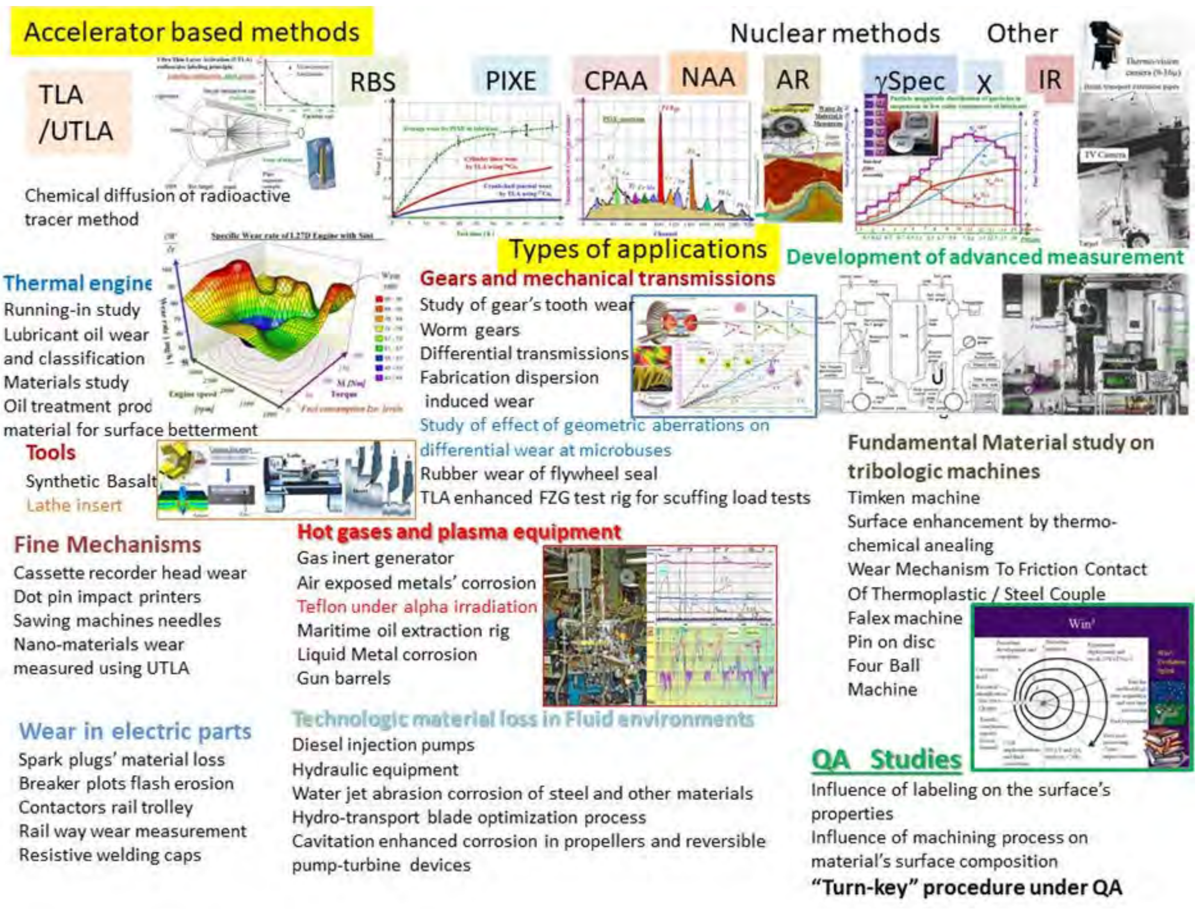

Fig. 1 – Accelerator and nuclear methods application range

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Complex stationary or mobile test benches have been built to integrate the nuclear methods with classical measurement technologies and other novel methods of operation and data processing. The results were indicated the material loss rate, duration of good operation, surface distribution of material loss, driving to profile optimization, material transfer rate inside tribology assembly, filter properties and behaviour, lubricants properties, granular aspects of material loss, material structure, as functions of operating conditions as temperature, pressure, stress, relative movement speed distribution, etc.

Measurements have been done in machine building industry, on subassemblies as automotive engines of various sizes, transmission gears, lubricants and oil filters, injection systems, etc. TLA method was successfully used in hydraulic and gas environments, measuring the parts wear in real time. Fundamental tribology studies have been performed using the method to increase the detail of the results.

From the very beginning the TLA or UTLA based methods were more expensive and complicated than the classical methods of measurement, but the advantage was that this method is giving more complex results of the studied element, in real time, that may be correlated with various operating regimes and other elements that are influencing the material behaviour. Using the method gave companies a leap in time of several years, because in inly few months, there was possible to obtain all the information obtained in few years using usual methods, only, but with an order of magnitude in detail, helping the designer and prototype manufacturer to optimize all necessary parameters in order to drastically improve the product in a time shorter by an order of magnitude, and when compared with the quantity of information obtained it becomes by at least an order of magnitude cheaper.

The measuring method did not excluded the usual measurement techniques, but used them associatively, improving the reliability of data, because the same values have to be obtained by all the measurement methods used, checking one-another, and having the differences clearly explained, and understood, in a more detailed manner. Measuring in real time all operational parameters opens the possibility of determining the inter-correlations among them, and improves the quality of information obtain in the testing process.

During this period several hundred experiments have been performed, and the method have been gradually developed following the quality assurance principles, and transformed into a turn-key procedure, with clear steps, stages and control means and methods, integration as many as needed nuclear and non-nuclear technologies. Methods as XRF, PIXE, RBS, UTLA, NAA, Gama Spectrometry, were integrated with optical, acoustical, mechanical and electrical methods using automated data acquisition, computer processing and results interpretation, benchmarking the computer simulation and using lessons learned for further improvements, following a spiral of evolution. The results were outstanding, assuring the industrial customer with the capability to shorten the time from design to market, cheaper and more accurate than with usual methods which were integrated in the measurement process, together with Quality assurance tests, increasing the market competitiveness.

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PROGRESS IN ELECTRON BEAM INDUCED GRAFTING FOR DEVELOPMENT OF ION CONDUCTING MEMBRANES FOR POLYMER ELECTROLYTE FUEL CELLS IN MALAYSIA

MOHAMED MAHMOUD NASEF[a,b*]

[a]*Chemical and Environmental Engineering Department, Malaysia-Japan International Institute of Technology,Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia*

[b]*Center of Hydrogen Energy, Institute of Future Energy, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia*

Ion conducting membranes (ICM) are playing a crucial role in electrochemical energy systems by supporting the desired migration from the dependence on fossil fuels to renewable energy. Radiation-induced graft copolymerization (RIGC) technique is a distinctive means for development of alternative ion conducting membranes for energy conversion devices to overcome low fuel barrier, low conductivity or high cost associated with widely used commercial membranes. The use of electron beam (EB) accelerator in irradiating polymer film provides essential advantages to speed up the IEM preparation procedure, reduce the monomer consumption (if simultaneous irradiation grafting is used), facilitate the IEM preparation upscaling process and improve the overall process economy and greenness. The objective of this talk is to review the latest developments in applying EB for preparation of ICMs for fuel cells in Malaysia. This includes proton conducting composite membranes for proton exchange membrane fuel cells (PEMFC), direct method fuel cell (DMFC) and high temperature PEMFC. The EB was also used to prepare a novel composite anion exchange membranes for alkaline electrolyte membrane fuel cell (AEMFC). The preparation of proton exchange membrane for PEMFC started by RIGC of 4-vinylpyridine (4-VP) with EB onto polypropylene (PP) nanofibrous sheet followed by immobilization of phosphotungstenic acid ($H_3PW_{12}O_{40}$, PTA) and subsequent casting of 2 thin layers of Nafion solutions leading to composite membrane with high conductivity and less water dependence. Similar membrane based on electrospun nylon-6 fibrous sheet demonstrated superior barrier properties compared to Nafion 115 especially at higher methanol concentrations when tested in DMFC. The membrane for high temperature PEMFC was prepared by grafting a binary mixture of 4-VP/1-vinylimidazole onto EB-irradiated poly(ethylene-co-tetrafluoroethylene) followed by doping with phosphoric acid (PA) under controlled conditions. The incorporation of two basic monomers was highly effective in enhancing PA doping level, proton conductivity and the overall performance of the membrane in fuel cell operation at 120°C. The anion exchange membrane for AEMFC was prepared by incorporation of imidazolium head group to EB irradiated nanofibrous substrates such as syn-PP grafted with vinylbenzyl chloride and crosslinked by 1,8-octanediamine and functionalized with OH^- group. The obtained membranes displayed not only high ion exchange capacity and ionic conductivity, but also reasonable alkaline stability and hight ionic conductivity (130 mS cm^{-1} at 80°C). The membrane showed a high-power density reaching 440 mW cm^{-2} at a current density of 910 mA cm^{-2} when combined with electrodes using diamine crosslinked quaternised polysulfone binder at 80°C with 90% humidified H_2 and O_2 gases making it a promising candidate for application in AEMFC. It can be concluded that EB is highly effective in development of membranes for fuel cells and more work is sought to expand its use for other applications including emerging batteries, water electrolysers, and antifouling membrane systems.

ACCELERATORS USE TO ENGINEER NANO-MATERIALS FOR ENERGY

L. POPA SIMIL

LAAS - Los Alamos Academy of Sciences, Los Alamos, USA

It is known for more than 2000 years that Damascus swords' performances were not possible without the existence and usage of the "Damascus steel", the first man made nano-hetero structural material that generalized is clearly showing that materials determine ultimate properties of the objects that made off. The actual nuclear energy has lower CO_2 emission, but because it is in its infancy, it is based on homogeneous "hot-rod" technology, it is complex, expensive and raises security and proliferation issues, has the potential for large scale accidents, and generates difficulties in dealing with waste fuel dispositioning.

The novel developed families of engineered nano-materials, eliminate almost all the drawbacks of the actual nuclear power, rendering it among the most efficient and environmental friendly energy source. Developing and optimizing these novel energy materials require intensive accelerator use in fundamental knowledge development and structural optimization experiments.

The novel nuclear materials as shown in Fig. 1, were developed in 6 families; each of them is intended to bring in harmony the structure with a nuclear agent active inside that material as:

- Micro-hetero structures, generally called "cer-Liq-Mesh" that self-separates the fission products from the nuclear fuel and minimizes their fuel damage, allowing breed&burn to near perfect burning; the fission products behave like medium mass accelerated ions, where the use of accelerators will help test the novel material structure and optimize it.
- Nano-hetero structures generically called "CIci", that form a super-capacitor, charged by nuclear energy and directly discharged as electricity; This structure has broad use for almost all moving nuclear particles except neutrons and gamma, and for each type of particle, the use of a similar accelerated one bring a valuable contribution to material selection and optimization as well to the entire structure test and characterization.
- Nano-clustered structure that enhances self-separation of transmutation products; where the initial idea was generated by UTLA method development, where the recoil energy is used for implantation, but because this energy inside neutron zones is small, nano-cluster enhanced selective diffusion properties are also used. Using low energy accelerators/implanters we may test various nano-clustered structures.
- Fractal immiscible materials with radiation damage self-repairing capabilities eliminating the need for re-cladding in near perfect burning structures. The dimensions of these structures may be optimized using ion-beams simulating the radiation damage inside nuclear reactors.
- Nano-structures with active NEMS used as fast control of nuclear reactivity by guiding neutrons in desired directions or ultralight shielding for mobile reactors. The guiding is similar to radiation channelling being possible to use ion-beams to test the NEMS operation.
- Nano-structures that create active-quantum-nuclear-environment for long range nuclear reactions control by using quantum states entanglement and collective quantum states control. This is a novel development with cutting edge concepts, where we may use accelerated ion beams in order to excite collective quantum states, and study possible long range quantum leaps, entanglement and quantum state teleportation.

The use of these advanced materials in future nuclear energy related application will render a high efficiency, minimal nuclear waste, and optimal nuclear fuel cycle, isotope, fission and fusion "batteries", delivering the needed planetary clean energy at will for the next 10,000 years, and even more.

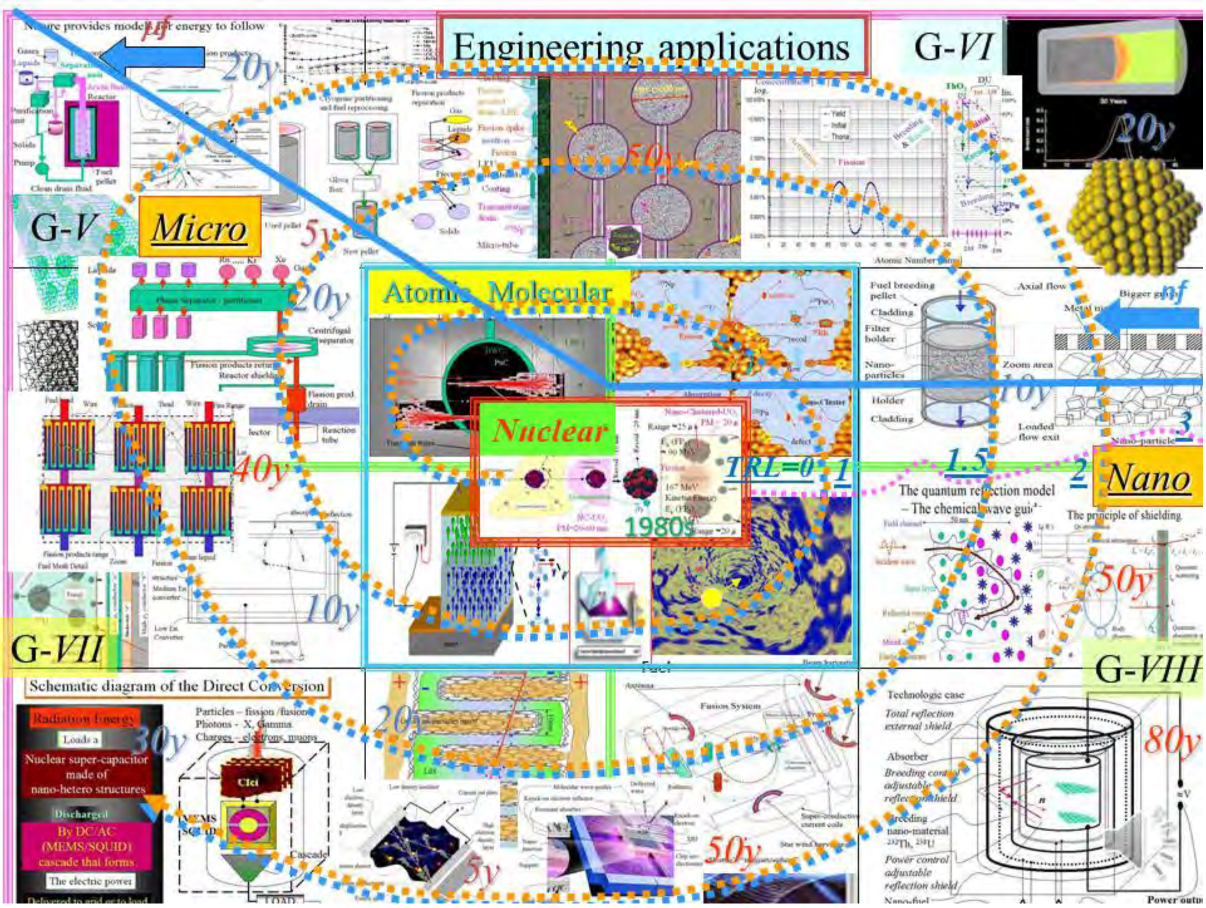

Fig. 1 Engineered, nano-nuclear materials knowledge evolution from concept to application

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PHOTODEGRADATION EFFECT OF THE ELECTRON BEAM IRRADIATED DEVULCANIZED NATURAL RUBBER/POLYPROPYLENE COMPOUND UNDER NATURAL WEATHERING CONDITION

<u>LEE TIN SIN</u>[1], Kheng-Hooi LOO[1], Soo-Tueen BEE[2], C. T. RATNAM[3]

[1] *Department of Chemical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Jalan Sungai Long, Bandar Sungai Long, Cheras, 43000 Kajang, Selangor Malaysia*

[2] *Department of Mechanical and Material Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Jalan Sungai Long, Bandar Sungai Long, Cheras, 43000 Kajang, Selangor Malaysia*

[3] *Radiation Processing Technology Division, Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia.*

This study aims to investigate the photo-degradation effect under UV source for the different irradiation dosages of the polypropylene/devulcanized natural rubber (PP-DVC) compound. The DVC was used to improve the impact resistance of the PP-DVC compound at the range of 0 – 20 phr. These samples were subjected to electron beam irradiation at a dosage range of 0 – 200 kGy to induce the formation of crosslinking networks in polymer matrix. Then, these samples further proceed for natural weathering testing for the range of 0 - 6 months. It was found that the addition of 5 phr DVC added in PP irradiated at 50 kGy has the optimum value for the mechanical properties after exposed to outdoor for 6 months. The gel content increased with longer exposure period due to the predominance of cross-linking formation by photo-oxidation under UV exposure. However, the fractured surface has changed from tear lines appearance to flake-like appearance. The crystallinity has reduced as the degradation of the PP matrix by chain scission and lead to poor dispersion of DVC particles in PP matrix when exposed to outdoor for a longer period. The carbonyl index increased as the carbonyl formation for PP after weathering is proportional to the number of chain scission that occurred in the PP.

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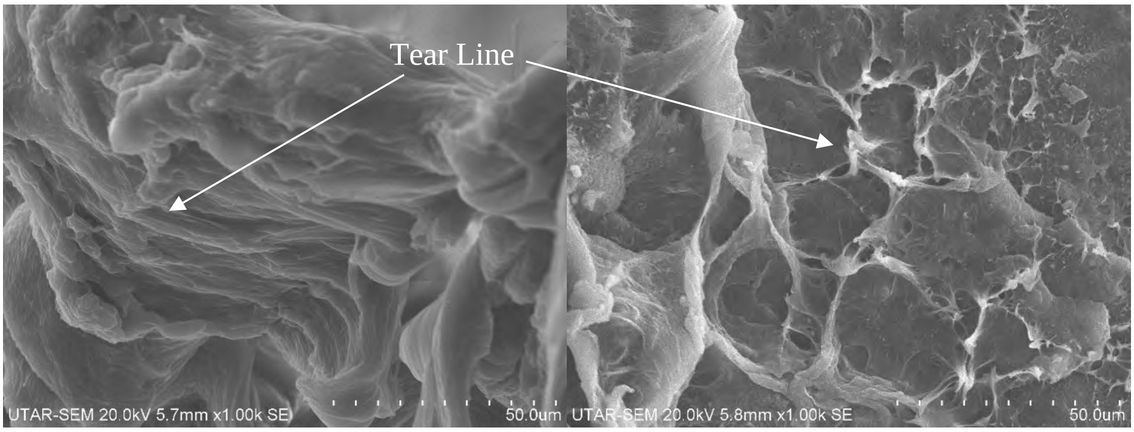
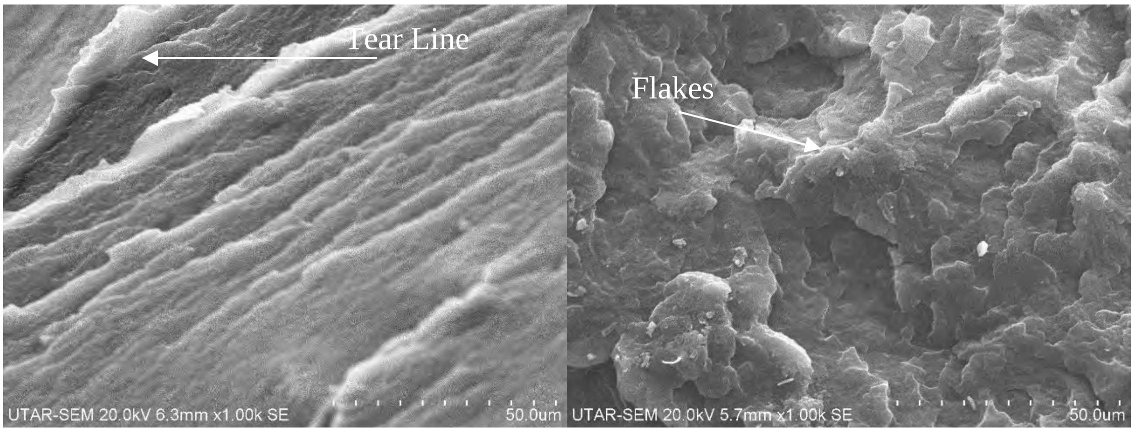
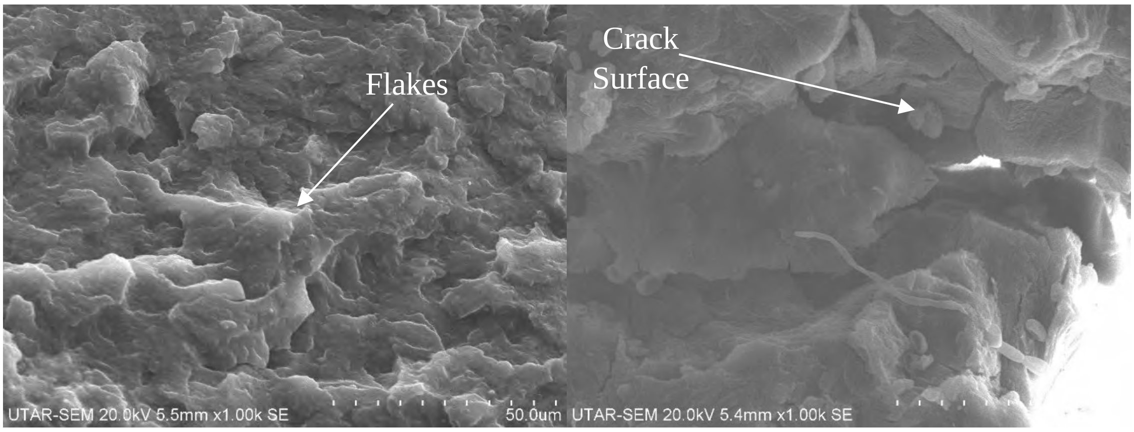


(a) 0 kGy (0 Month) (b) 0 kGy (6 Months)



(c) 50 kGy (0 Month) (d) 50 kGy (6 Months)



(e) 200 kGy (0 Month) (f) 200 kGy (6 Months)

SEM Micrographs of Fractured Surface for Different Irradiation Dosages of 5 phr DVC added in PP before and 6 Months Outdoor Exposure under Magnification of 1000x.

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ORGANIC CARBON CYCLING AND STABILIZATION IN PADDY SOILS PROBED BY FE K-EDGE X-RAY ABSORPTION SPECTROSCOPY

Danilo OLIVEIRA DE SOUZA

Elettra Sincrotrone Trieste, Trieste, Italy

Beatrice GIANNETTA

Department of Biotechnology, University of Verona, Verona, Italy

Paddy soils experience long-term redox alternations affecting the interactions between the biogeochemical cycling of iron (Fe) and carbon (C). Differences in particle aggregation and soil organic matter (SOM) turnover are likely to both affect and be affected by the trajectory of Fe mineral evolution/crystallinity with redox fluctuations. Evaluating the mechanisms for organic carbon (OC) stabilization in paddy soils still deserves attention particularly due to the complex interactions between C cycling and changes in the contents and mineralogy of hydrous Fe oxides in redox-active systems.

We evaluated the distribution of Fe species and organic C between different aggregate and particle-size fractions in topsoil (eluvial) and subsoil (illuvial) horizons of soils under long-term paddy and non-paddy management in NW Italy, as well as mineralogical changes in Fe phases by Fe K-edge Extended X-ray Adsorption Fine Structure (EXAFS) and X-ray Absorption Near Edge Structure (XANES) spectroscopy (Fig. 1).

Our findings [1] have shown that although paddy topsoils show higher contents of particulate OC in the coarser size-fractions with respect to non-paddy soils, most of the soil organic carbon is associated with the finer soil fractions, not only in the topsoil but also in the subsoil. This suggests that the management-induced differences in C stocks is not primarily due to the limited decomposition of crop residues under paddy management, but rather to the redox-driven changes in the association of OC with soil minerals. We show that OC stabilization through interaction with minerals is also affected by microaggregate stability. Paddy management may lead to microaggregate breakdown with a preferential release of clay-sized particles rich in both Short-Range Order Fe oxides and OC, while intra-microaggregate fine silt-sized particles may also serve as an important OC sink. Long-term alternating redox conditions generally resulted in paddy topsoil horizons that were depleted in pedogenic Fe with respect to non-paddy soils and led to a redistribution of Fe phases across different particle size fraction often as less crystalline phases (primarily ferrihydrite and Fe-OM associations). Nonetheless, the higher C contents indicate that higher C loadings can be achieved under these redox-dynamic environments. Moreover, illuvial horizons under paddy management were enriched in SRO hydrous Fe oxides and this contributed to enhanced microaggregate formation and C stabilization with respect to non-paddy subsoils.

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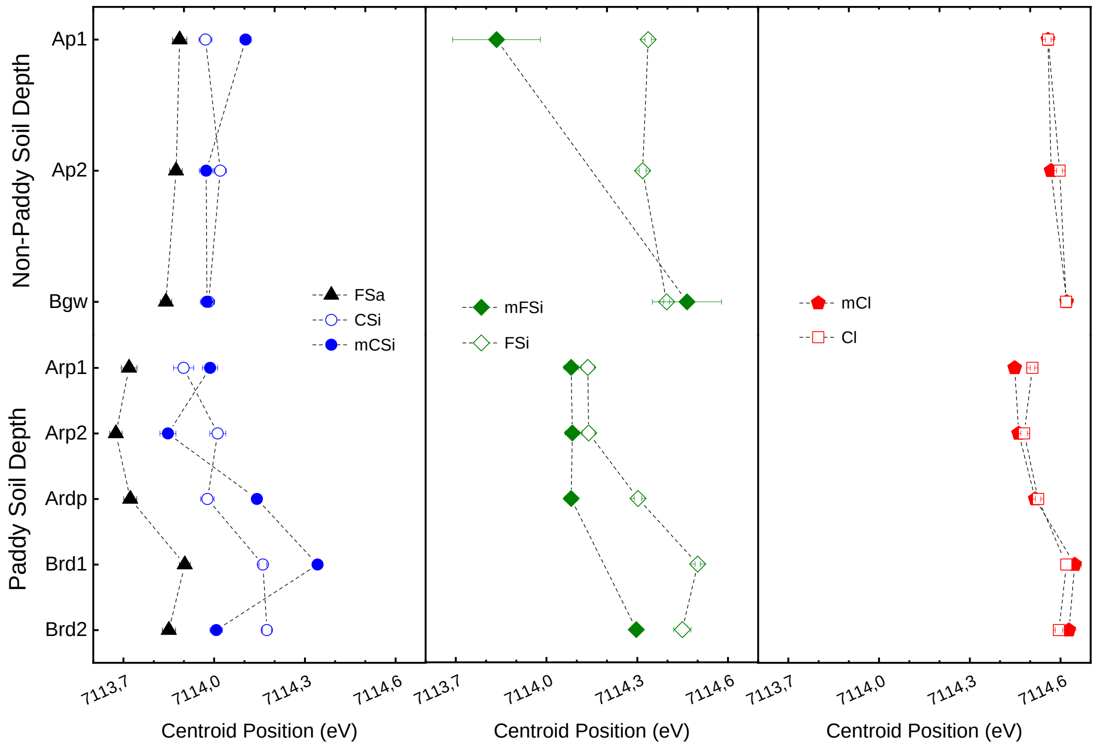

FIG. 1. Changes in average Fe oxidation state according to the pre-edge peak centroid position by fractions in paddy and non-paddy soil as function of soil depth.

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MOBILE FACILITY FOR GAMMA-ACTIVATION ANALYSIS OF GOLD ORES

V.G. GOSTILO, A.D. SOKOLOV
Baltic Scientific Instruments, Riga, Latvia

M.I. DEMSKY
CORAD, St-Petersburg, Russia

The results of the development of "Au-Isomer", a facility for gold bearing ores' gamma-activation analysis (GAA) for the mining industry, are presented. The facility is designed as a mobile one, its design allows disassembling the GAA unit and transporting it to another mine in four 40-foot containers. The irradiation system of the "Au-Isomer" GAA facility was created on the basis of linear electronic accelerator (LINAC) УЭЛР-8-10А, which was maximally adjusted to the tasks of gamma-activation analysis. LINAC generates an electron beam with a power of up to 10 kW and an electron energy of 7-9 MeV, allowing to adjust the energy of electrons in this range. The feature to adjust the energy of electrons for the analysis of elements in ores makes it possible to optimize sample irradiation conditions, so as to suppress associated element lines that may overlap with gold lines in the GAA spectrum. In turn, this allows to increase the accuracy of determining gold in the ore and to reduce the limit of its detection.

To ensure high stability of LINAC operation, an original electron beam stabilization scheme has been added, reducing the spread of its intensity to less than 2%. Constant control of the beam current and the electron energy is carried out, providing a visualization of parameters in the operator's program window. The electron accelerator is cooled by a chiller-based cooling system. The accelerator is powered by a three-phase circuit 380/220 V, 50 Hz; maximum power consumption of the GAA is 70 kW/h.

To ensure low detection limits and high accuracy in determining the concentration of elements in ores, the "Au-Isomer" GAA facility uses a two-channel precision spectrometric system for detection gamma radiation with large-area HPGe detectors (D = 110 mm). The results of using the facility for the quantitative analysis of gold bearing ores are presented. The values of gold detection limit (3σ), measured from the spectra of certified reference samples with a low background level, were 0.026-0.028 ppm with a single irradiation. In this case, the root-mean-square measurement error for a gold concentration of 1 ppm did not exceed 8%, and for a concentration of 10 ppm - 4%. The "Au-Isomer" provided the analysis of coarse samples (1-3 mm) with a capacity of at least 65 samples per hour.

The spectra of real samples of gold bearing ores with the presence of various associated elements have been investigated. Our results, obtained on real ore samples, confirmed the effectiveness of the following elements' analysis: Au, Ag, As, Ba, Br, Cd, Ge, Hf, Pb, Se, Th, U, Y and W. The presented spectra clearly demonstrate the possibility of analyzing the concentration of these elements when creating appropriate measurement procedures . In the process of measuring the spectra, it was noted that the main contribution to the background pedestal, on which the peaks of gold, silver, hafnium and other related elements are located, is given by the products of photofission of uranium and thorium. Therewith, the content of uranium in the presented ore samples is estimated by us as ~ 40-50 ppm, thorium ~ 100 ppm, barium ~ 300 ppm, yttrium ~ 200 ppm. The report presents real spectra of gold-bearing ores' samples with peaks of gold at 130 and 279 keV, and peaks of the accompanying elements.

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NEUTRON INDUCED FISSION STUDIES AT NCSR "DEMOKRITOS" BY THE NTUA

V. MICHALOPOULOU

National Technical University of Athens, Zografou/Athens, Greece

Fission is one of the most challenging and not well-known phenomena in nuclear physics and, at present, an ab initio theory able to predict fission cross sections as well as the characteristics of the fission process does not exist. The theoretical investigation of the cross section for the fission channel is mainly based on phenomenological analyses with parameters that need to be tuned in order to reproduce the experimental data. Thus, highly accurate data are needed for the testing of the existing nuclear models and consequently for the improvement of their predictive power. Furthermore, the development of the new generation of nuclear reactor technology, which aims at safer and cleaner energy production, requires highly accurate cross-sectional data of all the neutron-induced reactions mainly on minor actinides.

The neutron beam facility of the 5.5 MV Tandem T11/25 Accelerator Laboratory of the NCSR "Demokritos" has been extensively used over the past 10 years for fission cross section measurements on various actinides (^{237}Np, ^{234}U, ^{236}U, ^{232}Th), at and above the fission threshold [1-7]. All these isotopes are very important for the design of advanced nuclear systems for a more clean and safe future energy production as well as for the dissemination of nuclear waste. The neutron beam is produced via the ^{7}Li(p, n), the ^{3}H(p,n), the ^{2}H(d,n) and the ^{3}H(p,n) reactions, depending on the energy range of interest. The neutron flux (of typically 10^5-10^6 n/cm^{2}s) is calculated by means of the reference ^{235}U(n,f) and ^{238}U(n,f) cross sections. Special attention is given to the study of the neutron beam (monochromaticity, propagation of neutron beam among the targets etc.), due to the lack of effective threshold for the fission cross section, via detailed Monte Carlo simulations and experimental checks. The detection system consists of a stack of ionization gas cells based on the Micromegas Microbulk technology [8] for the detection of the fission fragments (FF). The mass and homogeneity of the actinide targets used are characterized by means of alpha spectroscopy and Rutherford Backscattering spectrometry, respectively.

The final experimental points, which are made publicly available at the scientific community via the EXFOR database, have low uncertainties of the order of 5%.

An overview of the experimental campaign, the description of the setup and the analysis as well as the future perspectives will be presented and discussed.

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NEUTRON INDUCED FISSION CROSS SECTION MEASUREMENT OF 241-AMERICIUM AT THE NTOF FACILITY

Z. ELEME, N. PATRONIS
Department of Physics-University of Ioannina, Ioannina, Greece

The n_TOF Collaboration
European Organisation for Nuclear Research (CERN), Geneva, Switzerland

High accuracy cross section data of neutron-induced reactions of minor actinides are needed over a wide energy range for the feasibility, design and sensitivity studies on innovative nuclear reactors (Accelerator Driven Systems-ADS and Generation IV fast neutron reactors). The concept of these systems is to incinerate/transmutate the existing actinides found in high-level nuclear waste. Representing almost 1.8% of the minor actinide mass in spent PWR UOx fuel, the ^{241}Am isotope ($T_{1/2}$ =433 y) is considered one of the possible candidates for incineration/transmutation. On top of that, its production rate increases within the spent fuel through the β-decay of ^{241}Pu ($T_{1/2}$ =14.3 y). Consequently, the accurate determination of the fission reaction rate of ^{241}Am over an extended energy range is of prime importance.

In the present work, the ^{241}Am(n,f) reaction cross section was measured with micromegas detectors at the vertical experimental area of the n_TOF facility at CERN using the time-of-flight technique. For the measurement 6 samples of ^{241}Am were used along with 2 samples of ^{235}U and 2 samples of ^{238}U that were used as a reference. In this contribution, an overview of the experimental set-up is given. Preliminary results will also be presented and compared with previous data and nuclear data evaluations.

THE EFFECTS OF STERILIZATION IRRADIATION ON PROPERTIES OF COMMERCIALLY AVAILABLE PET MATERIALS USED IN THE PRODUCTION OF VACUUM TUBES FOR BLOOD SAMPLING

[1]V.A. SHARAPOVA, [1]V.Yu. IVANOV, [1]O.N. RYABUKHIN, [2]V.P. SHVEYKIN, [2]I.S. KAMANTSEV

[1]*Ural Federal University, Yekaterinburg, Russia*

[2]*The Institute of Engineering Science, RAS (Ural Branch), Ekaterinburg, Russia*

Blood test collection systems are typically polymeric or made of glass. However, glass test tubes can easily break, blood can spill, or some of the blood can be absorbed into the cotton swab that covers the tube. PET vacuum blood collection systems do not have this drawback. All system components (the tube, the needle and the holder) are disposable. Such systems are lighter than glass ones and are much less traumatic. However, due to PET thermal sensitivity, these products require “cold” sterilization methods, such as ethylene oxide (EtO) treatment or radiation. Ethylene oxide is a highly toxic and carcinogenic gas. The products are placed in a container filled with EtO, heated to 80-100 C. After the eight-hour exposure the gas was evacuated, and the product is ventilated for several days. Radiation sterilization is "cleaner", faster, does not require opening the original packaging and even shipping containers [1].

This research is focused on investigation of electron beam irradiation effects on PET polymers commonly used in medical devices, specifically vacuum tubes for blood sampling. Irradiation was done using 8.5 MeV electron beam, with total doses ranging from 5 kGy to 25 kGy. The first step of the project was to determine the sensitivity of the infrared (IR) spectroscopy method [2] when studying changes in the physical properties of the tube material.

The revealed post-radiation changes in the IR spectra [3] can be useful for determining the degradation of PET products properties during radiation sterilization with electrons. Electron paramagnetic resonance (EPR) spectrometry is planned to be carried out to obtain information on the concentration of forming radicals in PET, which in turn reflects chemical transformations. We also plan to investigate the effect of radiation sterilization on mechanical properties of products immediately after sterilization and later, to investigate their shelf life.

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NEUTRON INDUCED FISSION STUDIES AT THE CERN N_TOF FACILITY

M. DIAKAKI
National Technical University of Athens, Athens, Greece
for the n_TOF collaboration

The study of neutron-induced fission is important in a variety of fields of basic and applied nuclear physics. For fundamental research it provides important information on properties of nuclear matter and fission process, while for cutting-edge nuclear technology it is a key ingredient for the design and operation of current and innovative nuclear reactors as well as for the transmutation of nuclear waste and nuclear fuel cycle investigations.

The n_TOF neutron time-of-flight facility makes use of the CERN Proton Synchrotron accelerator. It became operational in 2001 and provides pulsed neutron beams with high instantaneous neutron flux, based on the spallation induced by 20 GeV/c bunches of $7-8 \times 10^{12}$ protons impinging on a massive lead target. The facility has undergone a major upgrade during the recent long shutdown of CERN and a new spallation target has been successfully installed and commissioned during autumn 2021.

A major part of the scientific program of n_TOF involves the study of neutron-induced fission reactions, in order to provide high-accuracy and consistent experimental data on fission cross sections and other fission observables over a wide neutron energy range, from thermal to GeV ([1] and references therein, [2-4]). Depending on the actinide and the observable(s), either the experimental area 1 (EAR1), located at approximately 200 m distance from the neutron production point, or the new experimental area 2 (EAR2), located at approximately 20 m on top of the lead target, are utilised. The long flight path of EAR1 provides excellent energy resolution and wide neutron energy range, reaching the GeV region. The EAR2 is typically preferred when high activity or very low mass actinide targets are available and/or when the cross section is very low, or even unknown, thanks to the very high flux with respect to EAR1. Various experimental setups are used, depending on the observables to be measured [1]. A long series of isotopes have been studied from the natural Pb and Bi to the actinides ^{230,232}Th, ^{233,234,235,236,238}U, ^{237}Np, ^{240,242}Pu, ^{241,243}Am, and ^{245}Cm. The neutron induced fission cross section datasets, typically measured relative to a standard reaction (such as ^{235,238}U(n,f), ^{10}B(n,α), ^{7}Li(n,t), n-p scattering [5]), are made publicly available to the scientific community via the IAEA EXFOR database.

An overview of the fission studies performed will be presented and discussed, with a short description of the latest highlights, the various detection systems and data analysis techniques used, as well as the future perspectives of fission measurements at n_TOF. Emphasis will be also given to the innovative characteristics of the new spallation neutron source, the unique features of the PS accelerator in terms of energy, intensity, and duty cycle of the primary beam, that allow to collect high-accuracy, high-quality nuclear data.

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TOWARDS DETECTION AND IDENTIFICATION OF LEAD IN AEROSOL SAMPLES COLLECTED IN AN URBAN AREA IN AMMAN, JORDAN

H. SA'ADEH
Department of Physics, The University of Jordan, Amman, Jordan

M. CHIARI
INFN, Division of Florence, Florence, Italy

S. POLLASTRI, G. AQUILANTI
Elettra-Sincrotrone Trieste, Trieste, Italy

Air pollution is considered one of the most challenging environmental issues, as it has harmful effects on the ecological system and human health. These effects are mainly attributed to particulate matter (PM) properties like the particle size and chemical composition. Over the last few years the University of Jordan, Amman, Jordan, has been interested in studying the characteristic features of atmospheric aerosols in the framework of the International Atomic Energy Agency (IAEA) regional technical cooperation projects (IAEA TC projects RAS0072, RAS0076, and RAS0078) for ARASIA member states [1, 2]. Within the scope of these projects, aerosol samples have been collected on Teflon filters on a sequential basis (24 hr-sampling, 2-3 times a week). The elemental composition has been determined using particle-induced X-ray emission (PIXE) technique, either under vacuum using the PIXE-RBS beamline in the University of Jordan Van de Graaff Accelerator (JUVAC) [1] in Amman, Jordan, or using the external beam PIXE setup of the Tandetron accelerator of INFN-LABEC laboratory in Florence, Italy [2, 3].

Most recently, using the IAEA X-ray spectrometry (IAEAXspe) endstation [4] at the XRF beamline of Elettra-Sincrotrone Trieste in Italy, we have obtained further insights into the characteristic features of atmospheric aerosol samples collected from Jordan. The oxidation state of selected elements have been investigated using X-ray absorption near-edge structure (XANES) technique. The oxidation state of an element gives important information about its toxicity and environmental activity.

Of particular interest to us is lead, one of the harmful traces in Jordan aerosols, due to its ecotoxicity and human toxic potential. Lead (Pb) is a carcinogenic element, often comes from gasoline related to automobile and vehicular sources. The results obtained by PIXE analysis of aerosol samples from Amman [2, 3] clearly show that there is non-negligible emission of lead into the atmosphere, but they give limited or no information about its chemical state. In this contribution we review the elemental composition of aerosol samples from Amman obtained by PIXE, and we report on the first XANES results, which provide further insights about the chemical structure of Pb.

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PERFORMANCE COMPARISON OF METHODS FOR THE DETECTION OF ^{10}Be AT THE HELSINKI AMS FACILITY

B. C. GONSALVES, K. MIZOHATA, K. HELARIUTTA, P. O. TIKKANEN, F. TUOMISTO, J. A. RÄISÄNEN

University of Helsinki, Helsinki, Finland

Accelerator mass spectrometry (AMS) is used for the measurement of ultra-low isotope ratios, emphasizing long half-life radionuclides, applications reducing the carbon footprint, and raising the socio-economic impact of sustainable development. ^{10}Be with a half-life of 1.4~Ma is a naturally occurring radionuclide of cosmogenic origin with a wide range of applications, among others, in geological and environmental sciences supporting research and climate monitoring. AMS can separate interfering isobars, and measurement of ^{10}Be/^{9}Be ratios at the level 10^{-16} or below is also possible [1]. At the University of Helsinki, we have a 5 MV tandem accelerator that is routinely used for ^{14}C dating. In an ongoing project, we are developing the capability of our tandem accelerator to measure ^{10}Be. In this work, different detection systems, which can separate atomic and molecular isobars, are studied. These detection systems were tested during the first measurements using neutron activated BeO samples.

We investigated the response of two detector systems, namely, a Si detector and a gas ionisation detector with and without absorbers for the B and Be ions. We have carried out simulations of the effect of absorbers using SRIM. In the experimental setup, passive and active absorbers were placed in front of the detector in a vacuum chamber. As a passive absorber, we used Havar foils with a thickness range of 2 – 10 μm, and as an active absorber isobutane gas was used. The SRIM output was convoluted with the measured detector response. In this way, we were able to simulate the actual response of the detector system with absorbers. By a combination of experimental and simulated results, we were able to find out which detector type, together with what thickness of the absorber, would be ideal.

Through our previous work [2], we have determined the charge state to have the highest yield of Be through our tandem accelerator. By selecting the +2 charge state and a terminal voltage above 4MV, we obtain the best transmission of ^{10}Be through our system, dependent on the molecular background. Thus, in order to measure ^{10}Be, a proper detection system is required. The competing B-Be isobars were measured showing good energy separation. Isotopic ratios of ^{10}Be/^{9}Be were measured and compared to standards. To conclude, we make performance comparisons of the Si detector and a gas ionisation detector with and without passive absorbers in the context of ^{10}Be AMS. These results will be useful to the AMS community and can be used as a guidepost for ^{10}Be AMS. We report on first ^{10}Be AMS measurements from standards and activated BeO.

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ACCELERATOR APPLICATION IN MALAYSIA TO CLOSE THE GAP IN REALIZING SDG3

SITI NAJILA MOHD JANIB
Malaysia Nuclear Agency, Kajang, Selangor, MALAYSIA

MUHAMMAD FAKHRURAZI BIN AHMAD FADZIL
National Cancer Institute, Putrajaya, WP Putrajaya, MALAYSIA

Nuclear medicine in Malaysia began initially with the use of radioiodine and radiophosphate for the investigation and treatment of thyroid and blood disorders around 1960. Since these early years, its scope has expanded from just providing diagnostic services, to the present therapeutic and also interventional nuclear medicine.

The nuclear medicine services began its operation as a unit in the department of Radiotherapy in Kuala Lumpur Hospital and in the next 30 years only 3 additional centres began operation within the Klang valley. It is only in the 1990's that more centres were setup due to the advancement of nuclear medicine technologies both in the hardware and computerization.

At present, there are 33 nuclear medicine facilities (government and private) in Malaysia offering general nuclear medicine services and/or positron emission tomography computed tomography (PET/CT). The mushrooming of these centres, particularly with the utility of PET/CT, has strengthened the role of the nuclear medicine discipline in the management of oncology cases in Malaysia.

The Ministry of Health installed the country's first PET/CT camera in 2005. In the following year, the first cyclotron was commissioned. The assistance and support of the IAEA was invaluable in realising this early endeavour. From this humble beginning it served as an impetus for the development of similar facilities in Malaysia. To date five cyclotron (<18MeV) facilities specifically for use in nuclear medicine have been established. With the introduction of Positron Emission Tomography (PET), the setting up of cyclotron facility and the use of targeted delivery agents for imaging and therapy, the possibility of achieving earlier, more accurate and more specific diagnosis, promises significant improvements in clinical outcomes. This increasing insight into the molecular origins of disease, the visualization of pathological changes at the cellular and biochemical level, before physical changes is observed has reshaped the whole pattern of healthcare.

The use of PET and SEPCT radiopharmaceuticals in Malaysia is growing significantly owing to the demand for non-invasive diagnosis and effective cancer treatment. A surge in incidences of cancer, cardiovascular diseases, and other chronic diseases, a rise in the geriatric population, and increasing demand for targeted cancer treatment is propelling the need for nuclear imaging techniques and radiopharmaceuticals.

To be current with existing medical procedures and accelerator technology, Malaysia has plans to expand into higher energy machines. With the establishment of such a facility in the country, it can further broaden Malaysia's capability to produce various types of radioisotopes that will be used in nuclear medicine. This will enhance the accuracy and diversification of the types of treatments that can be offered to patients.

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DESIGN OF THE SWEEPER MAGNETS FOR THE HIGH-POWER BOMBARDMENT STATION FOR RADIOISOTOPE PRODUCTION AT iTHEMBA LABS

J.P. MIRA, A.H. BARNARD, H. ANDERSON, I.L. STRYDOM, J. BROODRYK, J. ABRAHAMS

iThemba LABS, Cape Town, South Africa

iThemba LABS is in the process of expanding its existing facility in the Western Cape in order to increase the production of medical radioisotopes. The basis for this expansion is the acquisition of a new 70 MeV cyclotron, which is phase one of the South African Isotopes Facility (SAIF). The cyclotron will be installed in the existing concrete vaults and will be connected to the newly upgraded radioisotope production infrastructure.

Four high-power bombardment target stations will be installed in two opposite vaults for the production of radioisotopes, with each vault hosting two target stations. Due to power dissipation in the vacuum windows and the target, heat spots can form during irradiation, which might cause the window or the target to break. In order to reduce the heat spots, two H-type dipole magnets are designed and will be installed on each of the four beamlines. The magnets will each be powered by a 2.4 kHz AC power sources with a 90° phase difference between the vertical and horizontal magnets. These magnets will sweep the beam in a circular pattern with a radius of 20 mm on the target surface. In order to prevent eddy currents flowing in the yoke, high magnetic permeability and low loss Manganese-Zinc (MnZn) soft ferrite material will be used to build the magnet yoke. The presentation will discuss the design of magnet yoke, coils, electronic setup and magnetic field simulations of the sweeper magnets.

MODELLING OF THE RADIATION AND SHIELDING AT THE SOUTH AFRICAN ISOTOPE FACILITY USING FLUKA

A.H. BARNARD, P. BEUKES, J.I. BROODRYK, G.F. STEYN, I.L. STRYDOM
iThemba LABS, Cape Town, South Africa

The South African Isotope Facility (SAIF) is a radioisotope production facility currently under construction at iThemba LABS in Cape Town. A commercial 70 MeV proton cyclotron from IBA with a number of beam lines equipped with isotope production stations, are being installed in retrofitted concrete vaults. The completion of SAIF will greatly increase the radioisotope production capability of iThemba LABS, and enable the existing Separated Sector Cyclotron to be dedicated to nuclear research activities.

As part of the design process of the SAIF facility, radiation and shielding calculations were performed using FLUKA to assess the expected dose levels for radiation safety purposes. An overview of the simulations is provided, discussing the FLUKA setup and initial validation simulations performed to gain confidence in the results. A more detailed discussion of some specific systems is given, specifically:

- A multi-layered iron-wax-lead neutron shielding of the isotope production stations;
- A louvre type shield for use in pre-existing air ducting labyrinths;
- Access labyrinths used by a robotic target transport system;
- Radiation leakage through gaps between the concrete roof beams in the vaults.

As part of an experimental validation campaign an experiment to assess the leakage rate between the roof beams in an existing vault was performed and this is compared to the FLUKA predictions.

NEAR at n_TOF/CERN: THE FIRST MULTI-FOIL ACTIVATION MEASUREMENT

M.E. STAMATI
European Organization for Nuclear Research, Geneva, Switzerland

N. COLONNA
Istituto Nazionale di Fisica Nucleare, Bari, Italy

A. MENGONI
Agenzia Nazionale per le Nuove Tecnologie, Bologna, Italy

N. PATRONIS
University of Ioannina, Ioannina, Greece

The n_TOF facility at CERN is a facility designed to study neutron induced reactions. It is based on a pulsed proton beam impinging on a lead spallation target and it consists of two flight paths. The NEAR Station is a newly developed experimental zone, located at a distance of only ~3m from the spallation target and just outside the target-moderator assembly's shielding wall [1]. The aim of the n_TOF NEAR Station is to take advantage of the extremely high neutron flux to perform measurements of MACS (Maxwellian Averaged Cross Section) mainly for nuclear astrophysics purposes but also for measurements important for other scientific fields such as fusion technology [2]. In all of the aforementioned cases, the neutron activation technique is going to be employed.

Although extensive simulations have been performed to obtain the characteristics of the neutron beam at NEAR, the newly built experimental area remains unexplored experimentally. Therefore, it is of utmost importance to identify the neutron beam flux and energy distribution prior to initiating any actual research activity. For this reason, a multi-foil activation project has been launched.

In the present work, the preparation and realisation of the first multi-foil activation measurements will be presented along with their preliminary results. The reactions under study were selected according to the cross-section's dependency on neutron energy as well as the product nucleus half-lives. Various reactions with different resonances have been considered for the characterisation of the thermal and epithermal energy regions while for the characterization of the fast neutron energy range threshold reactions were utilised. After the irradiation, the induced activities of the samples were measured using a 27% relative efficiency HPGe detector and compared to the simulations.

In this presentation, the newly constructed experimental area will be presented along with the first set of multi-foil activation measurements. The experimental results will be compared to the simulations and the first conclusions drawn on the neutron flux will be discussed.

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A COMPREHENSIVE OVERVIEW OF THE UNIVERSITY OF JORDAN VAN DE GRAAFF ACCELERATOR (JUVAC)

R. HASAN, H. SA'ADEH
Department of Physics, The University of Jordan, Amman, Jordan

Since 1983, the University of Jordan Van de Graaff accelerator (JUVAC) has been established as the first and unique, till now, ion beam analysis (IBA) facility in Jordan. It is equipped with a 4.75 MV single-ended Van de Graaff accelerator from High Voltage Engineering Company in vertical configuration. Being the first and only particle accelerator in Jordan at that time, it attracted many interested scientists specialized in various fields. However, nowadays there are less scientists/users in Jordan conducting research at this fantastic facility.

It is quite understood that the techniques used to run a particle accelerator as JUVAC have its roots in many core-level subjects of physics. Its basic principle of operation is simple enough to be sketched on a board in a freshmen physics course, but it is nevertheless robust enough to be imagined by undergraduate students! Being motivated by this fact, graduated and undergraduate physics students from the University of Jordan (UJ) joined the facility recently and took part in some IAEA projects running in Jordan. Among those students is the presenter of this contribution (Fig. 1).

This contribution aims to provide a comprehensive overview of the JUVAC facility; starting from its early history up to its current challenges and capabilities, describing its accelerating machine and presenting a literature survey of major scientific studies came out of JUVAC experiments over the years until now.

FIG. 1. Ruba Hasan (Physics undergrad, JUVAC, UJ).

THE PROOF-OF-CONCEPT RESULTS: DEVELOPMENT OF HYBRID ELECTRON ACCELERATOR SYSTEM FOR THE TREATMENT OF MARINE DIESEL EXHAUST GASES

Toms TORIMS, Guntis PIKURS
Riga Technical University, Riga, Latvia

Andrzej G. CHMIELEWSKI, Yongxia SUN, Andrzej PAWELEC, Zbigniew ZIMEK
Institute of Nuclear Chemistry and Technology, Warsaw, Poland

Goesta MATTAUSCH
Fraunhofer FEP, Institute for Organic Electronics, Electron Beam and Plasma Technology Dresden, Germany

Maurizio VRETENAR
CERN, the European Organization for Nuclear Research, Geneva, Switzerland

This paper provides comprehensive analysis of the proof-of-concept results and for the very first time offers complete picture of the novel hybrid e-beam technology capabilities to successfully remove multitude of the hazardous pollutants from the marine diesel engine off-gases. It confirms the feasibility of the particle accelerator system application within the real marine environment. Substantial abatement of the undesirable diesel engine exhaust gases, such as the nitrogen oxides (NO_x) and sulphur oxides (SO_x) as well as particulate matter (PM) and volatile organic compounds (VOC), has been achieved by using electron beam accelerator in combination with the simplified wet scrubber.

Relevance of this research is grounded not only in the effective demonstration of the particle accelerator societal application, but in the knowledge that this can be a tangible technological solution to address the pertinent needs of the maritime industry at large. Today international, regional and national legislation is imposing firm restrictions to the allowed NO_x and SO_x levels, literary within all major maritime trade routes. According to Annex VI of the MARPOL convention [1] SO_2 maritime emissions are limited to 0.5% sulphur content in fuel. In number of major trading areas these emissions are even stricter - 0.1%. Consequently, maritime industry is ensuring its compliance with the regulatory requirements by choosing between:

(a) expensive and in the long run unproven shift form the heavy fuel oil to the marine gasoline (which solves SO_x problem, with NO_x issue remaining); or

(b) by installing on-board exhaust gas abatement systems – scrubbers for SO_x and fuel combustion process modification (engine modifications) or catalytic reduction (SCR) devices for NO_x removal.

Both options are technologically challenging and very expensive. Thus, it is by no means a universal panacea for some 60 000 sea-going ships of the world merchant fleet. The hybrid technology which is being described here, can be viable and cost-effective alternative to the ship owners. Furthermore, virtues of this technology, calculations and empirical results are indicating that also other GHG (e.g. CH_4, N_2O and even CO_2) could be successfully removed from the marine diesel engine exhaust gases. This is very promising avenue since reduction of the GHG is one of the paramount EU priorities within the Green Deal and other similar international initiatives.

Additionally, new restrictions for the PM and VOC levels are in the sight and currently being considered by the global policy makers. Considering global efforts to fight climate change and to significantly reduce pollution caused by the ever-growing maritime traffic, clearly it is just a question of time when stricter GHG emission levels will come in along with requirements to cap the PM and VOC pollutants.

The proof-of-concept pilot project was successfully carried in Port of Riga in Latvia. It was a world premiere where operational sea-going ship exhaust duct was connected to the hybrid off-gases cleaning system, comprising an electron beam accelerator system and sea water scrubber. This was conceivable thanks to the collaborative effort between Riga Technical University, Institute of the Nuclear Chemistry and Technology, Fraunhofer FEP, CERN, Remontowa Marine Design, Milgravja Tehnologiskais Parks - Riga Ship Yard and Biopolinex, within the EU co-funded ARIES proof-of-concept project [2]. This multidisciplinary team embraced know-how and advanced accelerator technology expertise, combined with technical integration and high-end engineering knowledge as well as maritime industry capability.

The conference presentation and eventual scientific paper will explain all technological aspects of the test installation and will outline in detail the obtained results in the NO_2 [3] and SO_2 reduction with the special emphasis to the VOC removal [4]. Economical feasibility results will complement the promising conclusions of the ARIES proof-of-concept project. The next steps will be discussed and potential opportunities shall be delineated.

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SWITCHING IRRADIATION FACILITY IN JORDAN FROM CO-60 TO E-BEAM X-RAY

M. ETOOM, O. NATSHEH
Jordan Atomic Energy Commission, Amman, Jordan

Jordan Atomic Energy Commission (JAEC) is intended to switch the existing Co-60 irradiation facility to an e-beam/X-ray 5MeV irradiation facility, due to the high measures of security of Co-60 sources, as well as increasing prices of Co-60 sources, and the complicity of transportation to the unstable area (Middle East), which has been an issue in recent years. Some stakeholders are financially supportive to the switching mechanism from Co-60 to e-beam/X-ray in order to sustain the irradiation technology. The option of having e-beam/X-ray irradiation technology will allow JAEC to irradiate a wide variety of products no matter the density or dimension of product at high production rate by choosing e-beam or x-ray irradiation.

OBJECTIVE:

The existing facility will be used as e-beam/X-ray facility with some modifications. Source hoisting room will be used for the e-beam/X-ray machine (accelerator), or adding another room beside the existing facility for the accelerator. And for the existing concrete biological shield which must be increased to suit X-Ray applications. The power consumption for both e-beam/X-ray applications will be covered by the existing solar system of 50kW generation capacity to be increased to about 150kW. Also new ware house will be constructed. Modification of biological shield and power consumption will be considered from economical point of view whether it is feasible or constructing new building.

METHODOLOGY:

Biological shield: According to shielding calculations done by: E. Peri and I. Orion, using MCNP Monte Carlo Code [1], it is needed to add about 40 cm for the existing walls of irradiation room (180 cm), which can be done. In case of dimension restrictions lead could be combined with concrete to minimize thickness.

The first option is to get benefit from the existing biological shield, it is assumed to put the accelerator over the irradiation room in the old source hoisting room, using the 90^{o} orientation accelerator, and the ray-tube will pass through the opening of the plug in the ceiling. As the source hoisting room will be used for the e-beam/X-ray machine, so new walls will be constructed over the existing walls. In case of dimension restrictions lead could be combined with concrete to minimize thickness, the top of these wall will be in stairs shape, 20 cm width and height as shown in figure (1). The ceiling will stay opened during commissioning of the e-beam/X-ray machine, after that a precast reinforced concrete slabs will be put to close the ceiling, taking into consideration that the slabs width dimensions is different in each step so that breaks is not continuous through the ceiling.

Even though the possibility to add another room beside the existing facility for the accelerator, as second option, and hole in the side wall for the ray-tube, which can be done by using core (up to 3m) and wire cutting, as shown in figure (1), But this option is costlier than the first one.

Power consumption: There is an existing solar power system of 50kW power (average daily output 250kW/day), which can be extended by adding 100kW, as there is empty place for that, the total power generation will be 750kW/day during the year, and if the holidays are not considered the daily power generation will be 1MW/working day; this will give opportunity to operate 5 hours at full capacity in the working days, which is more than needed.

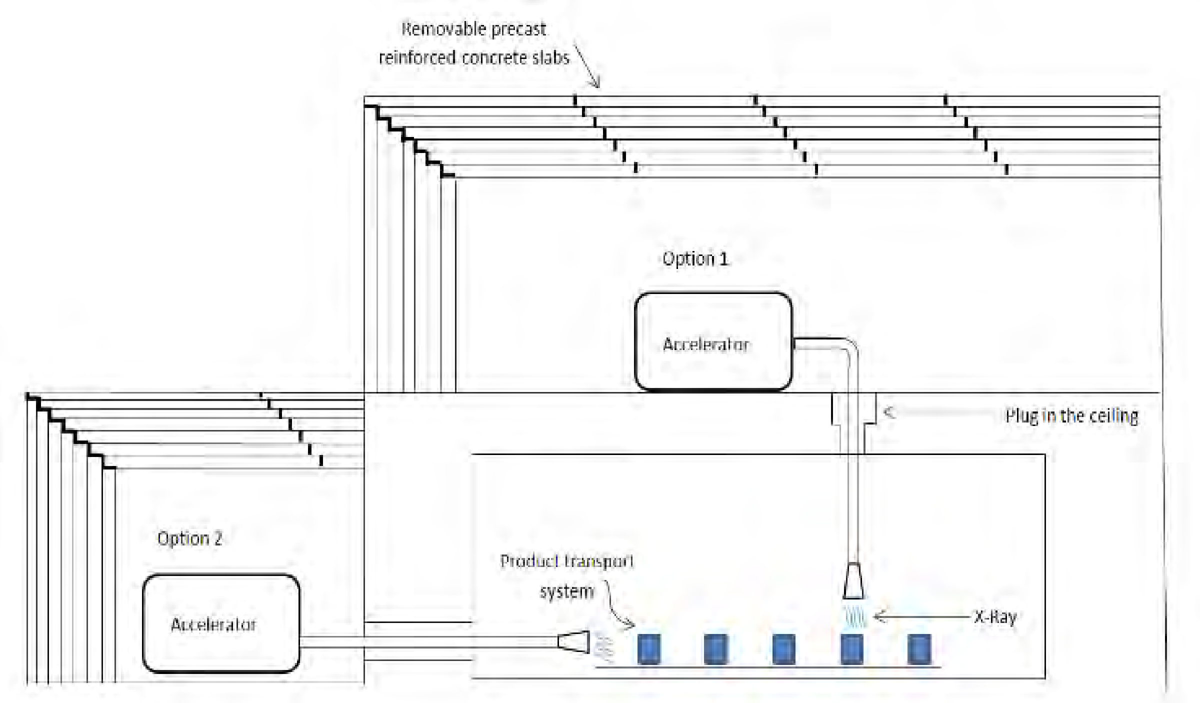

FIG. 1.

RESULTS

The existing facility can be switched to e-beam/ x-ray facility with extra shielding for the walls of source hoisting room, which is less in cost than constructing new building, the existing shield will cover more than 80% of the needed shield. Later the shielding calculations will be done by using MCNP Monte Carlo Code. The solar power generation potential is high in Jordan, so that the switching will be feasible on the long run operation. The new products transport system will be judged later according to the space left, and radiation protection aspects.

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COMPARATIVE ANALYSIS OF SOCIO-ECONOMIC IMPACT IN TWO PARTICLE ACCELERATOR CASE STUDIES

M. GASTROW, A. JUNGSTAND, A. THIELMANN, S. UTERMANN
Facility for Antiproton and Ion Research in Europe, Darmstadt, Germany

There is a paucity of studies looking at the social impact of large research facilities like particle accelerators [1]. Extant research is often indirect, and diverse in its theoretical perspectives - for example, the sociology of knowledge creation in big-science contexts [2], using social constructivism theory to examine impacts of large-scale research facilities [3], and using grounded theory together with theoretical constructs from social network, social capital, and inter-organizational learning theories [4]. One overview of the social impacts of big science found that 'the least understood, yet potentially the most significant aspect of accelerator facilities operates through their broader contributions to society and culture [5]. We are undertaking a comparative case study to better understand how the support offered through formal structured innovation programming has led to impacts such as strengthened innovation ecosystems, commercial applications of innovation, skills development, and broader social goods.

We use extensive interviews to create primary data identifying socio-economic outcomes. We are interested in positive and negative impacts, especially those with a long latency period - which are notoriously hard to quantify and are usually overlooked in the impact literature. In line with the work of M. Castells [6], in which value is created by transforming information into knowledge, we pay particular attention to knowledge spillovers as a socio-economic outcome. Our research identifies markers and criteria appropriate for particle accelerator-based outcomes; this will particularly include 'softer' socioeconomic impacts and the unspoken social impact mandates of accelerators borne of their public and educational nature.

Specifically, we test the applicability and transferability of innovation ecosystem model thinking to particle accelerators, their cultures and their supply chains and examine the extent to which design thinking can be applied to an open knowledge economy. Our study applies a novel spatio-temporal version of the Boisot social learning cycle [7] to innovation research to map the flux and codification of knowledge within the accelerator innovation ecosystem. This will identify the nodes in the system at which codified, abstract and diffuse knowledge is likely to germinate a new learning cycle: critical phases or 'tipping points' in the innovation ecosystem at which interventions are most likely to invoke radical innovation. Our findings are relevant for future innovation policy as well as for future strategic innovation programming at particle accelerators.

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SUPERVISOR WATCHDOG CIRCUIT FOR MONITORING ACCELERATOR BEAM PROPERTIES AND CONTROLLING THE SAFETY INTERLOCK SYSTEM

Iveta STEBLEVSKA, Mark R. DAYMOND
Queen's University, Kingston, Canada

A supervisor watchdog circuit was developed to monitor the dose and temperature in an accelerator beamline and control the safety interlock system of the accelerator. The implementation involved a D-type flip flop and subsequent logic gates to monitor the input and output signal states and used a series of LEDs to inform the user about the state of the system and to enable identification of issues causing the beamline to shut down. The design allowed for a manual circuit restart to be performed to continue signal monitoring and accelerator operation. The minimization of power consumption by the system was considered. The supervisor watchdog circuit will be installed into the tandem accelerator in the Reactor Materials Testing Laboratory at Queen's University to monitor the beam properties during nuclear material irradiation experiments. The scope for future improvements of the circuit such as automatic circuit restart and addition of new signals is discussed.

Keywords: watchdog; accelerator control; control system; accelerator electronics

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AMAZON CERAMICS AND THEIR COLOR PALETTE - THE USE OF ION BEAM ANALYSIS TO DETERMINE THE PIGMENTS

Márcia Almeida RIZZUTTO, Pedro H. O. V. CAMPOS, Cleber L. RODRIGUES, Tiago FIORINI SILVA

Instituto de Física, Departamento de Física Nuclear, Universidade de São Paulo, São Paulo, Brazil

Silvia CUNHA LIMA, Eduardo GÓES NEVES

Museu de Arqueologia e Etnologia, Universidade de São Paulo, São Paulo, Brazil

Rafael ALMEIDA

Museu de Arqueologia e Etnologia, ARQUEOTROP, Universidade de São Paulo, São Paulo, Brazil

Despite of the knowledge and discussion of polychrome ceramics in the Amazon for more than half a century, their material characterization still needs further studies and analysis. The characterization of these ceramics continues to be guided, in most cases, exclusively by the aesthetic aspect (macroscopic) and not by their technological characteristics (microscopic).

In other words, descriptions of polychrome ceramics are often restricted to observing the presence or absence of engobes and/or paints with color mainly determined as white, red and black.

The aim of this work was to characterize the pigments and their use in ceramic decoration in order to collaborate in the identification of specific technological choices made by different cultures and to investigate the variability of materials present that are so characteristic of Amazonian ceramics and their polychromies.

Therefore, archeometric analyzes (PIXE and SEM) were used on a set of polychrome fragments from four archaeological sites in the Central and Northern Amazon region associated with the Polychrome Tradition of the Amazon - Tauary, Conjunto Villas, Vila Nova II and Hatahara. The proposed analysis with ion beams comes from the better ability to separate the pictorial layers and thus better study the manufacturing technology of this set of ancient ceramic fragments. Measurements were performed with proton beams in the particle accelerator of the Institute of Physics of the University of São Paulo and elements such as P, K, Ca, Ti, Fe and Mn were identified in the different pigments and their correlations will be discussed.