19TH INTERNATIONAL MEETING ON RADIATION PROCESSING | STRASBOURG, FRANCE | APRIL 1-5, 2019

Report

The Business and Science of Radiation Processing in 2019

IMRP19 STRASBOURG

iia INTERNATIONAL IRRADIATION ASSOCIATION

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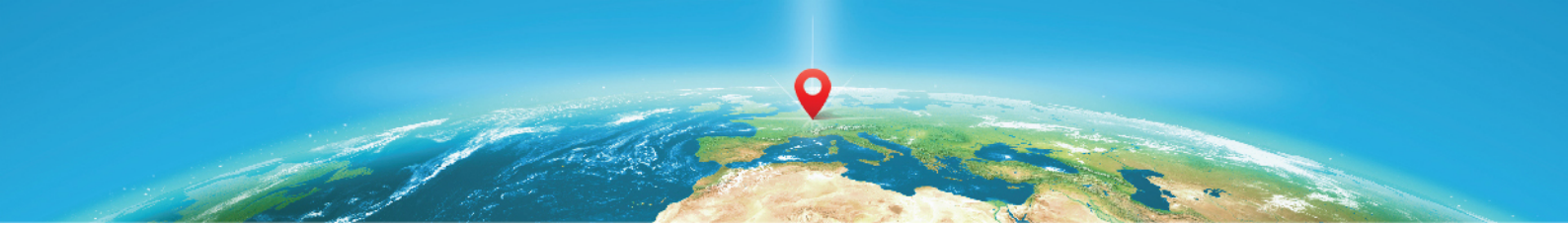
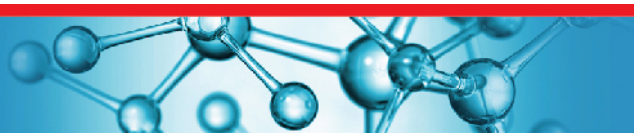




Introduction

FOREWORD

The 19th edition of the International Meeting on Radiation Processing (IMRP 19) was organized by the International Irradiation Association (iia) and held in Strasbourg, France during the first week of April 2019.

In the past, the scientific communications and posters presented at the conference have been published in a special issue of the Journal of Radiation Physics and Chemistry. This will also be the case for IMRP 19 but the iia decided to produce this complementary publication in order to provide a more holistic overview of the science and business of radiation processing.

The present publication has three major objectives:

- To be a reference document for those who participated in IMRP 19 as well as for those who could not attend the conference;
- To document and make some of the non-scientific contents of IMRP 19 available to a larger audience;
- To provide a picture of the state of The Business and Science of Radiation Processing at the time of the conference.

Summarizing a conference that was very rich in information, content and activities is a challenge. As a consequence, choices had to be made to select content and opinions had to be summarized. This publication does not claim to address every aspect of IMRP19, but we hope that the readers will find it valuable summary of the state of radiation processing at the time of IMRP19.

We look forward to receiving your comments and suggestions on this document so that we can determine if you find the publication useful. The comments that we receive will guide a decision regarding future post IMRP publications.

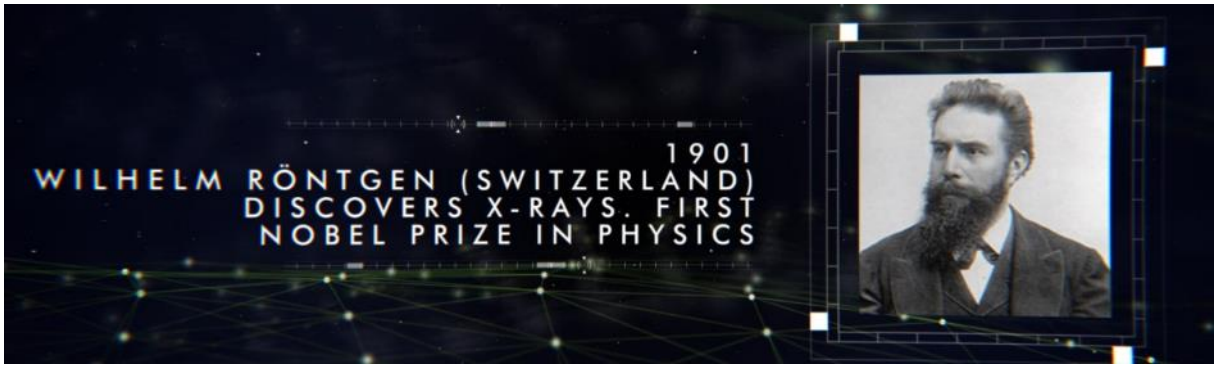
Paul Wynne

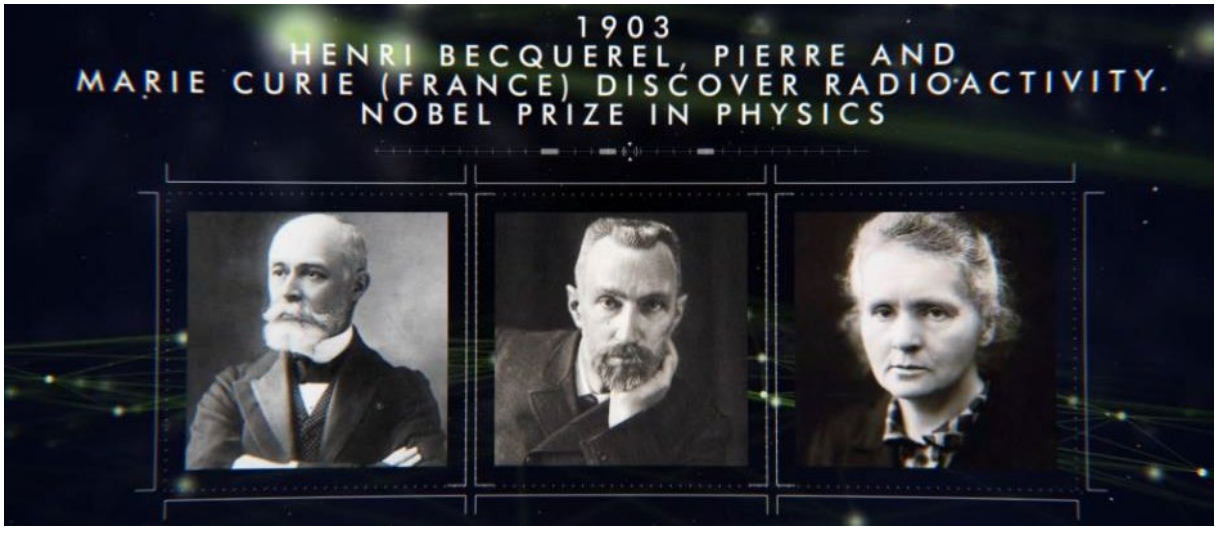
Chairman of the IMRP 19 Conference



FROM SCIENCE TO INDUSTRY: A TRIBUTE TO THE PIONEERS OF IRRADIATION

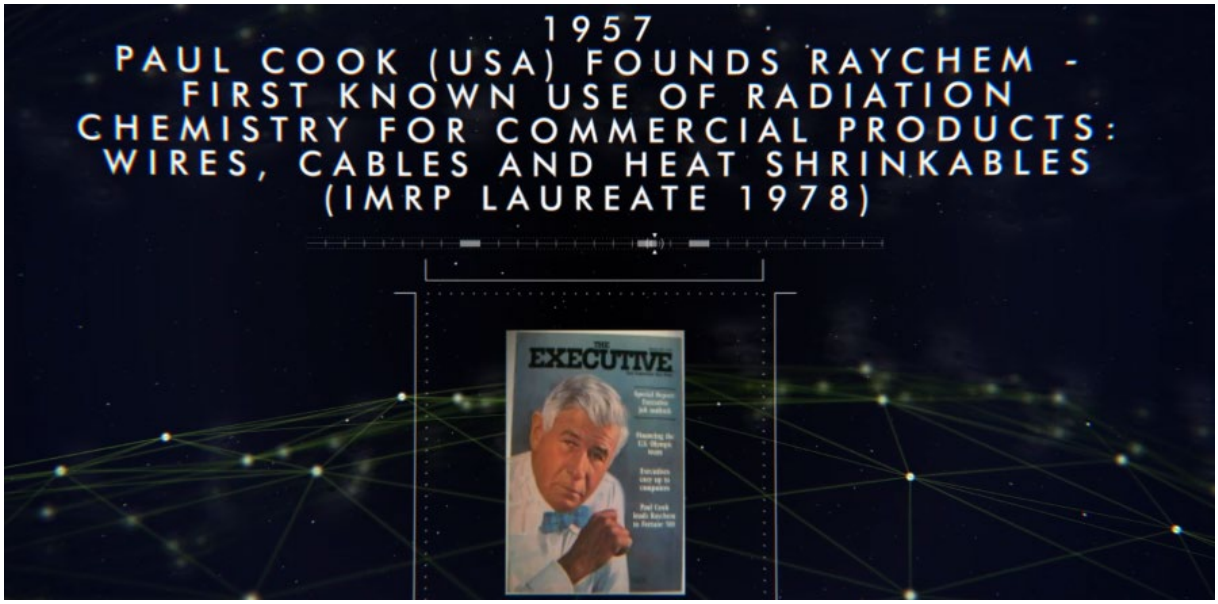
The following pictures are extracts from the video played in the introduction to IMRP 19. Irradiation has its origins in the pioneering work of leading scientists and academics from the 19th century onwards. The applications of irradiation continue to evolve and to benefit our planet and its people as a result of the actions and hard work of those involved in the business and science of irradiation.



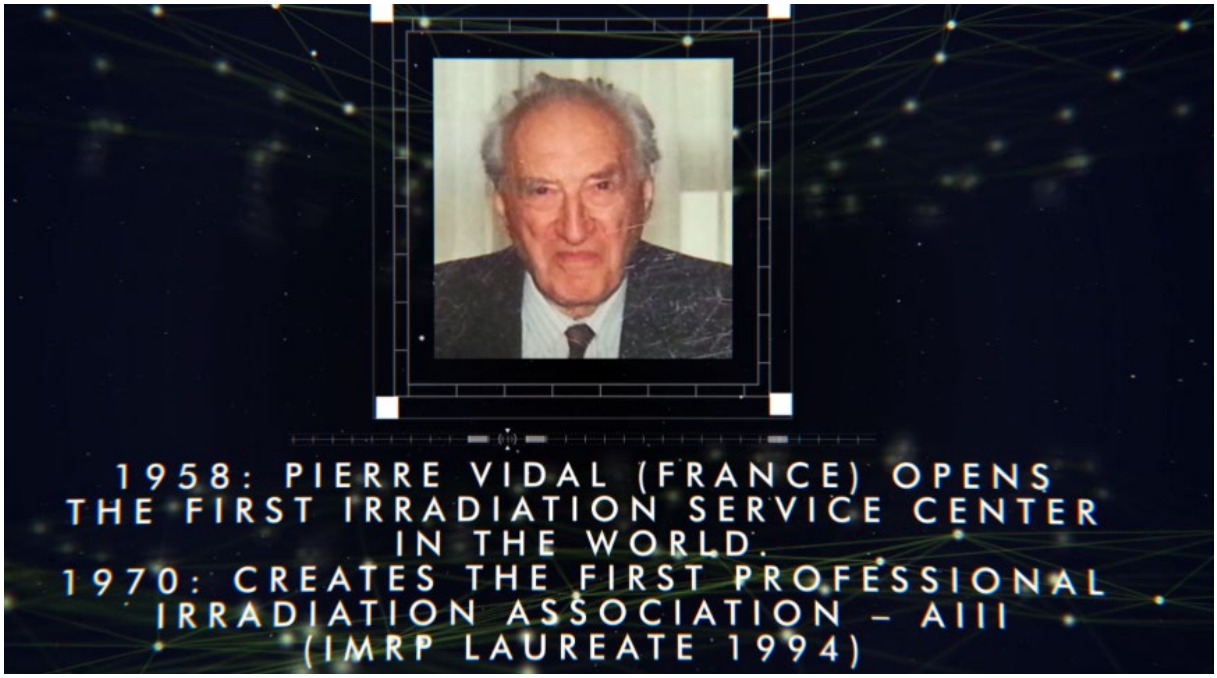


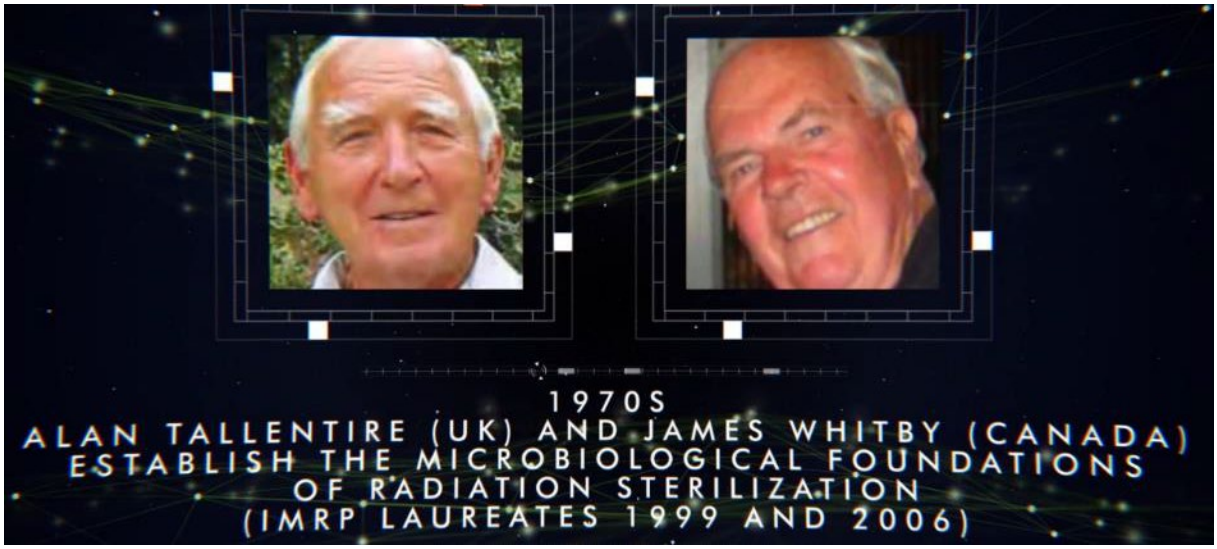

1934
IRÈNE AND FRÉDÉRIC JOLIOT-CURIE
(FRANCE) DISCOVER
MAN-MADE


1950s
ARTHUR CHARLESBY (UK)
PIONEERS RADIATION CHEMISTRY
(IMRP LAUREATE 1980)


1957
PAUL COOK (USA) FOUNDS RAYCHEM -
FIRST KNOWN USE OF RADIATION
CHEMISTRY FOR COMMERCIAL PRODUCTS:
WIRES, CABLES AND HEAT SHRINKABLES
(IMRP LAUREATE 1978)
EXECUTIVE


1964
JOHN MASEFIELD (USA)ESTABLISHES
IRRADIATED FOODS OF CANADA.
1972 FOUNDS ISOMEDIX
TO STERILIZE MEDICAL DEVICES
(IMRP LAUREATE 1984)


1958: PIERRE VIDAL (FRANCE) OPENS
THE FIRST IRRADIATION SERVICE CENTER
IN THE WORLD.
1970: CREATES THE FIRST PROFESSIONAL
IRRADIATION ASSOCIATION – AIII
(IMRP LAUREATE 1994)


1970S
ALAN TALLENTIRE (UK) AND JAMES WHITBY (CANADA)
ESTABLISH THE MICROBIOLOGICAL FOUNDATIONS
OF RADIATION STERILIZATION
(IMRP LAUREATES 1999 AND 2006)


1990s: YVES JONGEN (BELGIUM)
DEVELOPS THE RHODOTRON
INVENTED BY SCIENTIST
JACQUES POTTIER IN 1989
(IMRP LAUREATE 2003)

THE 19TH INTERNATIONAL MEETING ON RADIATION PROCESSING

The 19th International Meeting on Radiation Processing (IMRP 19) was held in Strasbourg, France on April 1-5, 2019.

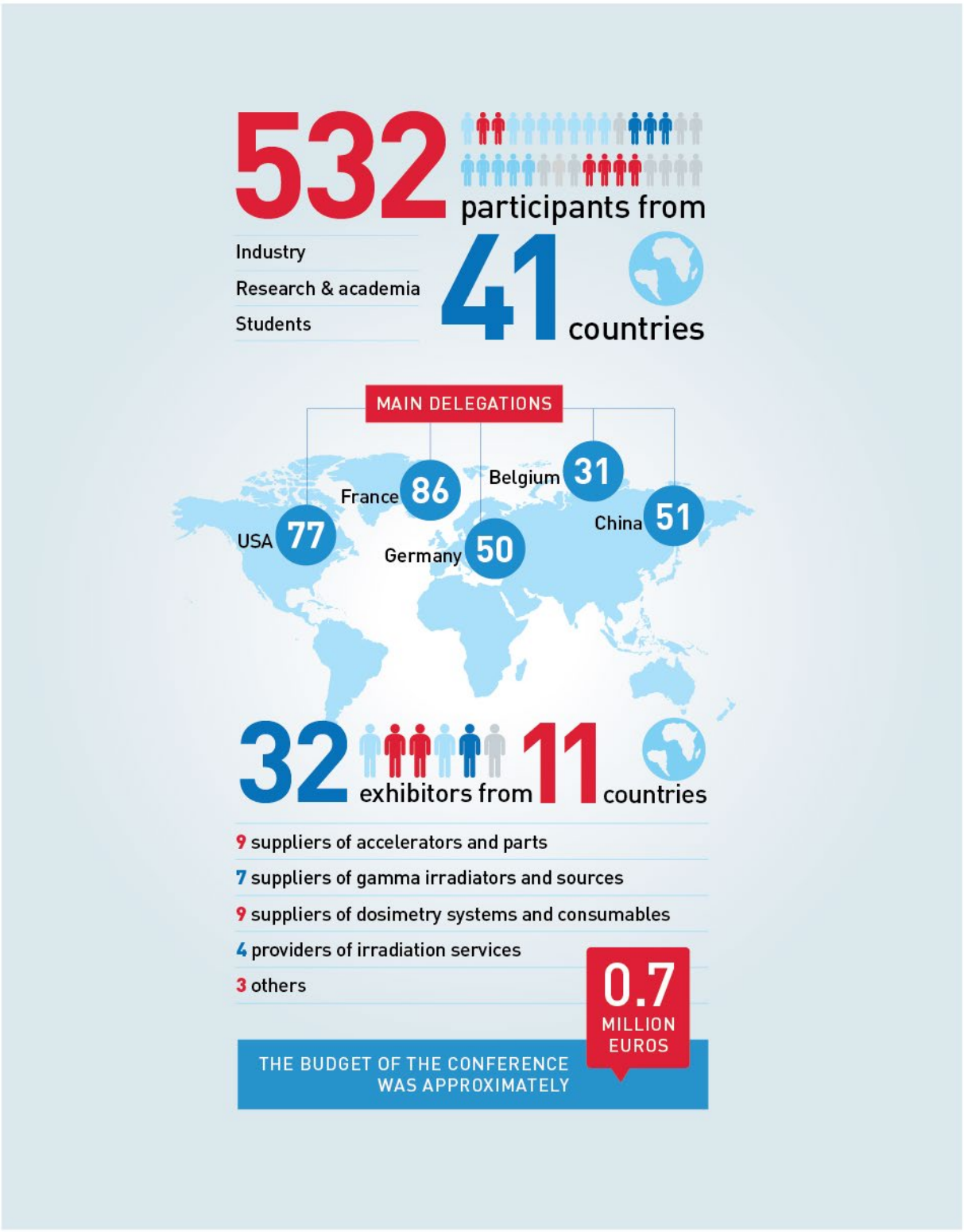
In addition to the three-day main conference, IMRP19 also included a professional exhibition, two pre-conference workshops, posters presentations, technical visits before and after the conference, and several side events giving participants opportunities to network. Additionally, for the first time, a training course for students and young professionals took place at the University of Reims Champagne Ardennes, France in the week before the conference. The program for IMRP19 was more focused than in previous editions with two plenary days and the introduction of additional panel discussions facilitated by a professional moderator. Extra time was planned for networking and visiting the exhibition area where an iia Innovation Stage was introduced to allow for commercial presentations.

In his welcome address, Paul Wynne, Chairman of the iia reminded the audience that IMRP provides a unique opportunity for those involved in the global irradiation community to come together. He added that the theme of IMRP 19 – *Where Business and Science Connect* – reflects an important aspect of our community and that members of iia are increasingly recognized as leaders in that community.

Irradiation touches the lives of a growing and significant proportion of the global village daily and in a positive way. A vast array of materials is routinely treated to enhance their characteristics and to make them safe for use. We encounter these materials in homes and as we travel, they improve the quality of our lives, help to make us well when we are sick and are increasingly used to counter the impact that our lives have on the environment.

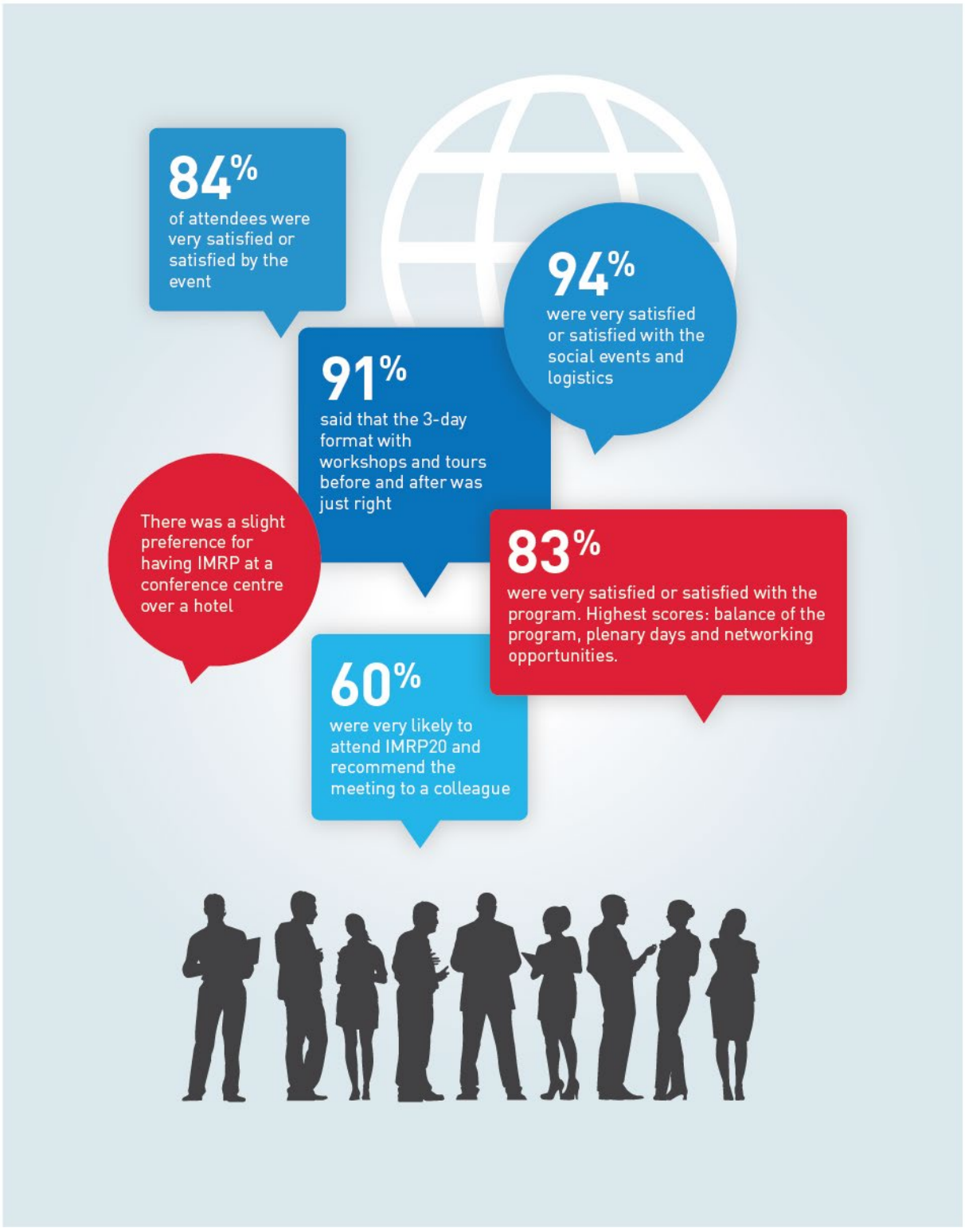
The tradition of scientific research that started with the pioneers in our industry continues to this day. We are fortunate to have passionate and exceptionally able scientists who continue to work in the field of nuclear science and technology and who continue to identify new products and new applications that require access to radiation processing. We should be proud of radiation processing and the part that we play in it.

IMRP 19 IN NUMBERS



WHAT THE PARTICIPANTS THOUGHT OF IMRP 19

Based on responses from 130 participants.



The preparation of IMRP 19 took about two years and required an immense amount of efforts from the iia team supported by the professional conference organizer IS Events Solutions (Canada) and, importantly, members of our Association who contributed to the program committee and to whom we are indebted.

The Organizing Committee

MARTIN COMBEN

PAUL WYNNE

The Program Committee

YVES HENON

XAVIER COQUERET
(URCA)

BART CROONENBORGHS
(STERIGENICS)

UWE GOHS
(IPFDD)

BRIAN MCEVOY
(STERIS AST)

THOMAS SERVAIS
(IBA)

ALAIN STRASSER
(AERIAL)

RICHARD WIENS
(NORDION)

JI SUP YOON
(KAERI)

Sponsors

Our sponsors are very important as their financial contribution was essential in enabling iia to offer a high-quality IMRP program whilst continuing to offer affordable registration fees. IMRP would not be possible without the continued support of sponsors. For IMRP 19 the sponsors were:

Regional Sponsors

REGIONAL SPONSORS

Aerial

iba

DIAMOND PARTNERS

中广核 CGN
Natural Energy Powering Nature

Nordion
A Sotera Health company

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BGS
IDEEN PLUS ENERGIE

Sterigenics
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STERIS
Applied Sterilization Technologies

EL PONT

SAPPHIRE PARTNERS

MEVEX

TOPAZ PARTNERS

FWT
FAR WEST TECHNOLOGY

Harwell
Dosimeters

PANEL ON GAMMA & ELECTRON IRRADIATION

Bruce Power

Exhibitors

IMRP is a unique opportunity for suppliers of products and services used for radiation processing to meet their customers and prospects from around the world in a single place over several days. It is no surprise that the number of exhibitors keeps growing. IMRP 19 had a record 32 exhibitors, double the number of exhibitors at IMRP in London in 2008 and almost four times the number who exhibited at the 2006 IMRP in Kuala Lumpur. The list of sponsors and exhibitors is given in Annex 1.

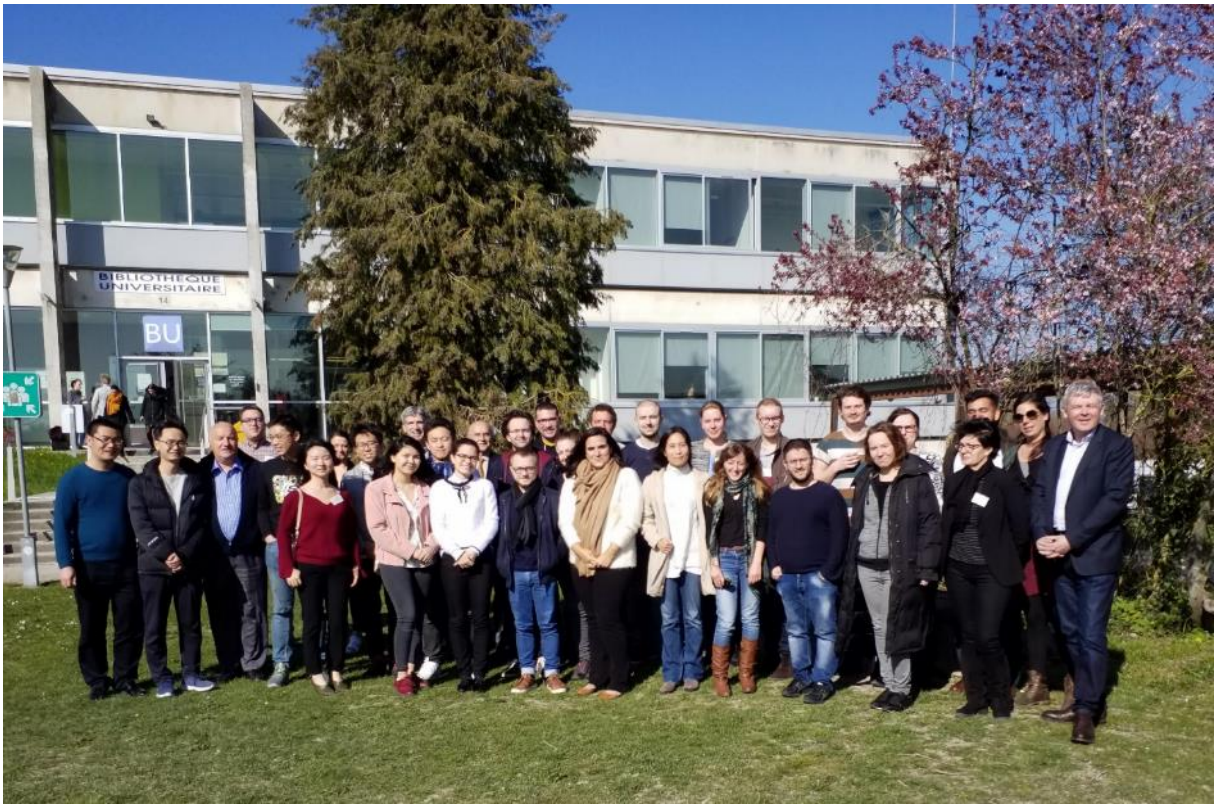
The program

PRE-IMRP TRAINING COURSE IN RADIATION PROCESSING FOR ADVANCED MATERIALS AT THE UNIVERSITY OF REIMS CHAMPAGNE ARDENNES

Co-organized by University of Reims Champagne-Ardenne (URCA) and the International Irradiation Association (iia), the Pre-IMRP 19 Training Course on Radiation Processing of Materials created synergies with IMRP19 through the complementarity of their scientific and technological contents. Importantly the training course offered an opportunity for young people engaged in the business and science of radiation processing to expand their knowledge and to integrate this with the commercial aspects of IMRP thereby helping to create future leaders for the industry.

The 3-day long training course offered a condensed overview of radiation processing applied to material enhancement. It emphasized the physical phenomena, the chemical mechanisms and the technological aspects of radiation processing. Presentations were given by leading scientists from academia and business. The attendees were thus given a comprehensive insight into, and understanding of, the radiation processing of advanced materials. Attendees were then able to build on this knowledge during the sessions on advanced

radiation chemistry that were presented during IMRP19. The course strengthened attendees' capability to carry out their academic or professional activities.



Presentations were given by:

- Xavier Coqueret (URCA, France) on radiation polymerization, determination of G(X) and G(S°, theoretical models and analytics;
- Muriel Ferry (CEA, France) on radiation-induces ageing of polymers,
- Sophie Gangloff (URCA, France) on biomaterials, bioburden and biocompatibility;
- Olgun Guven (Hacettepe University, Turkey) on radiation-crosslinking, radiation grafting, hydrogels and nanoparticles
- Yves Henon (iia) on industrial uses of radiation processing
- Byron Lambert (Abbott Laboratories, USA) on radiation processing of healthcare products;
- Michaël Molinari (LRM Nanosciences, France) on interactions between radiation and matter and on microscopies for nanomaterial characterization;
- Ralucat Musat (CEA, France) on kinetics of pulsed radiation-induced reactions.

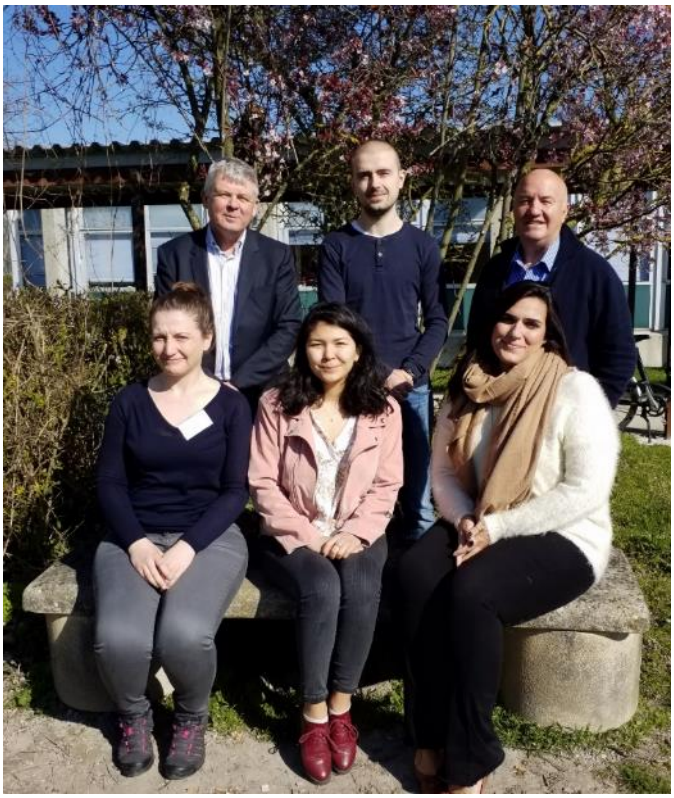
The oral presentations were complemented by demonstrations in the laboratories of the university.

Twenty-nine graduate students (MSc, PhD) and young professionals from fourteen countries attended the course. They were also given opportunities to visit the city of Reims with its magnificent cathedral and taste the local specialty: champagne. Nearly all participants also attended IMRP 19 in Strasbourg the week after and it was obvious that the course had created new friendships that should last beyond the event.

IMRP AND THE INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

The iia has NGO status with the IAEA and for many years the Agency has been associated to IMRP. At IMRP 19, the IAEA graciously supported four students to attend the conference as well as the Pre-IMRP Training Course in Reims. These four students were:

- Aida Krekesheva (Eurasian National University, Kazakhstan);
- Fabiana Lainetti, IPEN-CNEN/SP, Brazil);
- Ivan Maric (Ruder Boskovic Institute, Croatia);
- Ivana Sandeva (EEIT Faculty, Macedonia).



The Agency also had two delegates at the conference who both chaired a session:

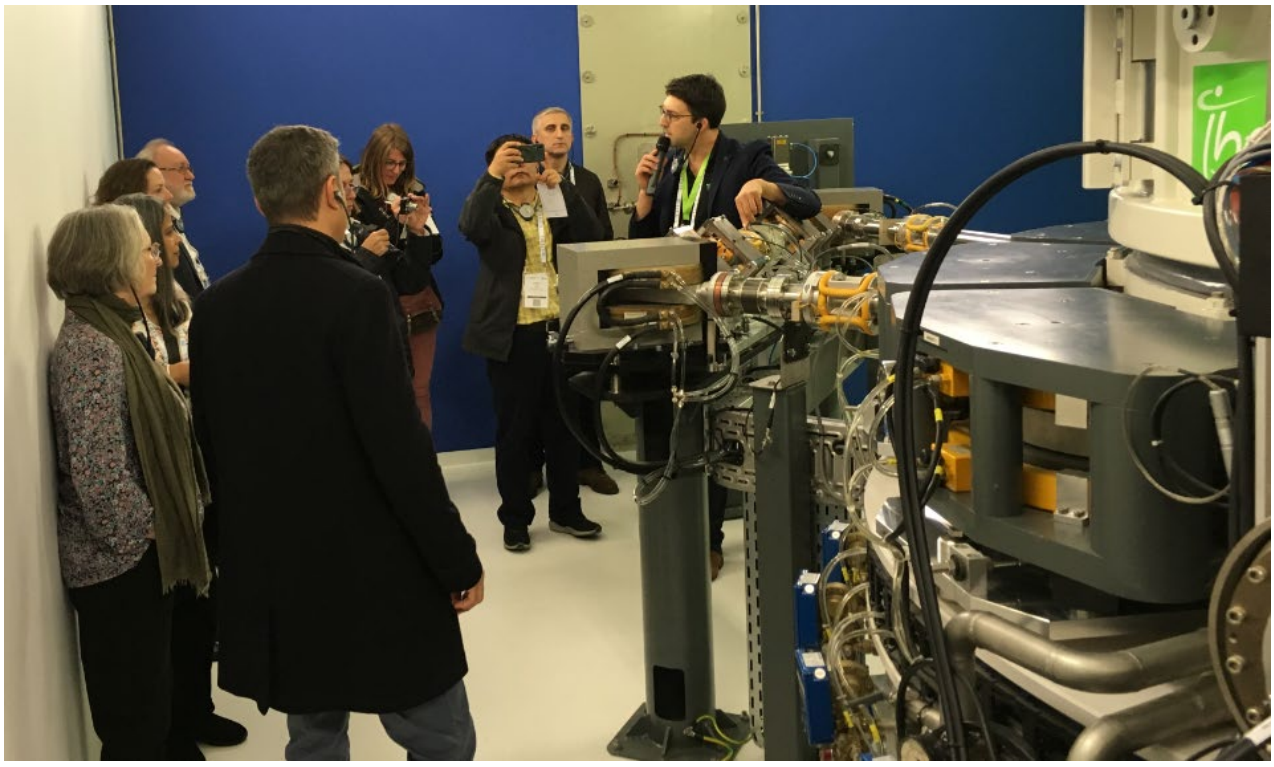
- Dr Carl Blackburn, Food Irradiation Specialist at the FAO-IAEA Joint Division;
- Dr Valeriaa Starovoitova from the Division of Physical and Chemical Sciences.

THE TECHNICAL VISITS

Aérial and BGS Beta-Gamma-Service made their facilities available for tours that were arranged immediately before and after IMRP19.

Founded in 1985 Aérial is a Technology Resource Centre specializing in food processing, irradiation and freeze-drying. Aérial is a designated IAEA collaborating center. Their facilities were visited by 120 delegates as 3 separate tours. The highlight of this tour was a visit to the brand new FEERIX irradiation facility based on an IBA TT300 Rhodotron with 2 beam lines, 10MeV E-beam and a 5 or 7 MeV X-ray. FEERIX is available to industry and research to:

- test compatibility of a wide range of products to E-beam and X-ray;
- investigate and validate new irradiation solutions during product development, and
- train staff in these irradiation technologies.



Over 80 delegates visited BGS's site in Bruchsal, Germany where the company operates 2 electron accelerators with an energy range of 4.5MeV to 10MeV including a large conveyor system enabling treatment of dimensions up to 12m x 1.2m by E-beam. Visitors were also shown around BGS's new gamma irradiator that was opened in May 2018 with a maximum capacity of 6 million curies of cobalt-60. One of BGS's application specialists demonstrated the effectiveness of irradiation on various materials.

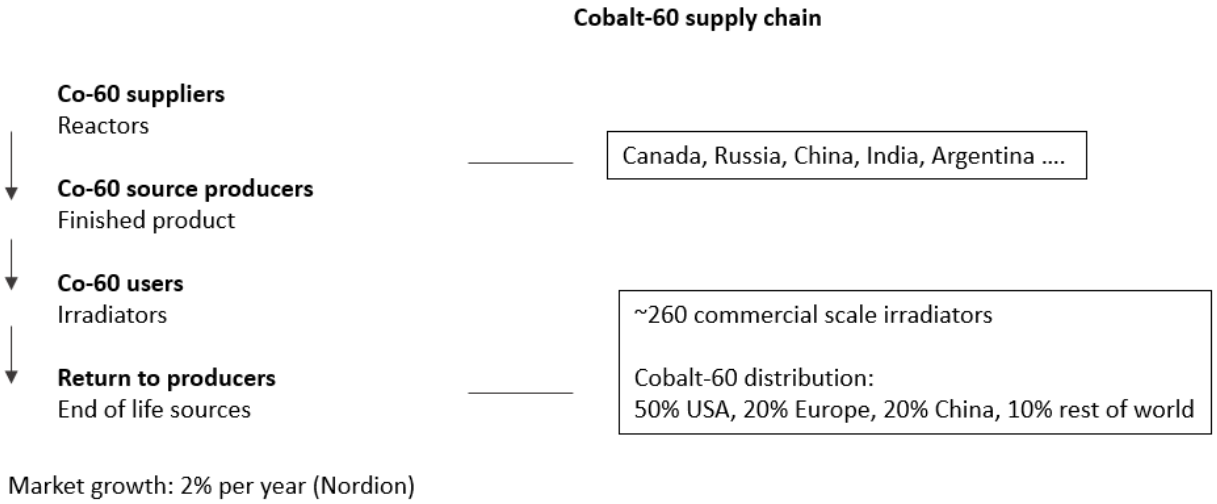
THE DOSIMETRY WORKSHOP

The dosimetry workshop that took place on April 1, 2019 was organized with the cooperation of the Panel on Gamma and Electron Irradiation. The Panel also sponsored the event and Florent Kuntz of Aérial coordinated the program. Mark Bailey (DTU, Denmark) addressed the fundamentals of dosimetry: interactions between radiation and matter, energy transfers, dose and dose distribution, and applicable standards. The concepts of measurement uncertainty were introduced by Deepak Patil (Steris AST) who elaborated the requirements of ISO 11137 and referred to ISO/ASTM 51707, the Standard Guide for Measurement of Uncertainty in Dosimetry for Radiation Processing. Peter Sharpe (NPL, UK) explained how traceable dose measurements are achieved – and lost. After comparing calibration at a calibration laboratory and calibration on site, he gave examples of estimations of uncertainty. How dosimetry is used for process definition, IQ, OQ and PQ was explained by Arne Miller (DTU, Denmark) with many practical tips. The role and use of measurement uncertainty in assessing process target parameters and process capability, i.e. a measure of how well a process can meet specifications. These concepts will appear in the soon to be published *Part 4: Guidance on process control* of ISO 11137-4.

After the oral presentations, the participants had an opportunity for hands-on practice with different types of dosimetry equipment that had been graciously provided by Aerial.

THE GAMMA WORKSHOP

Introductory comments by three users of cobalt-60 of different sizes and from different parts of the world, Hepro (South Africa), Steritech (Australia) and BD (USA) highlighted that they had the same questions regarding stability of supply, price, transportation and disposal. The aim of the workshop was to provide information and to address questions in the mind of attendees in order to reduce uncertainty and therefore make planning easier.



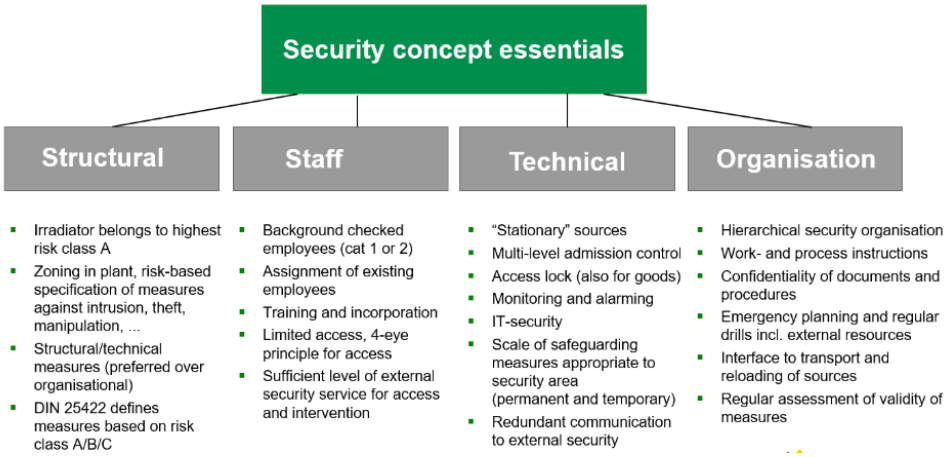
CREDIT: M. COMBEN, IIA

Nordion explained the reasons for the recent tightness in cobalt-60 supply. Their previous inventory was consumed due to a combination of events: the dissolution of another supplier (REVISS); the difficulties that JSC Isotope have encountered in bringing cobalt-60 to market; the reduced production output from Mayak in Russia and the shutdown of Embalse in Argentina for refurbishment. To ease the tightness Nordion implemented a number of short-term solutions such as the purchase of excess cobalt-60 from India and China and for the long term by securing additional supply agreements with operators of nuclear power reactors. This expansion program was reinforced by Bruce Power, a major electricity supplier in Ontario and a Nordion key supplier, who discussed the 30-billion dollars life extension program that will enable them to produce cobalt-60 till 2064. It was noted that climate change and air quality concerns have played a role in Canadian decisions to facilitate nuclear investment as part of a successful low carbon and renewable energy program. The continued production of cobalt 60 complements this program and enables nuclear energy producers to offer enhanced benefits to society.

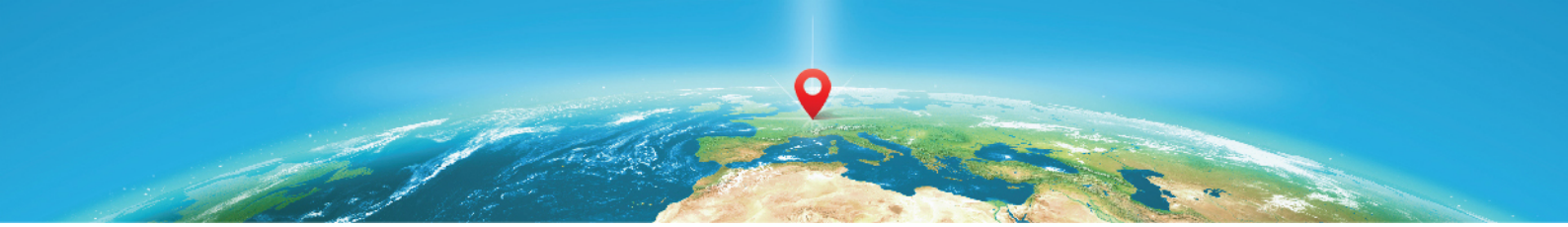
Transporting cobalt-60 has become more challenging over recent years. Since 2000, when IAEA rules limited the air freight of cobalt-60 to a level uneconomical for the radiation processing industry, sea freight and land transport have mostly been used. Consolidation of shipping companies and the refusal of some carriers and ports to accept radioactive material has reduced options for industry. Martin Comben (iia) presented the activities of the Transport Facilitation Working Group (TFWG), an independent multi-stakeholder group established in 2014 that proposes strategies and activities necessary to enable the efficient global transport of radioactive materials. The TFWG submits reports to the Inter-Agency Group (IAG), composed of representatives of the IAEA, ICAO, IMO, UNECE and TRANSSC.

A representative of the International Source Suppliers and Producers Association (ISSPA) presented the activities of the association in the domain of safety and security and expressed the opinion that the cobalt-60 supply will probably remain tight for some time.

Security expectations are now much greater than in the past. This was illustrated by BGS who commissioned their second gamma irradiator, located in Bruchsal, Germany in May 2018. During their presentation BGS outlined the way in which they approached current compliance requirements.



CREDIT: DR A. OSTROWICKI, BGS

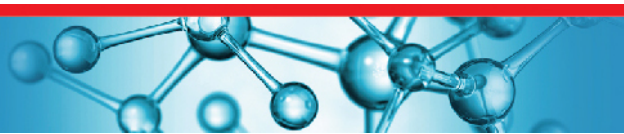


BGS reported that with the support and close cooperation of authorities and partners, the project to construct a new gamma plant took no more than 34 months from kick-off to start-up, which was relatively fast for a project of this size. Sterigenics reported a very similar experience in the UK with the new gamma irradiator that they opened in early 2019, their first greenfield facility in 25 years.

Prior to the 9/11 terrorist attacks it was generally accepted that radiological material possessed inherent security given the risk of death or serious injury which would result from exposure. However, post 9/11, operators and regulators have acknowledged that enhanced security is required to mitigate the risk of damage or theft. New organisations such as the National Nuclear Security Administration (NNSA), part of the U.S. DOE, have been established as well as groups such as the World Institute for Nuclear Security (WINS) and the Nuclear Threat Initiative (NTI). Regulators such as the U.S. Nuclear Regulatory Commission (NRC) have established new risked based obligations as outlined in 10, Code of Federal Regulation, Part 37. Industry has also been active, and leaders have worked closely with interested parties to build enhanced security procedures and controls. Of special importance in the current debate is the need for organisations to have an embedded security culture. NNSA has developed programs based on the concept of *deter, detect and delay*.

Sandia National Laboratories is one of among several U.S. laboratories, that supports the Office of Radiological Security (ORS) of the US National Nuclear Security Agency (NNSA). Sandia presented on the Device Delay program. The kits that were designed can delay access by up to five times longer, increasing the opportunity for first responders to arrive on scene. ORS has developed International Response Training courses to help provide site staff, security personnel, and local law enforcement with the training needed to adequately plan for an integrated response to a critical security incident involving a radiological source.

During the Q&A session, a representative from Nordion indicated 2021-22 as the horizon when cobalt supply issues will be resolved. The necessity to maximize the recycling of cobalt-60 sources and the principle of never having a single person inside the irradiation room (4-eyes principle) were among the various topics discussed



The conference

A total of 52 presentations were given over two days of plenary session and one day of parallel sessions.

Tuesday, April 2	Wednesday, April 3		Thursday, April 4
Opening	Healthcare	Food and Enhanced materials	Technology
Global developments	Drugs and biological products	Food irradiation	Dosimetry and modelling
Regional developments Review and update	Devices and materials	Polymerization and cross-linking	Low energy electrons and X ray applications
Applications Review and update	Complying with standards and regulations	Grafting	Technological innovations
	Discussion		Poster awards
			Debate: Connecting science and business
			IMRP Laureates awards
			Next IMRP – Closing

PLENARY SESSIONS OF TUESDAY APRIL 2, 2019

In his opening presentation Paul Wynne, iia Chairman, set the tone of the conference in his overview of radiation processing in 2019. The text is reproduced in full below.

TRENDS IN RADIATION PROCESSING

To-date the irradiation industry has evolved rather than having been subject to radical and sudden change. Gamma and electron beam technologies have complemented each other and have been used to support the development of different markets. Each technology has proved its value over an extended period and the benefits derived from irradiation processing remain as valid today as they were when first introduced commercially 60-70 years ago.

Foundational research on radiation and radiation technologies started in the late 19th and early 20th century with the work of scientists such as Crooke, Roentgen, Curie and Becquerel. The commercial application of radiation processing technologies began in earnest in the mid to late 1950s. Today the science and commercial application of radiation processing are both well established and there are a growing number of

examples of cooperation between institutes or universities and commercial organizations. Here in Europe the Accelerator Research and Innovation for European Science and Society project (ARIES) aims to improve the performance, availability, and sustainability of accelerators and to transfer the benefits and applications to science and society.

Many of us working in the field of radiation processing often tend to believe that gamma is the most widely used technology and that it was the first to gain significant commercial traction. However, the incorporation of Raychem (now Tyco) by Paul Cooke in 1957 demonstrates that the commercial opportunities presented by radiation polymer chemistry using accelerators arose a few years before sterilization using gamma irradiation developed commercially. Today radiation technologies are well established, and each continues to evolve and grow.

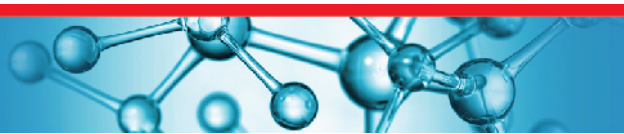
The application of radiation polymer chemistry using electron accelerators was best suited to inhouse applications whilst the cost and complexity of using gamma quickly resulted in commercial opportunities for specialist sub-contract irradiation businesses using panoramic irradiators. Whilst the lines have become somewhat blurred, radiation polymer processing remains largely inhouse and sterilization using an increasing range of technologies is largely undertaken by specialist contract operators.

In 2018 conservative estimates indicated that there were more than 1,500 high energy electron accelerators generating in excess of USD 85b (2011) and that there were more than 1,000 low energy accelerators. By comparison there are perhaps a little over 200 large scale (> 250 million curies) gamma plants in the world.

From the initial gamma plant at Ethicon in New Jersey (USA) in the early 1960s onwards, the sterilization of single use medical disposables remains the most important single application for gamma irradiation facilities. By the mid-1980s, gamma irradiation was used to sterilize approximately 40-45% of the disposable healthcare products with Ethylene Oxide sterilization representing about 50% of the market. Gamma was largely undertaken by contract operators whilst EO was largely undertaken in house. At that time EO was low cost and simple whilst gamma was relatively expensive but offered significant benefits.

By the late 1970s it was generally anticipated that food irradiation could become the most important application for the technologies as it would undoubtedly improve food security as well as food microbiological safety. The fact that irradiated food was recognized safe by many reputable international organizations in 1980 did not significantly change the reticence of regulators to liberalize the conditions under which the process may be used so the adoption of the technology has remained slow. Over this past decade, the rise of irradiation as a phytosanitary treatment for fresh produce is the success story that the promoters of food irradiation have long been waiting for. This success demonstrates that consumers do buy irradiated food when retailers are willing to offer them on their shelves.

In the early 1990's the death of ethylene oxide sterilization was widely predicted as gas emission limits in the work environment and into the atmosphere were being lowered, the level of gas residues in the products were also going to be lowered and the freons mixed with EO to prevent explosion were being banned as a result of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer. EO technology rose to the challenge by rethinking the process and introducing various technological innovations and, as a



consequence, EO has remained the leading sterilization technology despite often now being more expensive than the alternatives including gamma.

On the 11th September 2001 when the World Trade Centre and the Pentagon in the USA were attacked by terrorists, the world realized that terrorists were now prepared to die in the pursuit of their aims. Governments and regulators began to fear the consequences of a "dirty bomb" and this continues to have a profound impact on security regulations governing the use of radiological material.

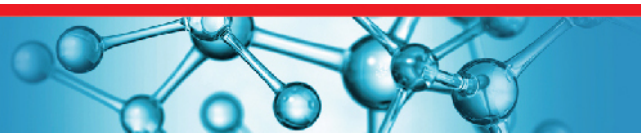
The IAEA responded quickly convening meetings and creating programs. Nuclear Security Plans were developed and are updated every few years. A Nuclear Security Series of recommendations was developed, and a Code of Conduct on the Safety and Security of Radiological Material published. At intergovernmental level, four Nuclear Security Summits were convened. Individual governments created their own programs such as the US Global Threat Reduction Initiative, part of the US Department of Energy. The DoE program now falls under the Office for Radiological Security (ORS) program. At regulatory level new rules were formulated such as 10 CFR Part 37 in the USA adding to the complexity of using cobalt 60 in commercial gamma irradiators. Security has implications for the supply, transport, use and disposal of radiological material. The gamma industry responded positively to these challenges with the introduction of new processes and upgraded facilities. Despite the increasing cost and complexity gamma remains much in demand.

Over the past 30 years there have been significant developments in the application of radio frequency electron accelerators. Perhaps the best known of these is the Rhodotron which has the power and energy to expand the range of products that can be processed and to compete with gamma. Recent developments by major suppliers have included multiple beams (high throughput and low overdose ratios), improved control systems, better modelling and improved performance prediction. The development of new lamps produced by low energy accelerators and X-rays is opening up new opportunities for the in-line processing of a broad range of products.

Electron accelerators are conquering new markets in "security" and "environmental" applications. They are providing physical and biological security systems at ports, airports and at border posts. The opportunities to offer environmental solutions for a variety of pollutants is exciting and should ensure that irradiation starts to be perceived as a beneficial technology for the global community and for the environment.

In a world that requires increasing access to electrical power it is increasingly recognized that nuclear power offers solutions to base load generating capacity not available from renewables. The importance of nuclear technologies in healthcare is increasingly recognized and it is becoming obvious that irradiation, nuclear medicine and nuclear power sectors must co-operate in promoting the safe and beneficial uses of nuclear technologies and in responding when legislation and regulations are being formulated.

Over the past 40 years large contract operators have increasingly become technology neutral whilst even smaller businesses now offer several technologies to meet the needs of their customers. Security considerations motivate some governments to implement alternative technology awareness and/or support programs to encourage companies to switch from e.g. gamma to electron beam / X-ray systems. This reflects



the fact that the radiation processing evolves at a pace which can be frustrating to those who wish to see rapid change.

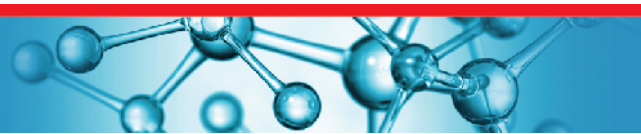
X-ray technology is still nascent. More accelerators are being installed with the capability of producing X-rays, but the technology has yet to be widely accepted by end-users. One of the key reasons for the slow pace of change is that the core application for gamma, the sterilization of single use medical disposables, is a heavily regulated sector which requires certification and approval before changes can be implemented.

Gamma technology is mature, well understood and used/preferred for many applications. The electron beam and X-ray sectors continue to evolve with new equipment, technological developments and an expanding applications base. These trends are likely to continue. There is continuing consolidation in the radiation processing industry which can have positive and negative impacts on the sector.

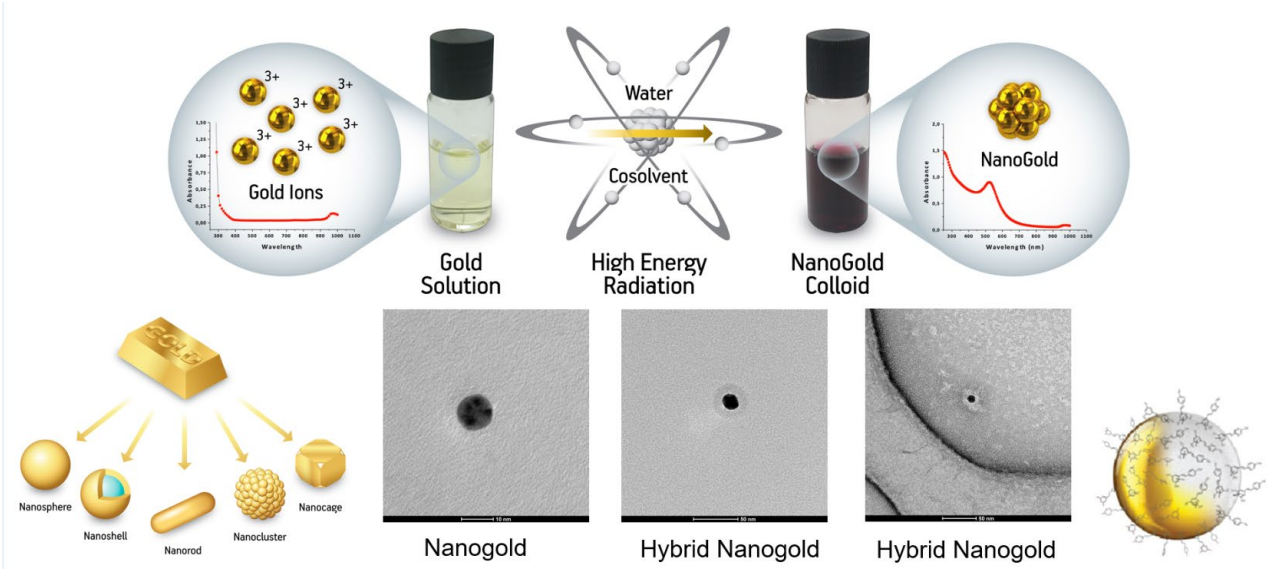
Today radiation processing touches the lives of a growing and significant proportion of the global village in a positive way daily. A vast array of materials is routinely treated to enhance their characteristics and to make them safe for use. We come into contact with these materials in homes and as we travel, they improve the quality of our lives, help to make us well when we are sick and are increasingly used to counter the impact that our lives have on the environment. The tradition of scientific research that started with the pioneers in our industry continues to this day. We are fortunate to have passionate and exceptionally able scientists who continue to work in the field of nuclear science and technology and who continue to identify new products and new applications that require access to radiation processing.

We can expect that the irradiation business will continue to grow. Despite the challenges, new gamma facilities are being constructed though at a slower pace. New cobalt production capacity is being created and existing facilities will continue to be used for many years to come. I believe that enlightened governments, regulators and NGOs increasingly recognize that the gamma irradiation community can contribute to enhanced security whilst allowing customers to retain access to the technology. Science continues to identify exciting new applications for electron beam technology and environmental concerns are re-awakening application opportunities that until now have waited for a suitable catalyst for use. The switch from gamma to X-ray will take time because of the inherent caution and licensing requirements of the healthcare system. Broad technological knowledge and skills will become increasingly important in irradiation companies of the 21st Century so that investment decisions can be based on an informed understanding of market requirements, technological capability and sound financial analysis.

Among the different research fields in radiation technology, material science is the most active. Gustavo Varca of IPEN gave the example of nanotechnologies. Nanotech has opened the possibility of imparting new properties or tuning existing properties to materials as a function of size and shape neither observed otherwise nor featured in bulk materials. Scaling down or up, nanotechnology allows unique changes and generates an emerging platform of nano-based systems with diverse applications for example in the biomedical and the environmental field. More specifically, high energy processing, via gamma, electron beam or x-ray processing, allows the creation of reactive species, directly or indirectly responsible for triggering or causing the nano-structuring process. Examples refer to nanoparticulate polymeric, metallic and protein systems, including hybrid ones (inorganic-organic nanoparticles), as well as nanocomposites - solid hybrid multiphase materials composed by at least one phase in the nanometer scale. Examples of applications of



such systems at an industrial level were presented in the fields of energy and wires and cables industry. Other uses of nanoparticles include theranostics, a new field of medicine uniting diagnostic and therapeutic applications to form a single agent, allowing for diagnosis, drug delivery and treatment response monitoring.



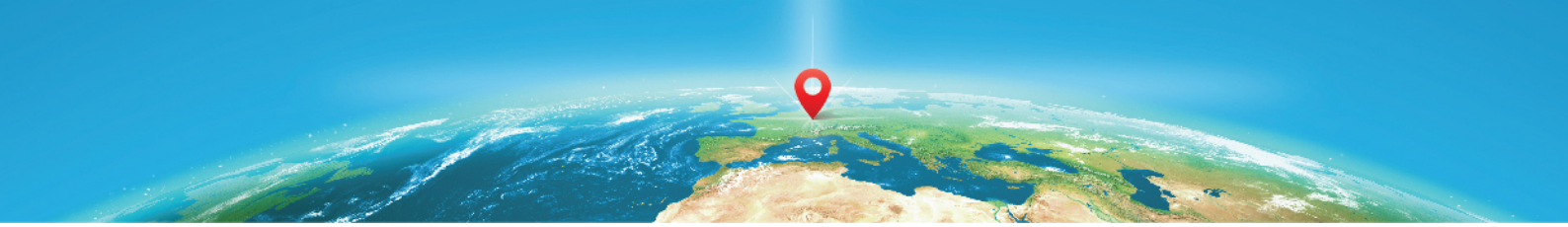
RADIOLYTIC SYNTHESIS OF NANOGOLD. CREDIT: GUSTAVO VARCA

GLOBAL DEVELOPMENTS IN DIFFERENT PARTS OF THE WORLD

Radiation processing has different dynamics in different regions and the interest in research, technologies and applications varies. Asia appears as the most dynamic in terms of new facilities, growth, diversity of applications, offers of equipment, and even research. Japan has for a long time been at the forefront of research in radiation chemistry and now this sector is also important in China and South Korea. China has the largest number of irradiation facilities in the world. Radiation technologies have been designated by the government as a priority for the country.

In North America and Europe, sterilization of medical devices is the main business. In South America developments are taking place but at a slow pace while radiation processing is still embryonic in Africa outside South Africa.

- The challenges and opportunities for sterilization in Europe- Mike Eaton, Steris, UK
- Irradiation landscape in the Americas - Phil Macnabb, Sterigenics, USA
- Asia - Kenneth Hsiao, CGN Dasheng, P.R. China



The first two presentations by Steris AST and Sterigenics, the world leaders in contract sterilization, were focused on the use of irradiation to sterilize healthcare products.

Mike Eaton, Managing Director of Steris AST Europe and Asia estimated the sterilization market in Europe at 12 million cubic meters with an average growth of 5% per annum. Eastern Europe has higher growth than Western Europe due to the lower cost of labour for manufacturing. Most of the devices are used in Western Europe or exported to the US.

	Sterilization market share (%)	CAGR 3 years (%)
Ethylene oxide	44	2.1
Gamma	38	2.9
Electron	17	12.3
X-ray	1	23.1

ADAPTED FROM DATA PRESENTED BY MIKE EATON

The current sterilization market dynamics in Europe indicate a movement to accelerators and ethylene oxide. Consolidation is still taking place with STERIS, Sterigenics and Ionisos all acquiring businesses. Over the past five years there has been notable expansion in both gamma and E-beam. New gamma plants were built by STERIS in Marcoule France and Bradford UK, by BGS in Bruchsal, Germany and by Sterigenics in Chesterfield, UK. New E-Beam plants were built by STERIS in Tullamore Ireland and Komenda Slovenia along with a major upgrade in Seriate Italy. A new X-ray facility will open in Venlo Netherlands in the summer of 2020. Mediscan installed their third Rhodotron – a duo EB - X-ray in Kremsmünster, Austria.

Globally, STERIS expects Europe to remain a large consumer of medical devices and a fruitful place to do business with good growth.

Phil Macnabb, CEO of Sterigenics, a Sotera Health company, elaborated on the predominance of North America in the healthcare business. USA and Canada have a population of 367 million, a GDP of 22 trillion US dollars and spend 3 trillion US dollars on healthcare. This explains why the sterilization market is dominated by North America, followed by Europe and then by Asia. According to cited market research by Medical Design and Outsourcing dated August 2016, offsite or contract sterilization accounts for the largest share of the market with gamma as the predominant technology.

The presentation about Asia by Kenneth Hsiao, CEO of CGN Dasheng, showed how active this region is both in the industrial use of and research on radiation processing. Polymer modification is the main application in Japan, South Korea and now China who all appear to have more research programs than in the rest of the world. China is the world number one for the number of gamma irradiators and accelerators in operation, number of accelerator manufacturers, number of irradiation service centers and quantities of food irradiated. Food irradiation is the main business of radiation processing contractors in China, where approximately one million tons of food are irradiated annually. Ethylene oxide remains by far the main sterilization method for medical devices in China. In India the interest in accelerators has recently grown. Besides the 20 gamma irradiators operating across the country, there are now eleven sites with at least one accelerator in operation, mostly for treatment of cables.

Estimated number of irradiation facilities in some Asian countries:

Country	Accelerators	Gamma irradiators
China	400+	130
India	20	20
Indonesia	2	2
Japan	400+	10
Malaysia	5	6
South Korea	42	3
Thailand	10	5
Vietnam	9	3

GLOBAL DEVELOPMENTS OF THE MAIN APPLICATIONS

The objectives of the five sessions were to give the participants a global view and an update on the main applications of radiation processing.

New opportunities in radiation cross-linking

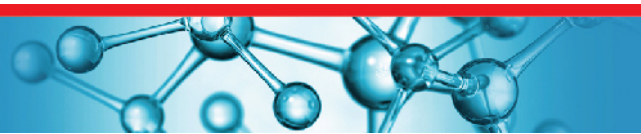
Andreas Ostrowicki, BGS, Germany

Dr Ostrowicki believes that the direction that the car industry is taking will result in more opportunities for radiation cross-linking of polymers.

Irradiated components have been used by the automotive industry for a few decades. Irradiation is a superior method of meeting the industry's requirement for high resistance material. To promote cross-linking, inclusion of additives into the compounds is often necessary. A quick test at 350°C, a welding tip test, was developed to assess the results. Other improvements to the polymers include better resistance to chemicals and abrasion or mechanical stress. Doses are generally in the range of 70 to 150 kGy, meaning that high-energy electron beams and X-rays are the preferred technology.

Working for the automotive industry implies being able to meet very high-quality requirements, comparable to those of the medical device industry. Logistics are also critical and product packing must meet both the demands of the car manufacturer and the capability of the irradiation facility. Finally, the pressure to lower cost is high.

The automotive industry is at the dawn of a new era. The ever-increasing traffic and its impact on climate and the environment, call for the rapid replacement of fossil fuels by alternative energies from batteries or fuel cells. This will require adaptation of infrastructures. Cars will essentially become electric equipment and a communicating device, merging mobility with working and living. This is going to radically change the way cars are designed and built. Reducing weight and dimensions will be major trends. The number of parts is



expected to be reduced by 90% to make construction simpler. Metal will be replaced by polymeric material wherever possible, even in the engine compartment, and this will pose many challenges even though temperature will be less high than now. Mechanical resistance and ageing behavior will be major problems. We already know for example that cross-linking by irradiation can extend the lifetime of cables by a tenfold. Consequently, the evolutions that will take place in the automotive industry will offer many opportunities and contribute to the expansion of radiation processing.

Irradiation of cables, wires and heat shrinkables

Roger Bryant, Huber+Suhner AG, Switzerland

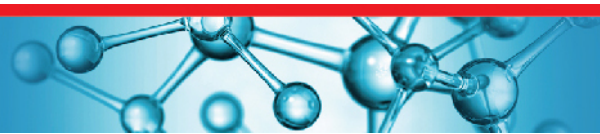
Since the start of radiation crosslinking of wire and cable by Paul Cook at the Sequoia Process Corporation more than 60 years ago, there have been a few significant changes in the basic process that was developed by the Raychem Corporation. The source of electrons is still usually a scanned beam DC accelerator of between 300 keV and 5 MeV and the product make multiple passes through the beam inside a protective shield with the product pay off and take up outside the shielding. There have however been many detailed changes and developments, not all successful. The greatest change has certainly been the industrialization of the accelerators, going from being fragile laboratory equipment to high powered machines capable of continuous operation. Paul Cook's first machine was 1 MeV 5 mA, today energies up to 5 MeV and beam currents over 100mA are possible.

Other types of accelerator have been proposed and tried. Non scanning single gap accelerators which are extensively used in the film and printing industries have been used for wire crosslinking but the maximum energy of 300 keV greatly limits the product range. Various accelerators and magnet systems to allow irradiation all around the product have been proposed but none seems to have made it past the prototype stage. RF accelerators have also been tried but the generally fixed energies reduce their applications. A constant 5 MeV will deliver too much energy to the copper conductors.

There are still three system configurations in common use:

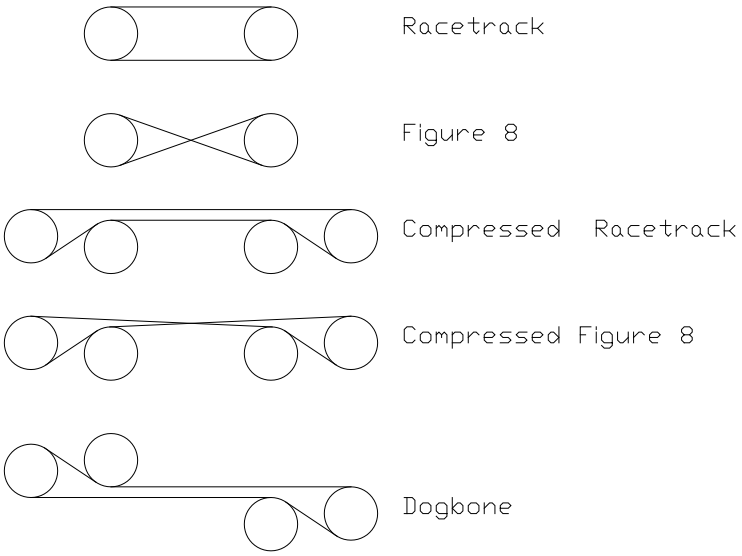
- Cable connected. The HV power supply and accelerator system are separate and connected by a HV cable. This is available up to 1 MeV and allows the greatest flexibility of accelerator positioning and generally the smallest (and cheapest) shielding configurations.
- Coaxial or Parallel. Here the beam tube is installed in the center of the HV power supply or parallel to it. This is used up to 5 MeV and requires the power supply to be inside the radiation shielding.
- Single tank bus bar connected. The HV power supply and accelerator are in separate chambers of a single tank and are connected via a busbar. This allows the power supply part of the tank to be outside of the radiation shielding. Units up to 1.5 MeV are in use.

Which system to choose depends on many variables, maximum energy required, floor area available, maximum building height, self-shielded or concrete bunker, etc. In general, self-shielded systems using steel and lead are more economical for 800 keV and below. Concrete bunkers are more cost effective for higher energies. There will always be exceptions, for example, if a machine may have to be moved then a self-

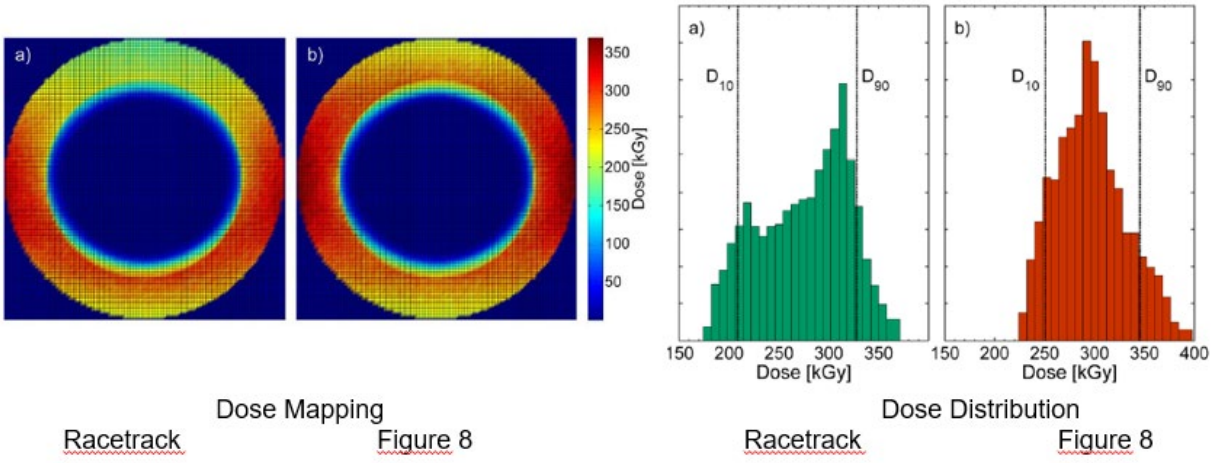


shielded 1.5 MeV system may make sense. For a complicated product handling system that requires good all-round access then a concrete bunker may be the best solution at 550kV.

There have been more variations in under beam handling systems all with supposed advantages and disadvantages. Here are 5 examples in reasonably common use.



They are generally used with a single scan horn mounted at an angle between 0° and 90° to the product line. The compressed versions have also been used with two scanners at 90° to achieve 4-sided irradiation.



COMPUTER SIMULATION – CREDIT: HUBER+SUHNER AG

For larger products the optimum dose uniformity is achieved with a drum twist system but then the production speed is limited by the maximum possible rotation speed. Four turns under the scanner will reduce the edge effects and with a typical 1.2 m scanner this will require a pitch of 3 turns per meter. A maximum rotational speed of 150 rpm will give a maximum linear speed of 50 meters per minute. Due consideration

must be given to radiation shielding where the product passes in and out of the bunker as the product must remain straight. Several solutions have been used including water filled tubes and a shielding wall enclosing the pay off and take up.

Patient-centric sterilization

Byron Lambert, Abbot Laboratories, USA

Built as if intended for my family is part of the Abbott quality statement. This is in line with the evolution of the standards in the US where the concept of end-to-end quality assurance is being implemented. The primary risk being mitigated with product sterilization is patient infection. A key need to progress patient-centric sterilization is perspective, i.e., clear focus on the most important issues facing patients while being willing to jettison non-value-added paradigms that limit development of innovative products for patients.

At the top of the infection risk-list for patients around the world, and the top two issues to be addressed by the industry, are healthcare associated infections (HAI) and sterilization reprocessing of complex devices such as endoscopes. Where there has been focus and attention, the number of Healthcare Associated Infections (HAI) is being reduced, but even in an advanced country like Canada HAI are still the fourth leading cause of death. Focus in this area, however, from organizations like AAMI are progressing solutions for consistent high-quality device reprocessing in the high-pressure healthcare facility environment.

The third sterilization challenge facing the industry is the sterilization of commodity-type medical devices. We are seeing turbulences with two technologies that for decades have been the work horses. The amount of ethylene oxide worker exposure and residues in medical devices are ongoing concern, while concern about the concentration of the gas in local communities led to a recent closure by local authorities of a large ethylene oxide contract plant in Illinois. It resulted in major disruptions of the medical device supply chain and sets a scary precedent since decisions did not appear to be based on well-correlated data. Gamma irradiation is the next most important method and requires the use of the radioactive material cobalt-60. Security concerns have led several US national agencies to strongly encourage the use of electron beam or X ray as alternative sterilization methods. These factors in processing commodity devices are providing impetus for accelerated innovation of both e-beam and x-ray sterilization as well as alternative gas sterilization technologies such as hydrogen peroxide, nitrogen dioxide and vaporized peracetic acid.

The fourth and final challenge discussed is finding viable sterilization solutions when developing innovative products. Innovative products are necessary to address numerous unmet clinical needs facing society. Toward that end, we are witnessing the technology convergence between pharma, biotech, bio-absorbable materials, IT/healthcare services and devices, including personalized products, all of which can bring enormous value to patients. These sensitive components, however, can lead to sterilization being a primary challenge in the development process. To avoid this, progress has been made from a regulatory perspective for products that cannot be sterilized at the traditional Sterility Assurance Level (SAL) of 10-6. A risk-based approach to alternative SALs is now available, in addition to aseptic processing, to get these products to market (ISO TS 19930 Guidance on aspects of a risk-based approach to assuring sterility of terminally sterilized, single-use health care product that is unable to withstand processing to achieve maximally a sterility assurance level of 10-6). Innovative products with components that are challenging to sterilize are

also driving technology innovation. This innovation is in the same direction as that seen for commodity products, both e-beam and x-ray sterilization as well as alternative gas sterilization technologies. The medical industry can expect much sterilization technology innovation in coming years.

The sterilization challenges and opportunities in both commodity product and innovative product sterility assurance are also driving the need for sterility assurance professionals to be growing and learning at an unprecedented pace. This can be achieved through collaborative forums and other resources being developed in the industry.

Terminal gamma sterilization in the pharma industry: 20 years of experience

Bruno Tissier, France

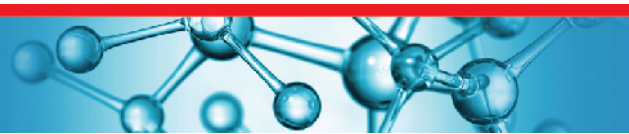
Bruno Tissier, a former executive of a major European drug company, presented his twenty years of experience with the terminal radiation sterilization of a high value drug. According to him, there are currently less than fifty radiation sterilized drugs on the EU market. Most are ophthalmic eye drops and ointments and antibiotics. Though irradiation terminal sterilization is recommended before aseptic processing in the decision tree on sterilization processes (EMEA, CPMP, 054/98 April 2000), some European drug agencies are still reticent in accepting irradiation as the still consider it to be a non-conventional process. The product is a high-value drug-device combination containing an injectable formulation of hormonal products to be released over several months. The market approval for the radiation sterilized drug required a very strong drug development file. Obtaining the replacement of sterility testing of the finished product by parametric release was especially difficult. VD_{max} was used to establish the minimum sterilization dose, considering that the bioburden is extremely low as products are prepared in an ISO 5 cleanroom.

For irradiation several tens of devices are placed in a box and the boxes are placed according to a validated pattern in a large insulated box with dry ice.

The company has now manufactured more than 250 batches annually for more than 20 years with no batch rejected. Various benefits have resulted from the use of radiation sterilization:

- Irradiation has proved to be a method that consistently provides a SAL of 10^{-6} or better in a safe and reliable way.
- The use of irradiation and parametric release shortened the manufacturing cycle time by one month. The risk of false positives during sterility testing no longer exists.
- No more costly samples need to be used for sterility testing and stability studies (except at T_0). The number of retained samples per batch could also be reduced.
- No risk of batch rejection due to false positive sterility testing
- No capital required for sterilization equipment.

In conclusion, the importance of having a radiation service supplier (and a back-up) who is knowledgeable and transparent and who acts as a partner of the drug manufacturer was emphasized.



Food irradiation success story: Use for phytosanitary purpose

Murray Lynch, Steritech Pty Ltd, Australia

In his overview of food irradiation, Murray Lynch, CEO of Steritech in Australia stated that safety of irradiated food is no longer questioned in countries where regulations are based on science, such as USA and Australia, but still debated where the topic is considered sensitive, as it is the case in the European Union or Japan. About eighty countries have permitted food irradiation. Though globally the adoption of the technology has been slow, trade of irradiated food is globally progressing. The volume of food irradiated worldwide exceeds one million tons, with spices and seasonings being the products most irradiated worldwide. It is in China that the largest volumes of food are irradiated. Besides spices and seasonings, more than 350,000 tons of spicy pickled chicken wings are irradiated to extend their shelf-life at room temperature. These pickled products are eaten as a snack and can be found in convenience stores across China. There is a similar example in Thailand with slices of fermented pork sausage (*naem*) irradiated for microbiological safety.

IRRADIATED SPICY CHICKEN WINGS

IRRADIATED FERMENTED PORK SAUSAGE

As experience has now demonstrated that irradiated food sells, regulators and national retailers are reassessing their stance on irradiation. Over the past decade, the use of irradiation as a phytosanitary treatment for fresh fruit and vegetables has been a success story with a traded volume growing from zero to more than 30,000 tons annually. Phytosanitary irradiation has a several advantages:

- It can be used for most pests and crops,
- It is simple fast and efficient,
- it provides better fruit quality
- It replaces post-harvest pesticides,
- It is increasingly accepted around the world

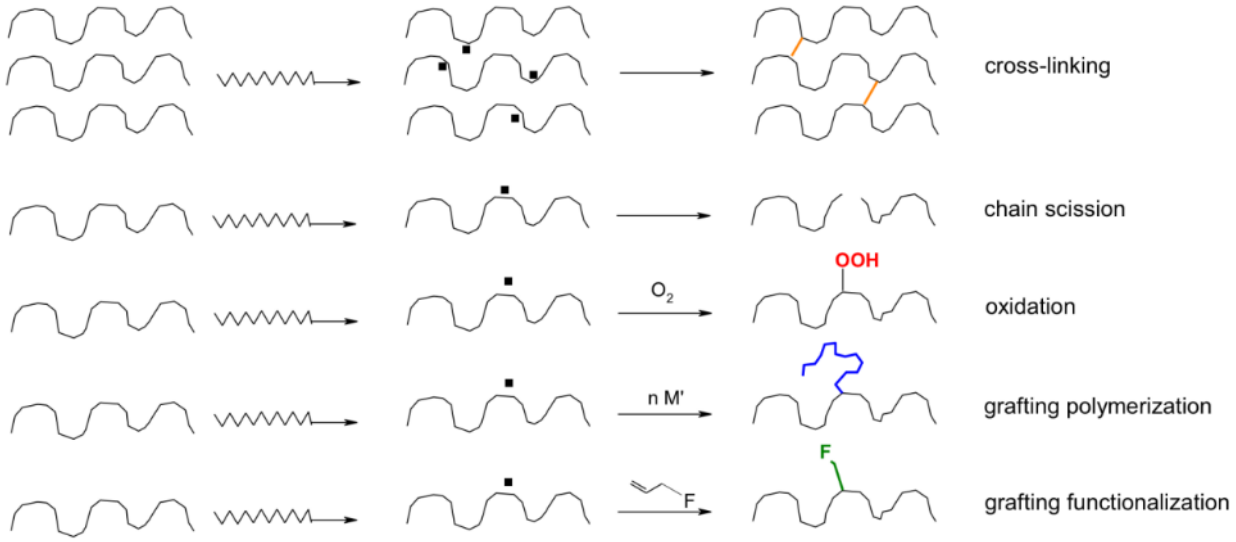
- Regulators find it extremely reliable.

Mexico and Vietnam are the largest exporters of irradiated fresh produce while the USA is the largest importer. During the season 2018-2019 Australia exported 5,200 tons of mangoes, grapes, tomatoes, cherries, lychees and other products mainly to New Zealand, USA, and Vietnam. A new X-ray irradiation facility is under construction in Melbourne for phytosanitary irradiation.

PARALLEL SESSIONS OF WEDNESDAY APRIL 3, 2019

ENHANCED MATERIALS

Globally the modification of materials is the main application of radiation processing in terms of volumes and this is generally done by electron beam, most often in-house but sometimes outsourced. Various effects can be obtained when irradiating polymeric material.



CREDIT: PROF. X. COQUERET, URCA

Today, more than half of all industrial electron beam accelerators are used to cross-link polyethylene in wire and cable insulation, heat-shrinkable tubing and wraps, heat-shrinkable food packaging films, and controlled density closed-cell foams. Irradiation is also proving to be an invaluable tool on a much smaller scale, for example in the synthesis of nanomaterials; a topic that was present in many communications.

Two parallel sessions were dedicated to enhanced materials: the first one on polymerization and cross-linking and the second one on grafting.

POLYMERIZATION AND CROSSLINKING

Session chair: Yoon Ji Sup - KAERI ARTI, South Korea

Breakthrough in radiation curing of high-performance carbon fibre reinforced composites

Xavier Coqueret, Université de Reims Champagne-Ardenne, France

Though cross-linking polymerization has advantages over the thermal curing process in terms of time and energy saving, the crosslinked composites have inferior mechanical properties and are more brittle compared to state-of-the-art thermally cured composites. Prof. Coqueret showed that the fibre-matrix adhesion could be improved, and the polymer network toughness upgraded by introducing various sensitizing agents in the reactive formulations. The radiation sensitivity could thus be increased, and the transverse strain of the fibre was significantly improved.

3D- edge layer modification using a low energy electron emitter coupled industrial robot system

Michael Müller, Leibniz-Institut für Polymerforschung, Germany

Incomplete curing of sheet molding compounds (SMC) during the industrial molding procedure are the main reasons for the observed coating problems of SMC parts due to the post-curing and outgassing during the industrial coating process. Furthermore, their surface properties, *e.g.* contact angle and surface roughness, are strongly dependent on the formulation components, the processing parameters of thermal molding and subsequent coating procedure as along with the used cleaning and pretreatment methods. Consequently, cost and energy intensive additional process steps are required in the automotive industry in order to reduce or avoid these problems for SMC-Class-A automotive parts. Therefore, a cost-efficient robust procedure is needed in order to overcome these disadvantages as well as to fulfill the industrial requirements. Based on electron beam (EB) curing and functionalization by low energy electrons, a novel pretreatment procedure was developed, and a patent was granted. The main idea is that the robot always guides the emitter perpendicular to the surface of the parts at a constant distance from the surface, even though the surface shape is complicated. The surface can thus be uniformly irradiated which solves the problem of incomplete curing. For the validation and the proof of 3D and inline capability of this novel technology two compact electron emitters of varying design type (area emitter/point emitter) have been coupled to a robot and different SMC-serial parts have been comprehensively tested. By one additional step, 3D edge layer post-curing and surface functionalization of the SMC-parts was successfully achieved under atmospheric conditions. Depending on the SMC formulation and the curing state after industrial molding procedure, individually EB conditions must be determined. Finally, it was proved, that an edge layer EB pretreatment can result in successfully coated SMC molds without carrying out thermal oven treatment, padding or flame treatment.

Geometry digitizing and design data for electron beam pathway coding (left) and robot coupled electron emitter

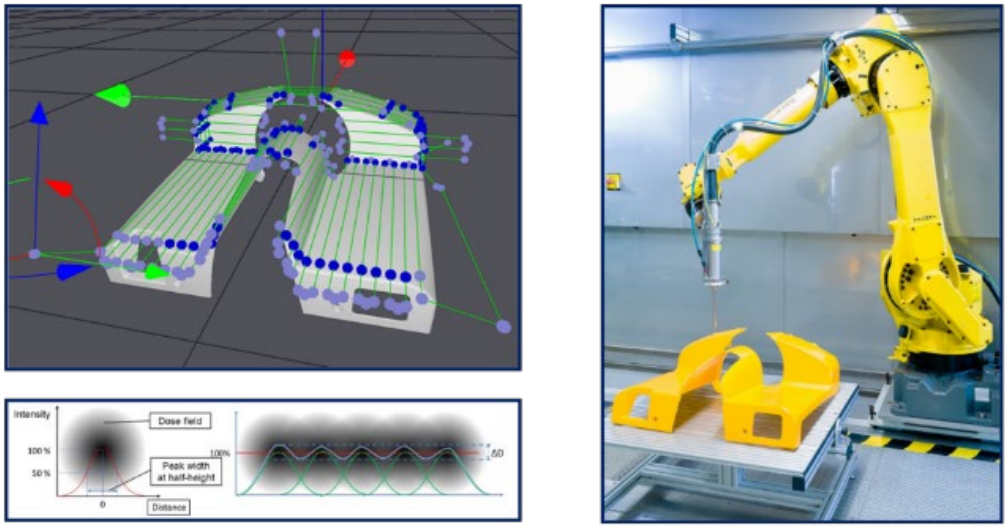


Figure 1 Geometry-digitizing and design data for robotic electron beam pathway coding (left) robot coupled electron emitter (right)

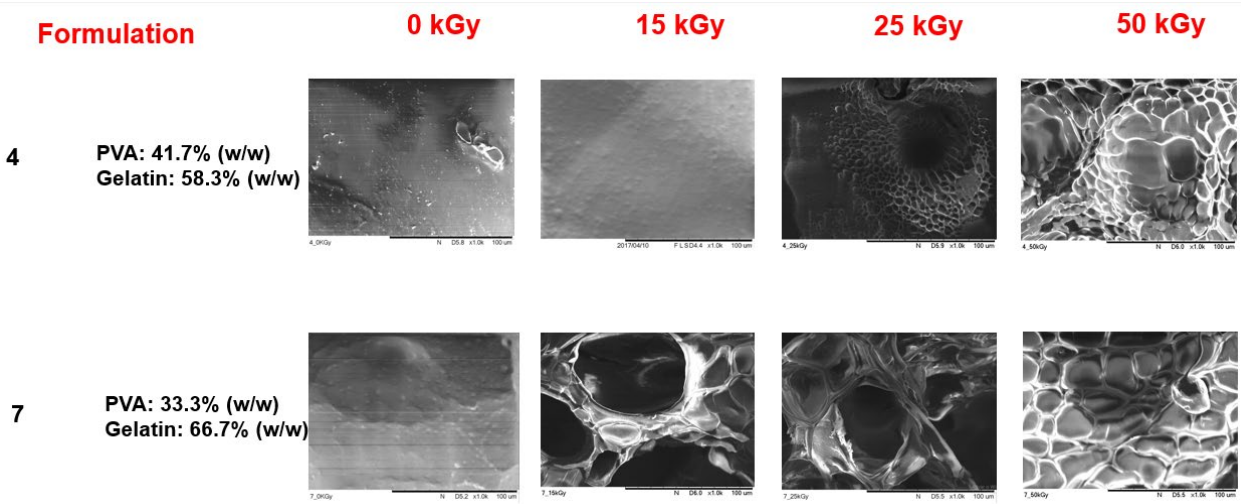
CREDIT: LEIBNIZ-INSTITUT FÜR POLYMERFORSCHUNG, PHOTO JÜRGEN LÖSEL, GRAPHIC ROY STREICHER

Radiation crosslinked polymeric scaffolds for advanced platelet-rich plasma delivery: Towards effective wound healing

Gustavo Varca, IPEN, Brazil

Platelet-rich plasma (PRP) is known to accelerate tissue regeneration and repair due to its abundance of growth factors related to angiogenesis, mesenchymal cell differentiation, and cellular matrix synthesis. Regarding wound treatment, the presence of FGF growth factor, responsible for fibroblast, myoblast and chondrocyte proliferation, as well as other growth factors related to the collagen production are highlighted. Based on the PRP fluid properties, the present work aimed the development of a novel polymer blend based scaffold suitable for PRP advanced loading and release for wound healing and related applications, capable of overcoming typical PRP loss during usage. Similar systems remain unavailable in the market. The scaffolds were composed by gelatin (7%, w/w) and PVA (5%, w/w), and the second formulation by gelatin (10%, w/w) and PVA (5%, w/w). The polymers solubilized in distilled water and heated up to 80 ºC under constant stirring for 1 hour were poured into glass molds, before cooling at 4 ºC for at least 24 h and irradiation at 15, 25 kGy. The samples were then frozen, freeze-dried and characterized by mechanical assays, differential scanning calorimetry, scanning electron microscopy and optical coherence tomography (OCT), loading, release, and adhesion of platelets and growth factors assays, and cytotoxicity. Samples irradiated at 15 kGy presented pore size diameter of around 1.4 µm and porosity of 54%, while at 25 kGy, the mean pore size diameter was about 1.1 µm and porosity 49%. Both systems presented suitable mechanical properties, non-toxicity, and an adequate pore size range to host and release growth factors and platelets over time. Thus, the developed systems featured suitable properties concerning dressings applications for wound treatments.

Surface Analysis by SEM (x1000)



CREDIT: NANOTHERA AND IPEN

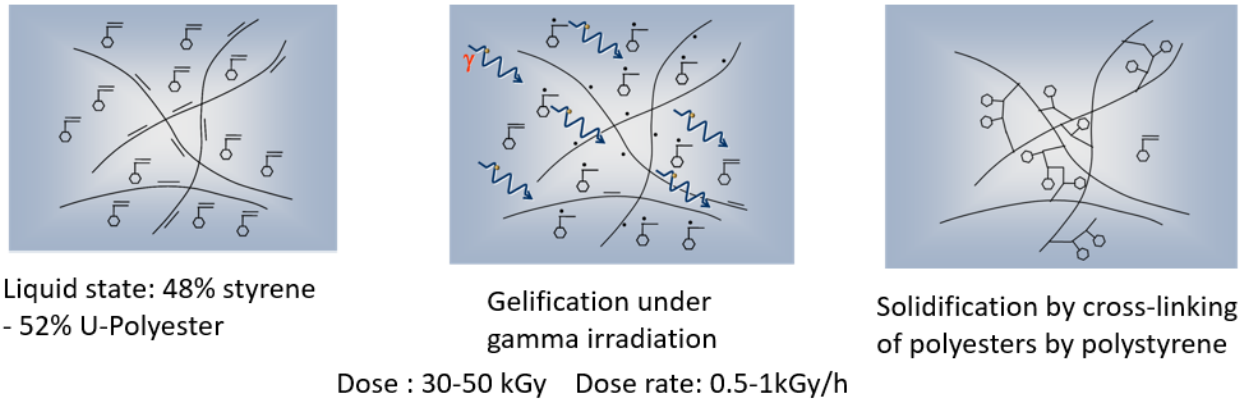
These new systems possess suitable properties for dressings used for wound treatments.

Consolidation of artefacts

Quoc-Khoi Tran, ARC- Nucléart, CEA, France

The Atomic Energy Commission in Grenoble, France has a very long experience of using irradiation to control insects and microorganisms in cultural heritage artefacts. They famously irradiated the mummy of pharaoh Ramses II in 1976 using cobalt-60. A dedicated entity was created with several partners including the French Ministry of Culture with a mission to preserve and restore artefacts made of organic (wood, leather, fibres) and porous materials. Consolidation is achieved by impregnation of styrene monomers followed by radiation polymerization.

Radical copolymerization of styrene-unsaturated resin



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The examples that were shown included an 18th century wooden polychrome sculpture of St Vincent, the figurehead of a 19th century schooner, the gun carriage from the wreck of the HMS Stirling Castle and a 30-meter long boat of the Roman period. The same process to the styrene polyester system is used for modern woods, such as the parquet at Incheon International Airport. A reversible alternative is being sought. The most promising seems to be formulations based on methyl methacrylate, butyl methacrylate, and Paraloid B72.

GRAFTING

Session chair: Valeriia Starovoitova – IAEA

Radiation grafting is a well-established method for the development of new materials by forming active sites on a polymeric backbone. The advantage of radiation induced grafting is the lack of contaminants since no catalysts or additives are added to initiate the reaction. Different types of grafted structures were discussed during the session, including porous membrane development and uses, development of fibers and graphene nanoflakes.

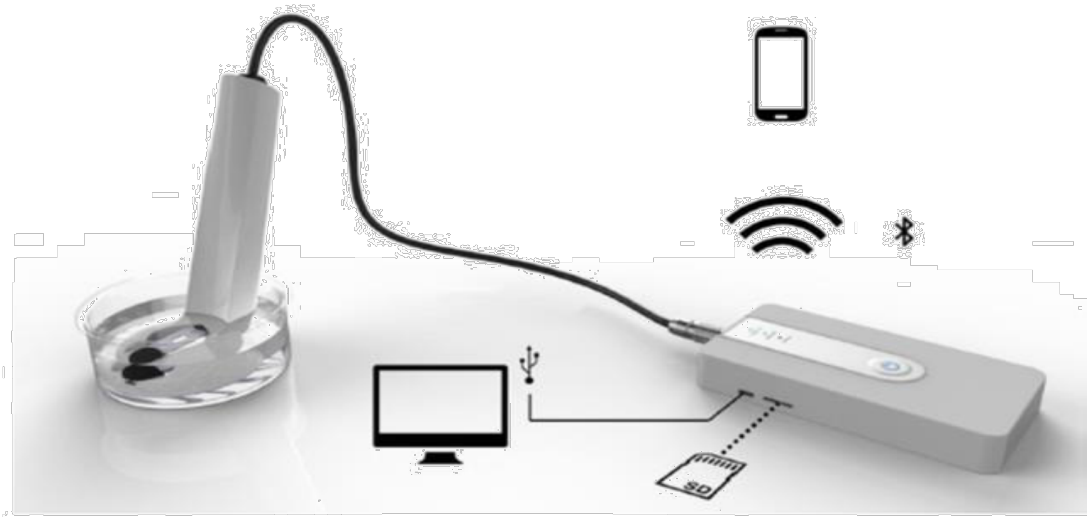
Early warning electrochemical sensors for monitoring toxic metal ions in water

Marie-Claude Clochard, CEA, France

Dr. Marie-Claude Clochard from Ecole Polytechnique presented her recent work on electrochemical sensors for monitoring toxic metal ions in water. This is one of many research themes of her laboratory that include energy (fuel cells, piezogenerators), nanoelectronics (pressure sensors), health (drug vectorization), the common factor being irradiated polymers. The topic was a functionalized nanoporous polymer electrodes sensitive and selective for heavy metal analysis. With their 3D nanostructure, which allows in situ sampling, these membrane-electrodes are ideal for self-monitoring of metals directly on-site. This technology relies on

ion-track etched nano-functionalized membranes made of a biocompatible, the polyvinylidene difluoride (PVDF). Poly-4-vinyl pyridine (P4VP), well-known to complex Hg(II) if grafted in PVDF track-etched membrane. After Au-sputtering, the resulting sensors measure mercury concentrations well below the limitations imposed by current standards for polluted soil leachate (EU directive of March 15, 2006). A performance evaluation on a set of natural water samples was performed to look at possible interferences. Finally, a first-generation prototype with an integrated potentiostat, a built-in software and a set of membrane-electrode pads was developed. A portable prototype has been developed and improvements are ongoing. It has the advantage of being portable, easy-to-use; very sensitive to detect Hg (II) and being capable of speciation of metal ions.

Protype



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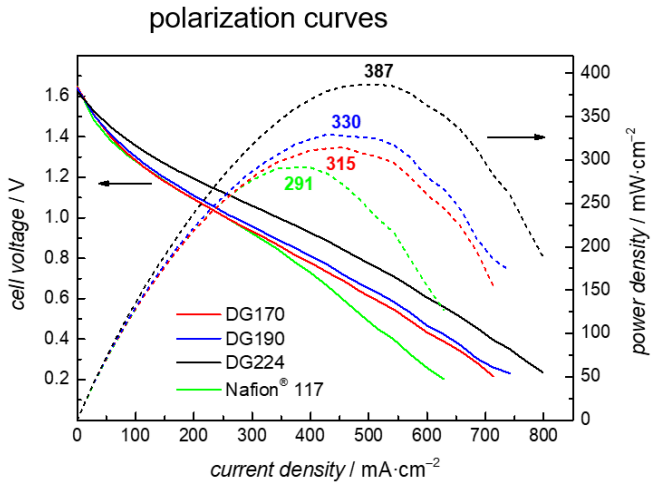
Polymer electrolyte membranes from pre–irradiation induced graft copolymerization on ETFE

Sabine Beuermann, Institute of Technical Chemistry, TU Clausthal, Germany

Polymer electrolyte membranes (PEM) are a key component in many fuel cells and in redox flow batteries (RFB). So far in most applications Nafion membranes are utilized. In search of alternate membrane materials various approaches are pursued. One of them is the radiation-induced activation of polymer films and subsequent graft copolymerization. In this contribution the preparation of PEMs in a three-step process was reported: firstly, commercially available fluoropolymer films, - poly(ethylene-co-tetrafluoroethylene) (ETFE), were activated via electron beam treatment; secondly, graft copolymerizations with functional methacrylates, e.g., hydroxyethyl methacrylate and glycidyl methacrylate, were performed; and finally, the functional groups were sulfonated yielding the final PEM. Alternately, co-polymerizations may be carried out with acrylic acid and hydroxyethyl acrylate, and subsequently the material is phosphonated to yield proton conductivity. The impact of the ETFE activation process especially the adsorbed dose on the grafting process, and consequently

the performance of the PEM was addressed. In order to reduce cross-over in vanadium redox flow batteries and to enhance the mechanical stability the polymerizations are carried out in the presence of crosslinkers. The electrical performance of the resulting membranes was evaluated by electrochemical impedance spectroscopy as well as in fuel cell and in vanadium redox flow battery (VRFB) tests. Stable electrochemical performance directly indicates membrane stability under typical VRFB conditions

PEM performance in VRFB



300 charge / discharge cycles performed

- almost no changes of the slope of the polarization curves
- PEM was stable in the VRFB during the whole process

challenge: crossover of electrolyte through PEM

CREDIT: X. LI, A. R. DOS SANTOS, M. DRACHE, X. KE, U. GOHS, T. TUREK, M. BECKER, U. KUNZ, S. BEUERMANN

Further studies and continuous development are in progress.

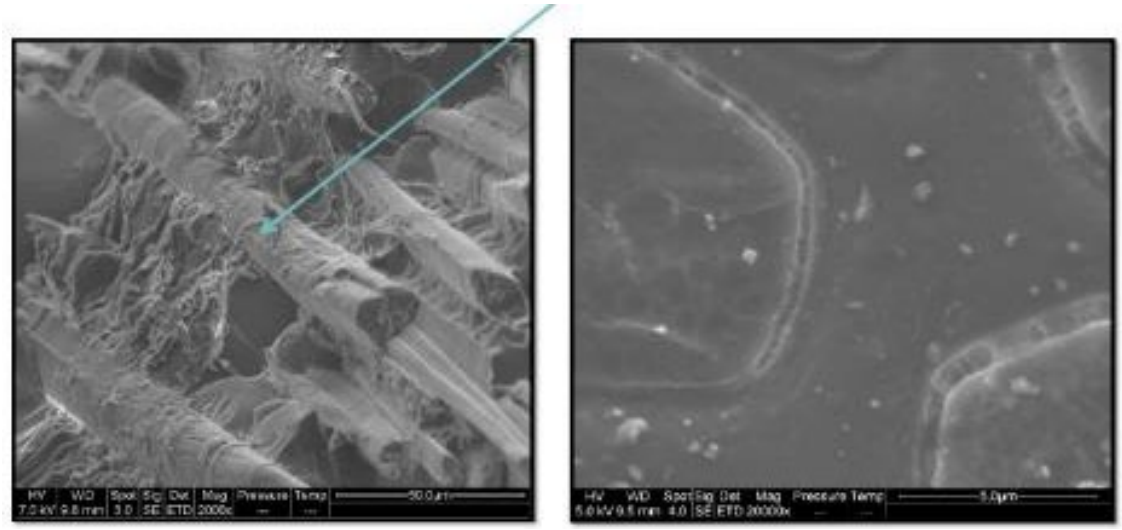
Composite reinforced by natural fibers modified by radiation induced grafting

Sophie ROUIF, Ionisos, France

Dr. Sophie Rouif, an R&D expert from IONISOS group, presented some interesting results on elastomer flax fabric and composites reinforced by flax fibers. Weight reduction allowed by low weight composites is of economic and environmental importance for transport, sports and leisure, and protective textiles. This work was driven by a need to replace glass fiber, which is not environmentally friendly. France produces 80% of the European market of flax which makes this research an attractive project. This work was conducted from December 2013 to the end of 2016 by seven partners and it is now being pursued by several of them. Adhesion between the fibers and the matrix is a major challenge for the use of polymer composites reinforced with natural fibers. The innovations concern the reinforcement of the fiber / matrix adhesion in the case of flax fibers with 2 different matrices (silicone elastomers or thermosetting), by means of the radiation-induced

grafting of an adhesion promoter (AP) on the fibers, intended to multiply the covalent interactions between constituents. Composites were made by stacking fabric, infusing it with epoxy resin, and curing. Several analytical methods have been used to characterize the grafting of AP on the flax reinforcement (dosing of free radicals, XPS) and the properties of the composites (tensile test, peeling test, microscopy).

Scanning Electron Microscopy after fracture ductile deformation demonstrating a connecting interphase between fibers and matrix



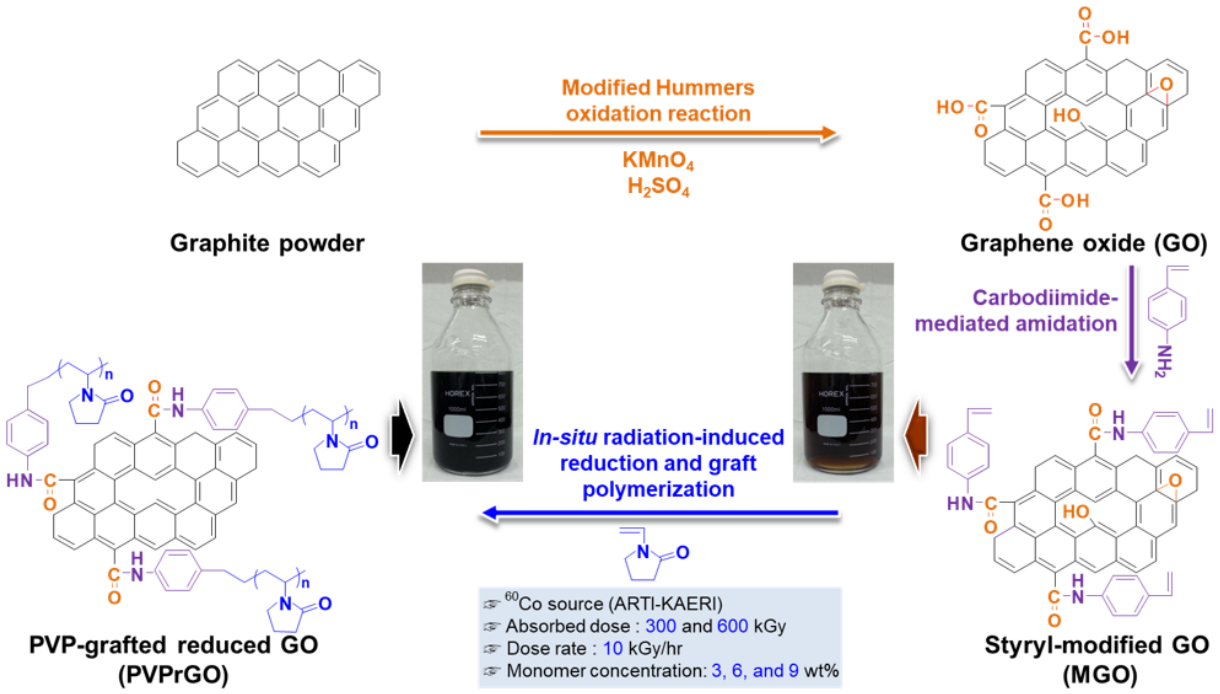
CREDIT: IONISOS

Solution processable polymer grafted reduced graphene oxide by irradiation

Junhwa Shin, Research Division for Industry and Environment, KAERI, South Korea

The interest in graphene nanoflakes (GNFs) is enormous due to their potentials in electronics, photonics, energy generation and storage, composites materials, and bio-applications. Nevertheless, the low dispersibility of GNFs in most solvents and matrices is a big hurdle for these applications. The purpose of the work was to prepare a solution-processable polymer-grafted reduced graphene oxide by using a reducing agent-free and room-temperature radiation technique and evaluate the solution-processed thin film. For the preparation of the poly(*N*-vinylpyrrolidone)-grafted reduced graphene oxide (PVPrGO), a modified GO (MGO) obtained by a coupling reaction of graphene oxide (GO) with 4-aminostyrene was dispersed in a monomer solution of *N*-vinylpyrrolidone (NVP) in DMF, and the resulting mixtures were then gamma irradiated at room temperature.

Preparation of PVPrGO



CREDIT: JUNHWA SHIN, KAERI

The analytical results showed that PVPrGO was successfully produced via γ-ray irradiation-induced reduction of MGO and simultaneous graft polymerization of NVP at the double bonds of MGO and that the properties depend on the grafting degree and absorbed doses. The grafting degree varied from 17% to 31% depending on the absorbed dose (300 or 600 kGy) and monomer concentration. The solution-processed thin film revealed that PVPrGO can form a full-cover uniform thin film with a good electrical conductivity, far superior to those from conventional GNFs. Results of UV-vis, FT-IR, XPS, Raman, XRD, and TEM analysis showed that the polymerizable styryl group is well bound to the COOH of graphene oxide (GO), and that PVPrGO is successfully prepared via gamma irradiation-induced reduction of MGO and simultaneous graft polymerization of *N*-vinylpyrrolidone at the styryl groups of MGO. The resulting PVPrGO showed long-term dispersion stability of 3 months, even at high concentrations of 5 mg/ml in 50 wt% aqueous EtOH or DMF. The PVPrGO exhibited a full-cover uniform thin-film morphology similar to GO and good electrical conductivity ranging from 0.003 to 0.95 S/cm depending on the grafting degree and absorbed dose, comparable to conventional GNFs.

HEALTHCARE: DRUGS & BIOLOGICAL PRODUCTS

Session chair: Dr Byron Lambert (Abbott, USA),

The oral communications and several posters illustrated the novel approaches that are being taken in these sectors: a growing preference for non-isotopic sources and the use of irradiation not only as a sterilizing agent to but also as a tool to create new products, including nanomaterials. Several Korean scientists showed that changes induced by irradiation can improve the properties and therapeutic effects of well-known drugs.

Radiation technologies for blood component processing

Lance Garrison, NNSA ORS, USA

Irradiating blood at 25 Gy (not kGy) using self-shielded cesium-137 is a well-established practice to avoid Transfusion-Associated Graft Versus Host Disease (TA-GVHD), a rare and usually fatal condition. Lance Garrison of the National Nuclear Security Agency (NNSA) presented a compelling case study of how regulatory bodies can appropriately incentivize change. In the US, the switch from cesium-137 to X-ray has been widely successful and is driven by a desire to enhance global security by removing the risk that high-activity radioactive materials could be used in acts of terrorism. The US aims to replace all cesium-137 blood irradiators with x-ray by 2027. Incentives for change uncovered new opportunities: UV Pathogen Reduction (platelets, plasma).

The other three presentations highlighted the power of radiation to facilitate development of vaccines and drugs.

Molecular characterization of i Salmonella Typhimurium and Clostridium Perfringens vaccine candidates irradiated by high energy electron beam

Sohini S Bhatia, Texas A&M, USA

Ionizing radiation has long been used as a processing tool in the medical and food industries for the inactivation of microorganisms. High energy electrons irreversibly damage nucleic acids by causing extensive double stranded breaks. We term this state the "Metabolically Active yet Non-Culturable (MAyNC)" state. In this MAyNC state, membrane integrity and metabolic activity are preserved, while irreversible DNA damage prevents replication. Thus, intact bacterial membranes preserve immunogenic and antigenic properties of attenuated vaccines, while lethal DNA damage assures the safety of killed vaccines. MinION sequencing by Oxford Nanopore Technologies identifies individual nucleotides by measuring changes in charge using nanopores. Because this sequencing platform uses long reads without further fragmentation, it can be used to analyze nucleic acid damage caused by high energy electrons. The objective of this study was to use MinION sequencing to analyze the genome of unirradiated and irradiated cells and examine whether molecular damage impacts MAyNC vaccine efficacy. *Salmonella* Typhimurium ATCC 13311 and *Clostridium perfringens* AUD1 were exposed to lethal doses of high energy eBeam at target doses of 2 and 10 kGy respectively. Culture methods confirmed inactivation. DNA fragment analysis and MinION sequencing was

conducted using DNA from unirradiated cells and irradiated cells 24 hours post eBeam exposure. Irradiated bacteria remained metabolically active despite the average length of DNA decreasing by at least 50%. These results emphasize the value of using MinION sequencing to analyze the biological state of MAyNC cells at a molecular level. Furthermore, these results suggest that MAyNC cells are able to serve as potential vaccine candidates.

Gamma irradiated prednisolone: A new drug candidate against cancer therapy

Hyoung-Woo Bai

Past studies have demonstrated the effectiveness of sterilization technique using gamma irradiation to improvement of several drugs, but less is known is the sterilization of prednisolone and its biological impact on liver cancer cells. The current study advanced this knowledge by further evaluating the consequences of gamma irradiation on prednisolone and elucidated its antitumor activity on liver cancer cells. Prednisolone was exposed to 50kGy radiation dose and the new refined product was corroborated with HPLC and LC/MS. Our results verified the formation of new daughter peaks together with the degradation of the main prednisolone peak. Moreover, the MTT assay revealed that irradiated prednisolone (IR-prednisolone) prevented the growth of liver cancer cells in a concentration and time-dependent manner. These effects were associated with apoptosis, then confirmed with DNA fragmentation, activation of cleaved caspases and PARP and alteration of the mitochondrial membrane potential by upregulation of Bax and downregulation of Bcl-2 expression. This study demonstrated that IR- prednisolone induced apoptosis through both intrinsic and extrinsic apoptosis pathways. In conclusion, this study is the first to report the effectiveness of gamma radiation for enhancement of prednisolone structure and its antitumor activity in Huh7 cells. These findings suggested the use of gamma irradiation technique for modifications of available drugs to provide more selection for cancer chemotherapy and cost reduction for new drug discovery.

Sericin with low doses of gamma irradiation reduced inflammatory response in skin cells

Young Ho Cho, Konyang University; South Korea

Sericin is a protein component of silk with many properties that are used for the formulation of cosmetics and drugs. The presentation showed that sericin-based biomaterials improve skin repair. As well, it has been suggested that increased reactive oxygen species (ROS) production and insufficient antioxidant system may be involved in various skin disorder because of the increased inflammatory response. Previously, it was attempted to develop a high-molecular-weight sericin by gamma irradiation to change its molecular structure, thereby increasing radical scavenging activity and inhibiting tyrosinase activity. However, the physiological activity of sericin was enhanced by irradiation with gamma rays, the molecular weight was too high to reach about 400 kDa more. In this study, we tried to improve the commercial application possibility by constructing optimal gamma irradiation doses for sericin. Low dose of gamma irradiated sericin exhibited more potent anti-oxidative activity and macrophage polarization to the M2 phenotype in cells and reduced anti-inflammatory response, compared with non-irradiated sericin. These results demonstrate that low dose

of gamma irradiated sericin protected against oxidative stress-induced cell death in part through the activation of Nrf2-mediated HO-1 induction and lowering the intracellular ROS content. Furthermore, low doses dramatically suppressed cytokine complex induced cell death and pro-inflammatory factors. From these findings, gamma irradiation below 10 kGy is effective for commercial applications in highly functional biotechnology products by increasing anti-oxidative and anti-inflammatory activity.

HEALTHCARE: DEVICES AND MATERIALS

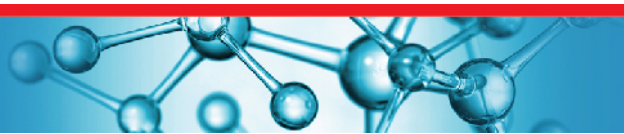
Session chair: Emily Craven (Mevex)

The second healthcare session consisted of four presentations which took the audience on a journey from basic research in materials, to clinical trials, to the characterization of established pharmaceutical products when sterilized with different radiation modalities, and finally to an industry collaboration looking a proactive characterization of polymers commonly used in medical devices to help enable transitions between radiation modalities.

The use of self-assembled polymerized fatty acids for corrosion protection of stainless-steel implants

Katarina Marusic, Research associate, Radiation Chemistry and Dosimetry Laboratory, Ruder Boskovic Institute, Zagreb, Croatia

Metals have biomechanical properties which make them suitable as an implant material. Among the used metals, stainless steel (SS) is the least corrosion resistant. Additional protection is needed to use SS in a larger variety of applications. Formation of a thin protective film on the metals surface is a good and practical way to enhance the metal's natural protective properties. Fatty acids are non-toxic compounds which have an affinity for adsorbing on metals with one end of their molecules, the carboxyl group. The rest of the fatty acids chain has hydrophobic properties and when adsorbed on the metal surface it makes the whole surface of the metal appear hydrophobic. Thus, by blocking access for water to the surface the dissolution of the metal is disabled. If the fatty acid is unsaturated the film can be polymerized by gamma irradiation making the film more durable and stable. Gamma irradiation can be a very convenient method for surface protection of implants which are commonly sterilized by gamma irradiation. In this case both polymerization and sterilization could be done at the same time. In this work elaidic acid was applied by self-assembling on the surface of SS forming a film which was then polymerized using gamma irradiation. The optimal conditions for the polymerization, as well as the corrosion resistance properties and stability, i.e. longevity of the film were investigated by electrochemical measurements. SEM was performed to analyse the structure of the metal's surface. FTIR analysis was performed to confirm polymerization occurred. Contact angle measurements were performed to investigate the hydrophobic properties of the metal's surface.



Combining sterilization with synthesis of nanoparticles for new wound dressings

Ademar B. Lugao, IPEN/CNEN-SP, Brazil

There is a pressing need for low cost wound dressings in developing countries. Hydrogels provide many benefits as wound dressing due to their mechanical properties, oxygen permeability, low adhesion to damaged tissue and pain control in addition to being relatively inexpensive to make. Radiation processing can be used to produce nanoparticles without the addition of reducing agents, producing a pure dispersion of nanoparticles with very well controlled morphology. Hydrogels composed of PVP, PEG, and agar produced by the *Rosiak process,* whereby molecular crosslinking and package sterilization simultaneously occur under irradiation, are used mainly as a wound dressing for chronic ulcers and wound burns. This presentation showed how this concept was extended in a different way: Production of wound dressings with metal (silver, gold, etc.) nanoparticles in a one-stage process, where, the ion reduction, nanoparticles stabilization, crosslinking of the gel and sterilization is done in a simultaneous way, the so-called one-pot process; The dressings were fully characterized by their mechanical properties, hydration and dehydration properties, and biological effect. The results showed that the mechanical properties were in the acceptable range and easily disregarded as a key factor for process control.

Hydrogels

CREDIT: IPEN

Effects of X-rays on active ingredients and pharmaceutical packaging

Iwan Weultjes, MSD AH, Netherlands

This presentation looked at active pharmaceutical ingredients which are currently sterilized with gamma, and individual impurities resulting from irradiation when compared between different radiation modalities. A comparative demonstrated that the amount of any impurity depended on both the modality and the dose applied, and that no one radiation source was clearly superior across all impurities. However, in all cases, impurity levels were within acceptable levels. This work provides evidence that it is important to test radiation effects on impurities in drug products when changing modalities. In polyethylene primary packaging, the maximum force to push a plunger in a cylinder was comparable up to 30 kGy but above E-beam required the lowest force.

Filling data gaps related to material effects in polymer medical products from e-beam and X-ray sterilization

Mark Murphy, Pacific Northwest National Laboratories, USA

In the medical device industry, currently it is estimated that 40.5% of products are sterilized with cobalt-60 gamma-rays, 4.5% with electron-beam (e-beam), and less than 1% with X-ray radiation. Due to growing safety regulations governing cobalt-60 use, continued advancements in e-beam and X-ray accelerator technology, and the greater irradiation durations and costs for cobalt-60 irradiation compared to e-beam and X-ray, switching to these non-radionuclide modalities is increasingly competitive. However, the breakdown of 40.5% cobalt-60 and 5.5% accelerator for product sterilization illustrates the difficulty that market forces and industry players have had in overcoming financial obstacles involved in the comprehensive irradiation testing of particular polymers, elastomers or associated medical devices, and in the construction of new e-beam and X-ray facilities. In this study, the National Nuclear Security Administration (NNSA) within the United States Department of Energy (DOE) has provided R&D funding to the Pacific Northwest National Laboratory (PNNL) in partnership with university researchers, leading medical product manufacturers, and contract sterilizers. The goal of this study is to determine which polymer and/or elastomer products involve the greatest data gaps and would be of greatest industry impact, to measure any physical effects that these materials exhibit when they are given sterilization-level radiation doses from e-beam or X-ray, and to determine whether these effects would preclude the use of e-beam or X-ray for associated medical products. . The collaboration will consider both commonly used polymers in medical device manufacturing as well as some commodity medical devices (such as the Becton-Dickinson blood *Vacutainer™* tube) which are presently sterilized by gamma. *Team Nablo*- named in homage to Samuel Nablo (1931-2018, IMRP Laureate) - includes medical device manufacturers, sterilization service providers, radiation equipment suppliers, university researchers and a US national laboratory. The data results will be communicated through industry conferences, posted on publicly accessible websites, and published in a peer-reviewed journal. For this conference the project status and some preliminary data will be presented.

COMPLYING WITH HEALTHCARE STANDARDS AND REGULATIONS

Session chair: Eamonn Hoxey

The third session in the healthcare strand focused on challenges in complying with the standards and regulations that are applicable to providing healthcare products that have been sterilized using radiation.

The new Society for Sterility Assurance Professionals

Arthur Dumba, United Kingdom

Arthur Dumba highlighted that new Regulations require manufacturers to ensure that personnel involved in the sterilization of products are competent but noted that the Regulations are silent on the way that competency is to be evaluated and determined. The need for competent staff includes those employed by both manufacturers and sub-contract sterilizers. Consequently, there is an opportunity for collaboration to create a framework against which sterility assurance professionals can be evaluated. The iia has taken a lead in supporting the initiative which now has the support of ASTM and several leading medical device manufacturers. The Society for Sterility Assurance Professionals was created as an umbrella organization to allow the collaboration to take place.

Arthur introduced the focus on the requirements for competence of personnel performing work affecting the quality of healthcare products as well as the staff that are assessing conformance with regulatory requirements. Competency includes three fundamental elements; knowledge, understanding and experience in application. Arthur noted that competence is derived from education, training, skills and experience but highlighted that there are no agreed criteria for assessing whether personnel possess the required level of competence. The Society for Sterility Assurance Professionals aims to provide an agreed pathway for sterility assurance professionals across manufacturers of healthcare products, sterilization service providers, conformity assessment bodies and regulatory authorities.

Medical Device Irradiation Sterilization	Acquire Knowledge	Requirements	Understand Execution	Demonstrate Understanding	Acknowledge Competence
Curricula Required	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**
Maximum acceptable dose: ISO 11137 Parts 1 and 2, TS13004, AAMI TIR 40, AAMI TIR 35, AAMI TIR 17, Panel Guide on the establishment of the maximum acceptable dose (Dmax,acc) for a product	K	U	A	A	KUAA
Dose Establishment: VDMAX / Method 1/ Method 2 ISO 11137 Parts 1 and 2, TS13004, AAMI TIR 40, AAMI TIR 35, AAMI TIR 17	K	U	A		KUA
Dose Mapping (Performance Qualification Requirements): ISO 11137 Part 1, 3, 4 and ISO/ASTM 52303.	K	U	A	A	KUAA
Dose Mapping (Operational Qualification Requirements): ISO 11137 Part 1, 3, 4 and ISO/ASTM 52303.	K	U			KU
Dose Audit & Dose Augmentation, and routine maintenance/Requalification: ISO 11137 Parts 1 and 2, part 4	K	U	A	A	KUAA
Dosimetry and terminology: ISO/ASTM 52628, E3083	K	U	A	A	KUAA
Dosimetry System Calibration: ISO/ASTM 51261	K	U			KU
Irradiation (technology specific) and terminology: ANSI Category II, III and IV standards. ASTM Gamma, ebeam, Xray documents. IAEA Safety Series 8.	K	U	A	A	KUAA
Reading and Handling dosimeters: ISO/ASTM 52628 ISO/ASTM 51649 (Electron Beam Energies between 300 keV and 25 MeV) Used in conjunction with the relevant ISO/ASTM standard that pertains to the dosimetry system being used: ISO/ASTM 51275 (for radiochromic film) ISO/ASTM 51607 (Alanine-EPR Dosimetry System) ISO/ASTM 51650 (Cellulose Triacetate Dosimetry System) may be adquate in addition to 52628.	K	U	A	A	KUAA
Product Family Adoption: AAMI TIR 35	K	U	A	A	KUAA

The modern accelerator and parametric release

Emily Craven, Mevex Corporation, Canada

Emily Craven discussed the potential for parametric release for products sterilized with both gamma and electron beam irradiation. ISO 11139 defines parametric release as a *declaration that product is sterile based on records demonstrating that the process variables were delivered within specified tolerances.* ISO 11137-1 requires the placement of dosimeters at one or more predetermined routine monitoring positions and for the results of these dosimeters, along with the monitoring of the process parameters, to be reviewed in order to release product as sterile.

Dosimetric release is standard practice in radiation sterilization to demonstrate that a process is in a state of control. However, the way that routine monitoring is performed in electron beam processing vs gamma processing provides a contradiction. In electron beam it is accepted practice to monitor routine doses on an

apparatus that is independent of product and therefore only captures variations is dose delivery. In gamma by contrast, the radiation properties are measured during OQ and completely predictable over time through decay, so the only useful measurement that the dosimeter is making is of the effect of the product. Two questions ensue: 1) If we are allowed to rely on administrative controls in electron beam to ensure that product is properly packaged and placed in an irradiation container, why is this not allowed for gamma? and 2) If we can provide a real time measurement of beam properties in electron beam that is more stable and reliable than dosimeters, why is dosimetric release still a requirement?

Emily discussed the developments in measuring the parameters of an electron bean irradiator and compared data from parameter measurements and dosimeter readings. It was concluded that parametric release is being used by other sterilization processes that have far less data collection, monitoring and control than electron beam does. Parametric release could significantly improve process capability in e-beam, and with it the ability to process more products which have tight does requirements. While we might not be there yet today, in the future parametric release for electron beam could be achieved with proper validation of novel tools that provide a real time measurement of beam energy and position.

Process dose vs product dose

Hervé Michel, STERIS, Switzerland

The presentation also discussed product release from radiation sterilization, comparing the use of a process dose to a product dose. He contrasted the product dose, the dose received by the sterilization load, with the process dose, the dose delivered at a given location. The goal of a radiation process is to expose a product to a radiation field and ensure that the dose received by this product is within given specifications. To demonstrate that the goal has been achieved, different methods were compared using example data:

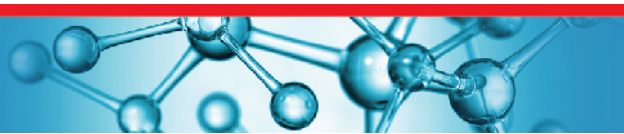
- Measuring the minimum and maximum dose during the routine process directly,
- Assessing the minimum and maximum dose received by the product based on a measured dose at a monitoring location and the minimum-maximum dose ratio, or
- Demonstrating that the process is controlled by monitoring a dose in a defined location.

It appeared that there were advantages in assessing dose to demonstrate that the process is under control as it can provide a better statistical approach to determining process output.

Application of recovery efficiency per the new ISO bioburden standard

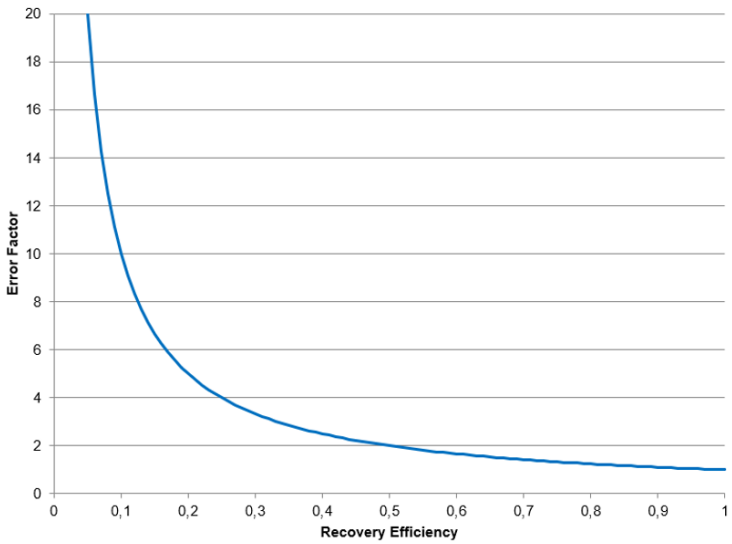
Martell Winters, Nelson Laboratories, USA

Martell Winters discussed the use of estimates of recovery efficiency in the determination of bioburden. The recovery efficiency is the ability of an extraction method to remove microorganisms from a product so that their number can be determined. The new version of the ISO bioburden standard, 11737-1:2018, no longer has a recommended minimum value for recovery efficiency. Previously the standard recommended that recovery efficiencies be greater than 50%, although the 50% value was arbitrarily established. In the revision process it was determined by the ISO working group that a more appropriate recommendation is to focus



on the consistency of the data and to consider the purpose for the use of the data. The recovery efficiency can be used to adjust the raw data of the number of microorganisms to take account of the microorganisms that have not been removed from the product. The presentation considered what level of recovery efficiency was required for a bioburden method and concluded that this depended on the use to which the data was to be put. Statistical analysis was presented to investigate acceptable ranges to recovery efficiency in the context of the level of bioburden being determined. Martell concluded that recovery efficiency can introduce a significant error to the estimate of bioburden, particularly if the recovery efficiency is low.

Error Factor induced by a Recovery Efficiency compared to a Perfect Recovery Efficiency (100%)



RECOVERY EFFICIENCY	ERROR FACTOR
10%	10.0
20%	5.0
40%	2.5
50%	2.0
60%	1.7
80%	1.3
100%	1.0

A recovery efficiency of 10% increases by a factor of 10 the error on the bioburden estimate

CREDIT: NELSON LABORATORIES

FOOD IRRADIATION

Session chair: Dr Carl Blackburn, IAEA

Surface treatment of shell egg by low energy electron beam

Noriaki Kataoka, Tokyo Metropolitan Industrial Technology Research Institute, Japan

Shell eggs are a significant source of cross-contamination and Salmonella infection, especially in countries where raw egg is consumed widely. Noriaki Kataoka presented the results of a series of experiments designed to develop a dry treatment to ensure that the external surface of shell eggs is free from *Salmonella enteritidis*. This would be preferable to the current commercially applied surface treatment involving rotating eggs conveyed through a wet process where a disinfectant plus a hot water wash is followed by warm air drying. The external surface of the eggshell is the major source of contamination. The concept investigated was the ability to deliver a dose that is enough to destroy Salmonella on the external surface of whole eggs without

exceeding 0.1 Gy in the edible portion of the egg. Indeed, legislation in Japan is such that at 0.1 Gy the egg would not be considered irradiated food. The results indicate that electrons of 80 to 150 kV are optimum for imparting a dose to the shell of more than 6 kGy but less than 0.04 Gy to the internal egg. In factories egg conveyor systems rotate eggs as they pass through the wet process and this mechanical process would also be necessary to ensure that an EB could irradiate the entire external shell surface. Experiments determined the optimal parameter settings for the effective irradiation of shell eggs on a system that mimicked the type of egg conveyor used in industry including the effects of conveyor speed and egg rotational velocity. Research also determined the effect of egg size on the internal dose to the edible egg portion and focused on six standard egg size categories.
An EB machine for in line surface irradiation of shell eggs in line is still to be manufactured but this work demonstrated that it is technologically feasible.

Phytosanitary irradiation: Does MAP creating a low oxygen environment threaten treatment efficacy?

Peter A Follett, USDA ARS, USA

Peter Follett investigated the efficacy of phytosanitary irradiation treatments of sealed packages containing low molecular oxygen concentrations. Modified atmosphere packaging (MAP) is used widely in the food industry to prolong the shelf-life of food, including fresh fruit and vegetables, by excluding molecular oxygen. Molecular oxygen enhances the effectiveness of ionizing radiation to damage biological systems and most PI treatments state a minimum absorbed radiation dose that is effective against pests at ambient atmospheric oxygen levels. Hence the concern that these doses might not be sufficient at MAP conditions and then irradiated. The efficacy of the PI treatment is not usually established for pests held in low oxygen systems. Experiments with large numbers of three specific pests indicate that the pests are weakened by maintaining the low oxygen atmosphere post irradiation. In contrast to published literature, this study maintained the MAP post irradiation. This post-irradiation weakening counters the radioprotective effect of MAP to some degree. The conclusions were that MAP can indeed provide radioprotection but at sublethal radiation doses and very low oxygen concentrations. Approved irradiation doses overwhelm any radioprotective effects and under commercial conditions, MAP might in fact improve control due to toxicity of low O_2 and high CO_2. On this basis, restrictions relating to MAP should be reconsidered.

Antifungal and insecticidal activity of nanocomposites-based films containing encapsulated nanoemulsions of essential oils

Monique Lacroix, Institut Armand Frappier, Canada

Plant essentials oils have antimicrobial and insecticidal properties. Bio-nanocomposite based packaging containing plant-derived essential oils (EOs) is currently playing an important role in food industry. When encapsulation under nanoscale, the bioactivity of EOs can be enhanced, thereby enabling the reduction of the EOs doses required to ensure the biological activity. Biopolymeric films are ideal matrices for incorporating active compounds. Nanocrystaline cellulose (CNC), has reinforcing properties and can improve

the physico-chemical properties of biopolymers, as well as assuring a control release of active compounds during storage. Combining irradiation with active films can increase microbial and insects radiosensitivity and reduce the dose of individual treatment while maintaining the quality and safety of the food product. The fumigant toxicities of eight individual essential oils and binary combinations were investigated against the rice weevil *Sitophilus oryzae* and four fungi. The formulations developed (tea tree or mint in combination with thyme) showed significant antifungal and insecticide properties. Bioactive films based on chitosan and CNC showed the highest biological activities, maintains effectiveness and slow release of EOs during storage. Combination of active films based on chitosan and CNC with γ-irradiation (750 Gy) was synergistic and caused 4 log UFC/gr reduction of fungi for more than 8 weeks and a 95% insect mortality was observed after 10 days of storage. These results showed that the bioactive films and γ-irradiation in combination could be commercially used to control pests and extend shelf life of rice products.

Food irradiation: A regulatory false positive?

Steffen Foss Hansen, DTU, Denmark

The presentation was based on the assessment of food irradiation in relation with the precautionary principle (PP). The PP is used in a variety of forms by policy makers where an activity raises questions about risks or safety and precautionary measures are deemed necessary even though no scientific cause and effect relationship has been proven. The presentation focused on how food irradiation is one of four examples (with swine flu; saccharin and Southern leaf corn blight) where the application of the PP, has in hindsight, proved to be unnecessary and has led to over regulation. Safety evaluations over some 30 years have indicated that the process is safe when applied correctly.

PLENARY SESSIONS OF THURSDAY APRIL 4, 2019

DOSIMETRY AND MODELLING

Dosimetry is at the core of radiation processing. Over the past decades considerable progress has been achieved and many standards have been developed to give more confidence in the dosimetry systems. Still, many would like to see dosimeters that would be easier to use without requiring the level of knowledge that is currently necessary. Some even dream of not having to use dosimeters at all. While this is unlikely to happen very soon for medical or food applications, approaches such as modelling and parametric release will in time reduce the need for dosimeters.

Modelling to predict or optimize dose distribution or throughput

Christopher Howard, Nordion, Canada

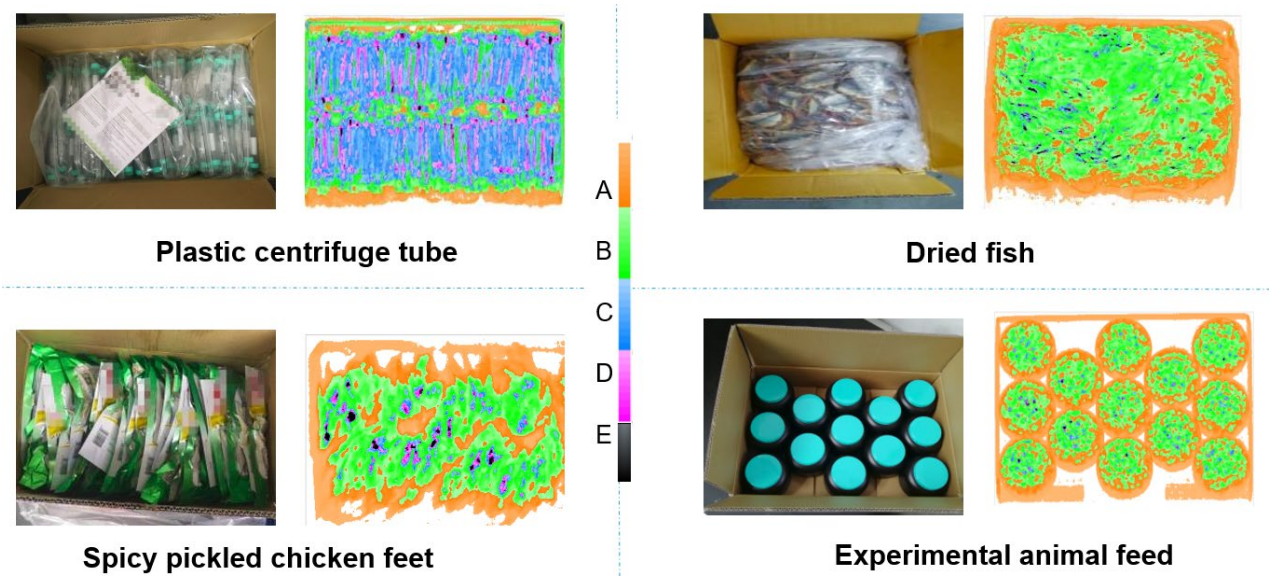
Mathematical modelling is a powerful tool for predicting the dose delivered in a gamma irradiator, but it is still under-used in the radiation processing industry. Mathematical modelling can be used to streamline process qualification and feasibility studies. Christopher Howard of Nordion described how the gamma irradiation of an actual medical device was modelled. Mathematical modelling was used first to predict the outcome performance qualification, including optimization of dosimeter placement and product configuration within the irradiation container. Then, the product was dose mapped and irradiated using the common performance qualification approach. The match between the results of the dose to product and the dosimeters readings were presented. This type of work can be used to optimize dose distribution or throughput. It can also lead to improvements in the gamma irradiation process, possibly lead to the reduction of the number of dosimeters required in routine, and the virtual validation of the product, its packaging and orientation.

Image of mass thickness distribution using an X-ray detector

Qin Huaili, Nuctech, P.R. China

The Chinese company Nuctech is one of the world leaders in X-ray inspection systems. Nuctech suggests developing the technology of X-ray detection to quickly measure the mass thickness of the items to be irradiated by accelerated electrons in order to predict dose distribution and if the packaged product will be treated within specifications. Mass thickness is indeed the most critical factor to control the quality of E-Beam irradiation processing.

Image of mass thickness distribution in various packaged products



CREDIT: NUCTECH

An algorithm for an X-ray mass thickness detector was developed. The product is divided in many columns parallel to the incident beam direction. Mass thickness values are obtained for each portion, each column being 1.5mm by 1.5mm. A series of mass thicknesses is thus obtained. For example, 53,000 data points are obtained for an item 40 cm long and 30 cm wide. Using the mass thickness data, dose distribution within the item can be predicted. Through Monte-Carlo simulation, the values of the maximum dose and minimum dose can be obtained. A user-friendly software system was also developed. It generates a perspective image of the item showing the mass thickness distribution and dose distribution. An analysis report includes DUR values and suggestions of arrangement to meet the DUR requirement at different energy levels.

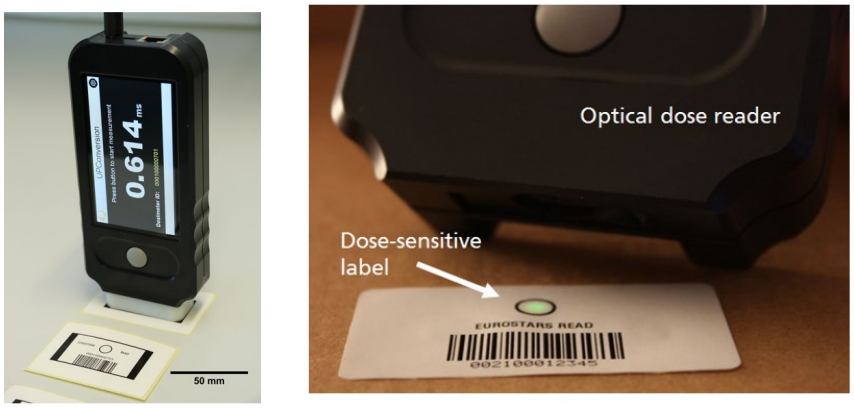
Novel dosimetric approach using irradiation sensitive inorganic phosphor

Christiane Schuster, Fraunhofer Institute for Ceramic Technologies and Systems, Germany

Dose measurement is essential for OQ, PQ and routine monitoring. However, most dosimetry systems presently used are time-consuming as they do not lead to instant results in a continuous process. They are difficult to use if not inapplicable for 3D dose mappings and dosimetric sensitive materials are usually too thick to allow optimization of radiation processes in terms of lateral or depth dose distribution when irradiated with low energy e-beams.

Christiane Schuster presented a solution being developed by Fraunhofer, Aérial and Freiberg Instruments GmbH. The new dosimetry system is based on an inorganic phosphorous material. It was observed that the applied E-beam dose correlates with the luminescence decay time of the phosphor, thus allowing dose determination. The dynamic range of the luminescence response ranges from 0 to 100 kGy with the highest sensitivity between 0 and 10 kGy. The phosphor powder can be integrated into polymer matrices to formulate inks and lacquers which allows labelling of specific surface areas or coating of entire 3D product surfaces prior to radiation exposure. Furthermore, with adjusted phosphor particle size, a dosimeter of less than a few micrometers thickness could be produced for the measurement of high-resolution dose depth profiles. The first results on the characterization of printed radiation-sensitive paper labels were presented with a project of hand-held optical device for simultaneously reading the absorbed dose and a barcode for coding product and dosimeter information.

Prototype of hand-held optical device that can read both a barcode and an absorbed dose



CREDIT: FRAUNHOFER, AÉRIAL AND FREIBERG INSTRUMENTS GMBH

Absorbed dose to water determination by alanine EPR dosimetry

Abbas NASREDDINE, Aerial-CRT, France

Low energy X-ray generators now appear as potential alternative solutions for blood bags, seeds or some food products. The future developments call for adequate dosimetry systems to perform IQ/OQ/PQ and monitoring. Passive dosimeters such as alanine are now most commonly used to measure absorbed doses in X-ray cabinets. Abbas Nasreddine of Aérial and his colleagues investigated the water equivalency of alanine dosimeter, for low energy X-ray irradiation. Previous studies reported a lower response of the alanine dosimeter for low energy X-ray compared to cobalt-60 irradiation, which can lead to underestimating by up to 30% of the true absorbed dose to water. Thus, two correction methods were investigated in order to estimate the true absorbed dose to water using alanine dosimeters. The first correction method consisted in determining a relevant X-ray beam specifier in order to relate this physical quantity to the alanine to water dose ratio determined by Monte Carlo simulations. At first, the X-ray spectrum's effective energy E_{eff} was the chosen beam specifier. Results were compared to ratios of absorbed dose to water between alanine and ion chamber measurements. The second correction method consisted in weighting the X-ray spectrum by the energy mass absorption coefficients. The results of both correction methods showed that using the E_{eff} as the sole beam specifier could induce an inaccuracy up to 8%. Alanine to water dose ratio calculated by Monte Carlo simulations showed a good agreement with the results of weighting the whole X-ray spectrum by the mass energy absorption coefficients. The correction protocols and results that were presented enable users of low energy X-rays to measure more consistently the true absorbed dose with Alanine /EPR dosimetry systems.

NIST high-dose program and the future of chip-scaled radiation dosimetry

Ileana M Pazos, National Institute of Standards and Technology, USA

Ileana Pazos of NIST Physical Measurement Laboratory presented the two main calibration services offered by her Institute: i) calibration irradiations of customer supplied dosimeters with Co-60 gamma rays and ii) dose interpretation of customer irradiated NIST transfer dosimeters. While these services support conventional high-dose and high-energy ionizing radiation applications, there are technical difficulties to extending traceability for applications that involve low-energy electron beams or heterogeneous materials, wherever the resulting dose fields are highly non-uniform over the scale of existing dosimetry systems. Over the past two years, NIST has initiated a research program into developing micron-scaled sensors for addressing such challenges. Initial investigations demonstrated the durability of silicon photonic devices in Co-60 and 1 MeV electron fields, while more recently, NIST has obtained the time-resolved response of these devices to radiation heating. The results establish the feasibility of real-time dosimetry measurements at microscopic spatial scales. NIST expects that this technology could have wide applicability to the current and future field radiation processing.

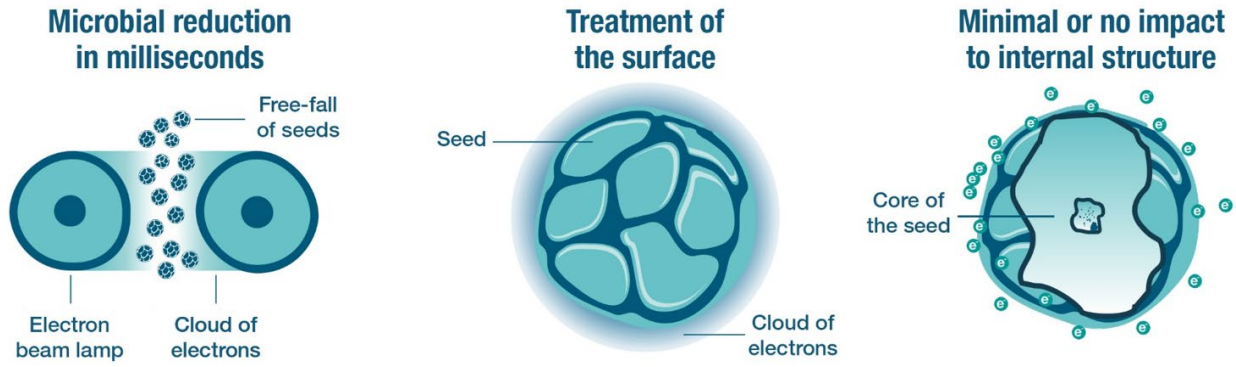
LOW ENERGY ELECTRON BEAMS AND X RAYS

Over the recent years there has been an increasing interest in low energy electron and X rays (300 keV maximum). Their very low penetration can be sufficient for surface treatments. Chemical modification by low energy machines – curing - is a classic application in the film and package industry. Using low energies to sterilize insects (SIT) or to inactivate microorganisms is more recent and seems to be finding its way for packaging, food and medical devices. Other applications in radiation chemistry and for environmental purpose are also being suggested.

First machine installed for the low energy electron irradiation of food ingredients

Nicolas Meneses, Bühler Group, Switzerland

Dry foods with low-water activity (a_w < 0.85) do not support microbial growth and are often considered a low risk. However, while growth does not occur in dried foods, vegetative cells and spores can remain viable for several months or even years. This means that dry foods may still carry food-borne pathogens, such as Escherichia coli O157:H7 or Salmonella and pose a significant risk to consumers. The Bühler Group, a leading manufacturer of food processing solutions, screened 18 physical processes for microbial inactivation and insect disinfestation used for dried foods. Their conclusion was that low energy electron beams are optimal to meet the requirements of effective and rapid reduction of microorganisms, higher product quality, environmental sustainability, ease of use, small footprint, and low cost. In the process that Bühler developed, a curtain of seeds free-falls between low energy electron beam lamps where each seed is homogeneously exposed to a cloud of electrons. Due to the low energies of the electrons, only surface of the seed is treated, preserving the internal quality of the seed.



CREDIT: BÜHLER GROUP

Within milliseconds, which is enough to inactivate the microorganisms, each seed is homogeneously exposed to low-energy electrons. The effect and depth of inactivation is controlled via the number and energy of the electrons (less than 300 keV).

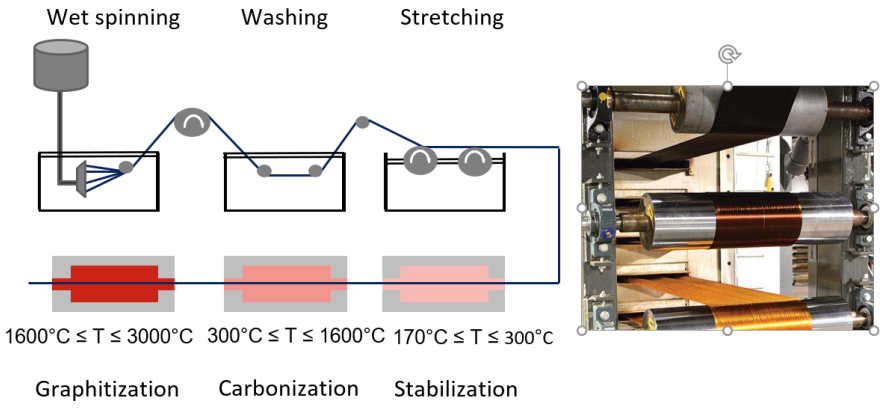
The Laatu™, an equipment to decontaminate spices that can be easily integrated into existing processes was introduced at the Hannover Messe in 2019. Applications to other dry foods are under development.

CREDIT: BÜHLER GROUP

In-line electron beam modification of polyacrylonitrile precursor fiber

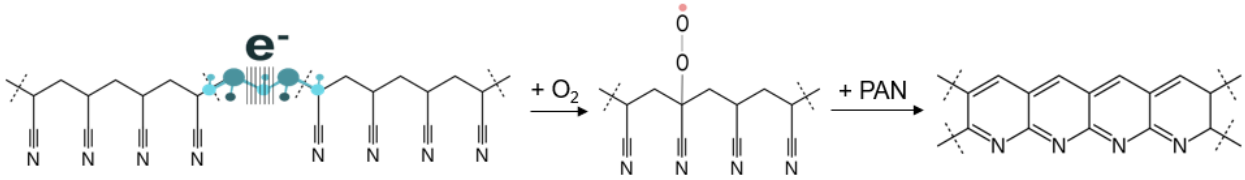
Anne-Katrin Leopold, Leibniz Institut für Polymerforschung Dresden, Germany

Four times less dense than steel with high strength and high modulus, carbon fibers production grows at 10-13% per year but remain expensive. Polyacrylonitrile (PAN) fibers are the most commonly used precursor to produce carbon fibers.



CREDIT: LEIBNIZ INSTITUT FÜR POLYMERFORSCHUNG

The thermoplastic PAN must be converted into a non-plastic ladder polymer in order to withstand its further processing at higher temperatures (T ≤ 1600 °C). As a possible substitute to the energy and time-consuming thermal stabilization phase, irradiation by electron beam (EB) was tested as a new method to stabilize the PAN precursor fiber after their wet spinning.



The processing parameters of wet spinning are highly influencing the physical structure which is decisive for the EB induced chemical reactions with as-spun precursor fiber. A coagulative bath was used to precipitate the fiber, which was continuously stretched during washing in three water baths with varying temperatures. Finally, the precursor fibers were dried and coated. The EB treatment was probed at various steps. The influence of temperature, atmosphere and stress during spinning on the electron induced chemical reactions of PAN was studied as function of dose. After EB treatment, all samples were stored in air at room temperature and comprehensively analyzed in order to determine the optimum processing parameters. The results showed an influence of temperature on the electron induced cyclization. Dose rate also has an influence on which also affects the electron induced cyclization.

It was demonstrated that in-line EB treatment of PAN precursor fibers, at temperatures above the glass transition temperature, offers a new and accelerated process of in-line stabilization. Further experiments in order to construct an in-line electron beam treatment are planned.

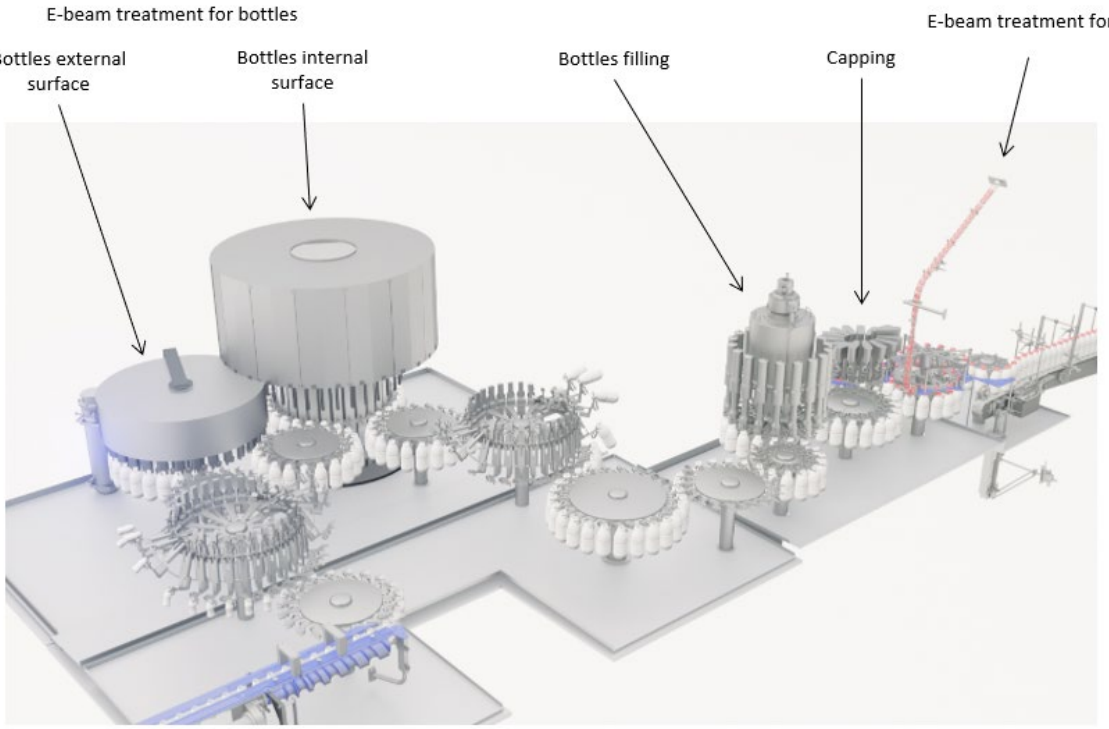
Low energy EB decontamination for aseptic filling

Nicolas Geslot, SERAC, France

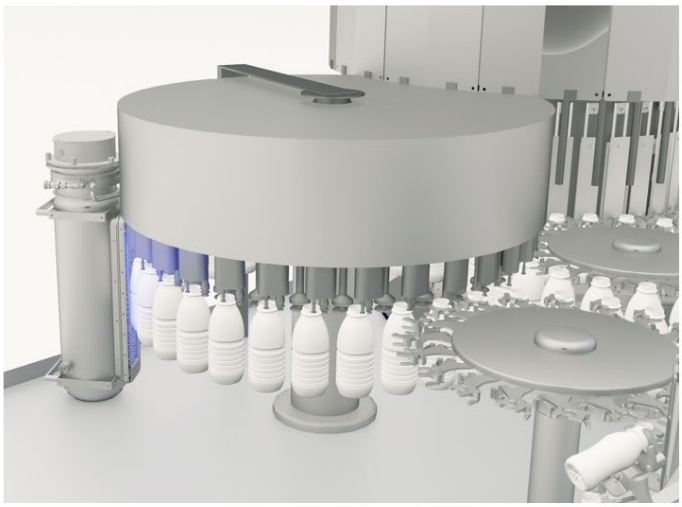
Serac is a well-established French Group with subsidiaries in Brazil, France, Malaysia and the United States. Serac manufactures machines to fill and cap bottles, but also to decontaminate bottles, aluminum lids and caps. The dairy market is half of the business. Since 2017, Serac has been offering a system called BluStream based on electron beams to decontaminate bottles and caps and fill them aseptically. The FDA-approved BluStream machine can aseptically fill up to 600 PET or HDPE bottles of 50 ml to 10 l per minute using doses of 9 to 25 kGy.

A first electron emitter named ITB, for Internal Treatment Bottle is made of a long nozzle that goes into the bottle to decontaminate the whole internal surface. The voltage is 125kV and the emitted current can reach 2,5mA. A second type of emitter, named OTB for Outside Treatment Bottle, has a large and long window to decontaminate the whole external surface of bottles. Both the voltage and the current are higher: 150kV up to 25mA.

The BluStream aseptic filling system



Bottles infeed by conveyor and screw



External bottle decontamination

Bottles rotate in front of a fixed flat OTB emitter (left). Machine speed linked to current.

Internal bottle decontamination

Bottles are brought up around the fixed ITB emitters (top). 15 to 40 ITBs in function of machine speed. Motion depends on bottle size.

WITH PERMISSION FROM SERAC

The system has many advantages:

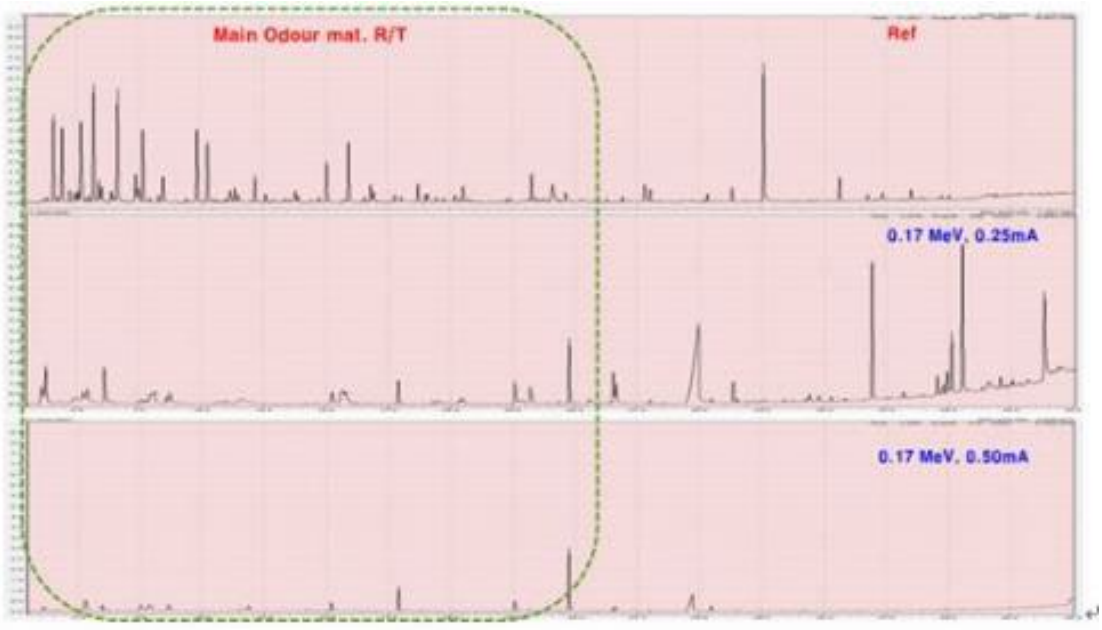
- It requires no chemicals, no water and no compressed air;
- It can be maintained without loss of production and the emitters have a lifetime longer than 10,000 hours;
- Three parameters to control (tension, current and time) Instead of six or seven for hydrogen peroxide or peracetic acid;
- The bottles can be made with less PET than with chemical sterilization;
- No humidity and less noise in the machine environment and no residues on the bottles and lids.

Removing odors from gaseous effluents by low energy electrons

Byungnam Kim, Korea Atomic Energy Research Institute, South Korea

A low energy electron accelerator (LEA) is an effective tool for low density target materials such as gases. The penetration depth in air is more than 30 cm on a 0.2 MeV electron accelerator. In a joint study of KAERI and ECOCORE in South Korea, an LEA was used for in-situ purification of the air exhaust coming from a ventilation line in a food factory in order to remove bad odors. The initial Odor Unit [OU] in the air of a sesame oil factory was 14,422OU. The odor decreased to less than 30 OU after electron beam treatment at 0.17 MeV, 0.25mA, with a flux of 46 l/min. This means that the electron treatment removed 99 % of the odor. In a GC-MS analysis the same results as in a sensory test were found. Before industrial application there are still a number of hurdles including low penetration depth, small irradiation area and short lifetime of electron guns.

GC-MS analysis of odorous substances



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TECHNOLOGICAL INNOVATIONS

Gamma irradiation is a robust and proven technology that has been in use for more than half a century. There has been little technical evolution other than the introduction of IT to control and monitor the process at the end of the 20th Century. There is no need to change something that works but rendering their ageing irradiators more efficient or more flexible is on the agenda of many operators. The situation is quite different with accelerators. Competition between a growing number of manufacturers and the pressure from clients for more reliable, efficient and flexible machines have been strong drivers for innovation.

Modernization of a gamma sterilization facility

Matthias Lamm, Framatone, Germany

Worldwide more than 200 gamma irradiators are currently in operation and the demand for sterile medical devices continues to grow by 4 – 5% per year. This demand will fill the licensed capacity in 5 to 6 years. However, the ability to expand the capacity of the existing irradiation facilities is limited. Due to the advancing plant age, the availability of the facilities is additionally limited by the growing maintenance need of automation and conveyor technology, technological obsolescence and decreasing spare part supply.

Innovative methods for more precise dose rate calculation and innovative technologies for a higher processing flexibility and faster process times were presented as this provides a mechanism to expand throughput and hence capacity without having to invest in new facilities. By precisely recalculating the dose distribution, the source loading can be optimized, whereby higher dose rates and higher throughputs or more uniform treatments can be obtained. More robust conveyor systems also enable the processing of mixed goods at a faster pace. These upgrades contribute to an economic and safe system operation in the long term.

The modernization of the medical sterilization facility of BBF in Kernen, Germany, built in 1969, was taken as an example. This project demonstrated how upgrades of the automation systems, conveyor system and radioprotection calculations go hand in hand for a successful long-term operation of gamma irradiation facilities.

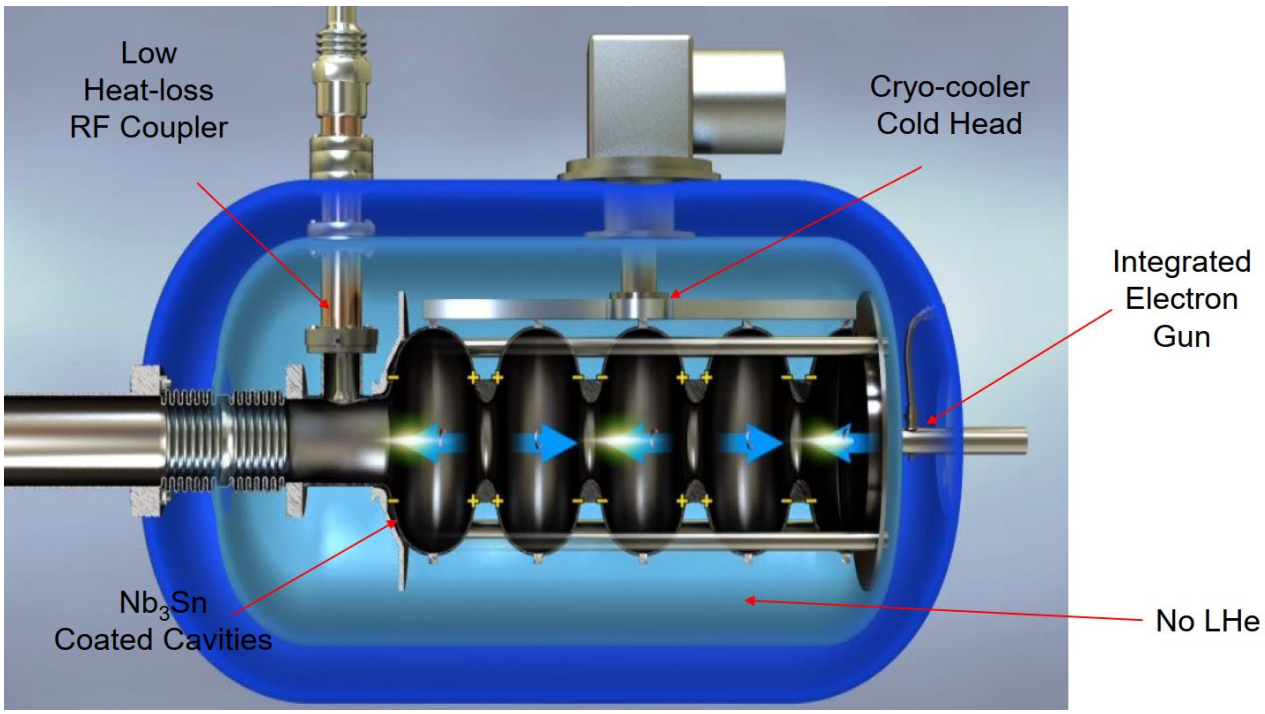
Superconducting Accelerator: Latest Developments

Jayakar Charles Tobin Thangaraj, Fermi National Accelerator Laboratory, USA

Emerging industrial applications involving radiation and material processing demand high average power irradiators with excellent energy-efficiency. The presentation introduced a new class of simple, turn-key superconducting radio frequency (SRF) accelerators that will find broad use in material processing, medicine, security and other niche applications. Leveraging recent R&D breakthroughs in high-temperature SRF cavities, cost-effective radio-frequency sources, modern cryo-coolers, and high average current electron guns, Fermilab has developed a novel design for a compact SRF high-average power electron beam linear accelerator. This linac can generate electron beam energies up to 10 MeV in continuous-wave operation.

Through detailed thermal, RF and particle simulation, it was shown that a single accelerator module can deliver average beam power as high as 250 kW and above. A power of 1 MW can be reached by combining several modules. Dr Thangaraj believes that such high average power will enable new opportunities for high power x-ray radiation sources for medical sterilization or x-ray curing. Compact and light enough to mount on mobile platforms, the machine will enable new in-situ environmental remediation applications and novel applications for in-situ crosslinking of materials.

The compact SRF accelerator



CREDIT: FERMI NATIONAL ACCELERATOR LABORATORY

This linear accelerator can generate electron beam energies up to 10 MeV in continuous-wave operation. It was shown through detailed thermal, RF and particle simulation that a single accelerator module can deliver average beam power up to 250 kW and above. A power up to 1 MW can even be reached by combining several modules. Fermilab predicts that such high average power will enable new opportunities for high power x-ray radiation sources for medical sterilization or x-ray curing. Compact and light enough to mount on mobile platforms, this type of machine will enable new in-situ environmental remediation applications and novel applications for in-situ crosslinking of materials.

Individual pulse positioning, from process design to process interruption

Geoff Paul, Mevex, Canada

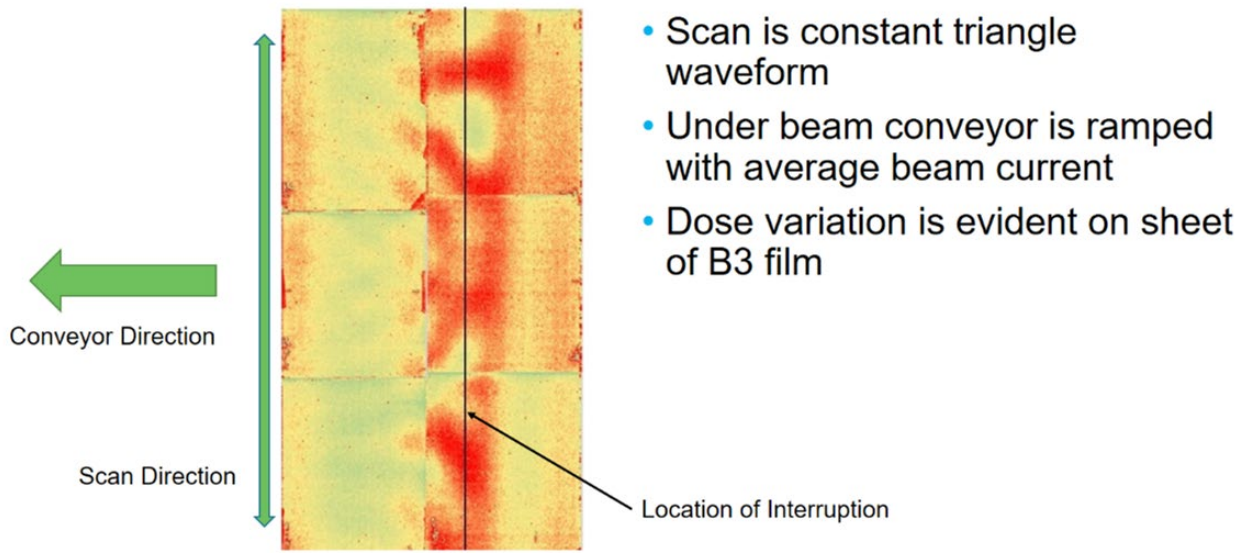
As our capabilities evolve, so should our processes. Many electron beam and X-ray processes rely on scanned pulses of electrons in order to provide a uniform distribution of dose to the surface of a product. The scanned

waveform is often a triangle or sawtooth intended to provide an even spacing between pulses in both the direction of scan and travel. This works very effectively for processes that never stop and never vary.

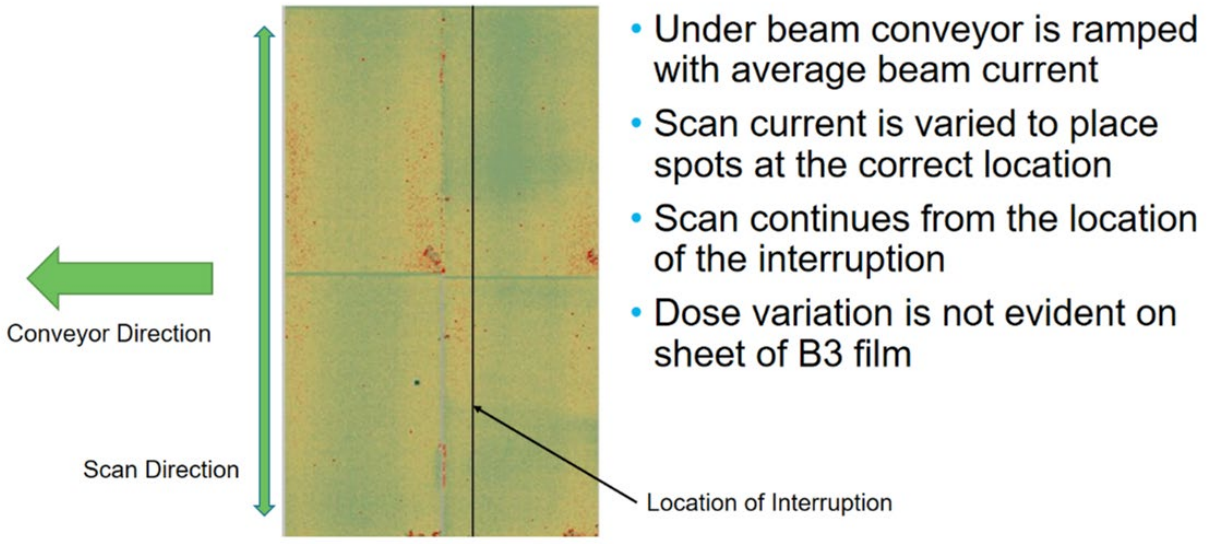
The same scanning technology based on smoothly varying analog signals has been in use for decades. This effect can now be achieved using digital technology that does not place the same smooth-motion limitations on how the beam is scanned. The idea is that instead of painting every box with the same shower of electrons, the painter can choose where to move the brush, to provide the right dose to the location where it is needed. The digital scanning system allows for the placement and tracking of individual pulses on a product in real time. The implementation was done using a Field Programmable Gate Array or FPGA to control the triggering and the scan. The operating parameters are passed to the FPGA from the accelerator control system.

This technology has been applied to process interruption at several electron beam sites, resulting in process interruption studies which are indistinguishable from travel uniformity without an interruption. Several other examples of the application of a digital scanning system were presented, including applications in process design.

Visualization with B3 film of Dose Variation without Pulse Positioning



Visualization of Dose Variation With Pulse Positioning



CREDIT: MEVEX

Innovations around pulsed beams

Jeremy Brison, IBA Industrial, Belgium

IBA provided a perspective on the current electron beam and X-Ray irradiators market, an update on new projects since the last IMRP and a view on technological evolutions to come.

Since last IMRP IBA has built a new manufacturing facility in Belgium. More than 10 new systems have been ordered and installed, representing 550kW of e-beam and 1.2MW of X-Ray. These new centers represent the equivalent of more than 70 MCi of cobalt-60 to what is currently installed, which is more than the organic growth of the sterilization market. This confirms that some conversion from other technologies is indeed taking place.

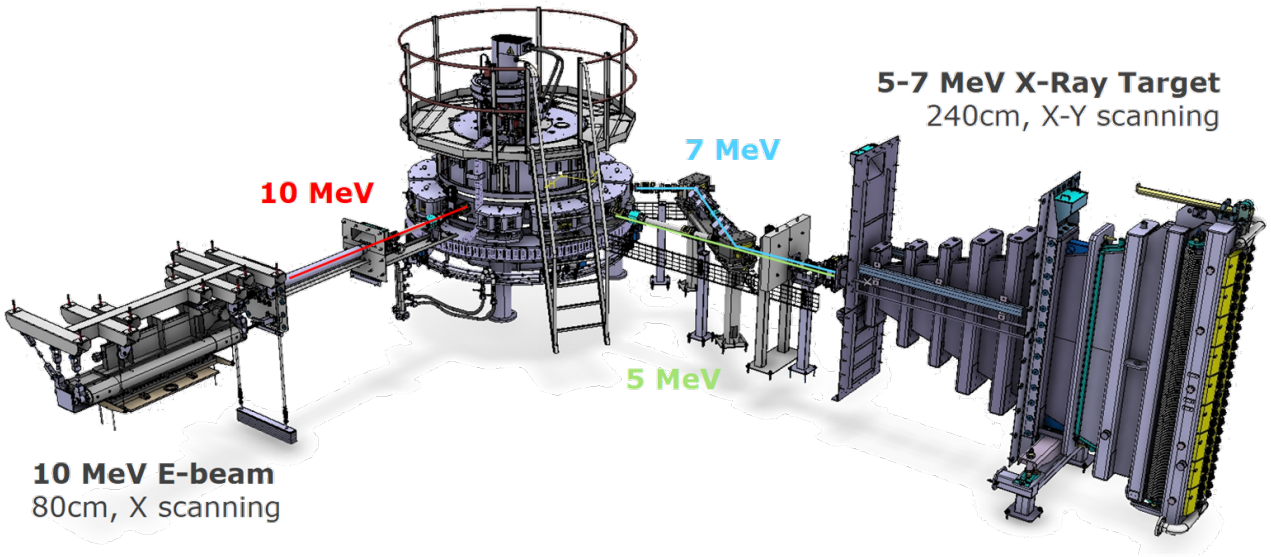
From the analysis of the recent projects, IBA has identified several key unlocking factors regarding the irradiator market: global process integration, "pay as you grow" from 20 kW, dual technology with X-ray for product studies and validation, and maximum electrical efficiency. The second part of the presentation focused on the last two factors.

The radiofrequency (RF) pulsing principle was elaborated. Examples of energy savings and detailed Monte Carlo simulations of the effect of beam pulsing on the sterilization process were given. The data showed that at 20% beam pulsing (the beam is turned on 20 % of the time at 50Hz), the process is not impacted for conveyors speeds up to 50 meters per minute, while the global electrical efficiency is increased from 10% for a typical Linac and 15% for a continuous Rhodotron, to 25% for the pulsed version.

A new concept called the "variable energy Rhodotron". This new simple feature, based on the introduction of a delay between the beam and the RF system, allows continuous varying of the energy of the Rhodotron at the same beam exit. According to IBA, it will allow an increase of the process versatility without compromise on the high power, efficiency and beam quality of the Rhodotron.

Finally, IBA provided an update on its accelerator roadmap, including a status of the factory testing of the new TT50, the final design of the TT300-HE for radio-isotopes production at 40 MeV, and the opening of the FEERIX center in Strasbourg. The latter is equipped with all irradiation modalities in e-beam and X-Ray and is already open to collaboration, hands-on training, product testing and more.

The FEERIX facility at Aérial in Strasbourg, France



CREDIT: IBA

CONNECTING SCIENCE AND BUSINESS: THE DEBATE

PANELISTS, FROM LEFT: BYRON LAMBERT (ABBOTT LABORATORIES, USA), SURESH PILLAI (NECBR, USA), ALAIN STRASSER (AERIAL, FRANCE), KENNETH HSIAO (CGN DASHENG, PR CHINA), SHIN JUNHWA (KAERI, SOUTH KOREA)

Are science and business connecting? If so, are they connecting enough and, if not, how to make them connect more? These were the main questions discussed during the debate.

The opinions that were voiced reflected the different backgrounds of the panelists.

Byron Lambert is from a US medical device manufacturing company where he develops drug-device combinations and looks especially at the sterilization aspects. He emphasized the complexity of the process and the long time that it takes, usually 10 to 15 years to get a product to market. This process would be even more difficult without collaboration with academia but also with other companies. He appreciates the support that he receives from radiation contractors such as STERIS or Sterigenics who also try to innovate, working for example on the use of alternative gases.

Suresh Pillai, whose Electron Beam Research Center is part of Texas A&M, considers that his job goes beyond educating students and considers it as a duty to also educate and support entrepreneurs and more generally the private sector to develop research but also the commercial use of irradiation. He believes that the

expansion of radiation processing requires 'evangelists' who translate for the industry community the language of the scientific world.

Alain Strasser initially came from a University when he co-founded Aerial, a technical resource center, and he noted that he and his team had to acquire an industrial culture and be multidisciplinary in order to be successful and bridge the gap. In France, the academic world is not naturally inclined to collaboration with the private sector, though the drying-up of government funds pushes them in this direction. Also, the French government has long thought that the mission of public research organization is fundamental research, not applied research. Alain also noted that for a concept to go from science to business it is often a long journey, though it may happen faster when enhancing polymers than when developing a drug. It is also important to offer the tools and the training that industrialists need, not only experiments at the laboratory scale. Assessing economic feasibility at an early stage is also important. These are among the reasons why the FEERIX project came into existence.

Byron Lambert commented that researchers must indeed be taught that there is value in commercialization. Suresh Pillai mentioned that young researchers are increasingly business minded and are good at finding funding for their projects. Funding from federal funds have dried up very much so increasingly they turn to private industry. Entrepreneurs and specialists have a different language; researchers must be told that there is value in commercialization

Kenneth Hsiao, CEO of CGN Dasheng who offered modified polymers before becoming a manufacturer of accelerators, reminded the audience that a little more than ten years ago he knew nothing about irradiation. The knowledge and know-how of his company entirely came from universities and research organizations in China. Market drives the development of the company: when a need emerges, CGN Dasheng finds it natural to approach those who know more than it does to find a solution. However, given the growth of the company, CGN Dasheng has now established a research center with Tsinghua University where efforts will be joined to develop applications of electron beams. Collaboration with research goes beyond China: an agreement has been signed with Nuklear Malaysia for the production of hydrogels.

Jun Wa Shin spoke of the experience of KAERI in transferring know-how to the industry. There were a few success stories, in particular one with a company that was worth 600,000 dollars and is now worth 1 billion dollars after adopting a KAERI irradiation process for discoloration of green tea extracts and making some ingredients more active for use in cosmetics Another example is irradiated herbal extracts now used for patients undergoing radiotherapy. However, the amount of transfer has been limited and it is fortunate that the Korean government is very supportive of radiation technologies, granting 70 million USD to KAERI each year. In 2018 a demonstration multipurpose EB accelerator was inaugurated to be able to demonstrate the technology to the private sector on a significant scale. The measure of success may be when the government must no longer fund research activities.

The panelists agreed that science and business do connect, especially during IMRP and due to the mixed audience more at IMRPs than at most other conferences. One panelist underlined the value of space in the IMRP agenda in order to allow more time for interaction and networking. Kenneth Hsiao revealed that during this IMRP he had just signed an agreement with a European research organization. There was also a feeling that more could probably be done and that iia might have a role to play in this. One panelist mentioned the

'old-fashioned' approach of the pharma business to radiation sterilization as a proof of the need to disseminate the experience acquired with other applications. He also reminded that it is John Masefield, Chairman of the iia, who tirelessly promoted the concept of alternative SALs more than 20 years ago, a concept that has only now been accepted in some sterilization standards.

POSTER AWARDS

A total of 74 posters were presented during the conference. The Program Committee established a short list of 20 posters in different categories. A Poster Committee composed of Paul Minbiole (E-Beam Services, USA), Xavier Coqueret (Université Reims Champagne Ardennes, France), Shen Yilling (BRCRA, China), Monique Lacroix, (Institut Armand Frappier, Canada) and Arne Miller (DTU, Denmark) selected the three best posters. The Best Poster Awards were presented by Dave Pymer of Harwell Dosimeters to the authors of these three posters:

Continuous electron induced reactive processing – a sustainable reactive processing method

Authors: Carsten Zschech, Mathias Pech, Sven Dr. Wießner, Ines Dr. Kühnert, Uwe Gohs, Michael Thomas Dr. Müller. Leibniz Institute of Polymer Research Dresden (IPF), Composite Materials, Dresden, Germany.

The research advanced the understanding of electron induced reactive processing (EIReP), a technique that causes physical and chemical modifications in polymers and helps meeting the needs of different technological applications using electron beam technology. The results suggest that EIReP is an alternative pathway for the preparation of high-performance polymeric materials. Also, the feasibility of a scaled up in line unit demonstration unit using a 300 keV electron emitter working continuously was demonstrated for the first time.

Cancer drugs modified by gamma radiation showed enhanced efficacy in cancer treatment

Authors: Remigius A. Kawala, Fatuma J. Ramadhani, Byung Y. Chung, Hyoung-Woo Bai. Korea Atomic Energy Research Institute (KAERI); University of Science and Technology, Korea.

The awarded addressed the use of ionizing radiation to modify the structure of Kenalog (Kenalog-IR), a synthetic glucocorticoid drug used to treat various cancers. The concept embroidered in the work refers to incrementally modified drugs, a novel approach that provides a structural modification for drugs with low efficacy. Specifically, radiation was proven to be a useful tool to enhance the efficacy of Kenalog against melanoma cells.

Comparison between gold nanoparticles synthesized by radiolysis and by EGCG-driven gold reduction

Authors: Lucas F. de Freitas, Jorge G. S. Batista, Adriana K. Cavalcante, Ademar B Lugão. Centro de Química e Meio Ambiente (CQMA), Nuclear and Energy Research Institute (IPEN), Sao Paulo, Brazil.

The research compared the two "green methods" (free of toxic reagents) for the development of gold nanoparticles focusing on size, stability, optical properties and toxicity in zebrafish. Both methods were useful for the synthesis of nanoparticles in terms of size and optical properties, mainly via reduction by EGCG. Stability and toxicity results were shown to be more promising for the radiolytically synthesized gold nanoparticles.

JOURNAL OF RADIATION PHYSICS AND CHEMISTRY

The International Irradiation Association in cooperation with Elsevier will publish a digital special issue of *Radiation Physics and Chemistry* containing selected papers and posters presented during IMRP 20. All participants were invited to submit their manuscripts using the EVISE system.

The guest editors of this Special Issue will be Yves Henon (Chair of the IMRP 20 Program Committee) and Gustavo Varca (iia Scientific Advisor) in cooperation with the Editor-in-chief Prof. Dr. Piotr Ulanski. All submissions will be peer-reviewed by at least two independent reviewers. The submission system of Radiation Physics and Chemistry was open from April 15 to September 15, 2019.

It is anticipated that this Special Issue will be published in late 2019.

IMRP LAUREATES

The iia has given Laureate Awards since the second International Meeting on Radiation Processing held in Miami in 1978. The Award represents the highest honor that members of the irradiation community can bestow on their colleagues. These Awards are presented to individuals that have made an outstanding contribution to the advancement of the science, technology or business of radiation processing. The Laureate winners are selected by the Awards Committee from nominations and recommendations made by the iia membership. The Awards Committee is made up of members of the iia Board. A structured process is used to remove subjectivity as much as possible. Each nominated individual is scored against 20 criteria that are important characteristics of a Laureate winner. Each criterion is weighted to reflect its level of importance to the Award selection process.

List of recipients of the IMRP Laureate Award

LAUREATES	IMRP #	YEAR
Charles Artandi, Paul Cooke	2	1978
William Baird, Arthur Charlesby	3	1980
Toshikazu Higashino	4	1982
John Masefield, Vivian Stannett	5	1984
Ken Morganstern, Joe Silverman	6	1987
Frank Fraser, Frank Ley, Sam Nablo	7	1989
Marshall Cleland, Joseph Farkas	8	1992
Jan Leemhorst, William McLaughlin, Pierre Vidal	9	1994
Sueo Machi, Arne Miller	10	1997
Masaaki Takehisa, Alan Tallentire	11	1999

Joyce Hansen, Robert Morrissey	12	2001
Yves Jongen, George West	13	2003
John Corley, Theo Sadat, James Whitby	14	2006
Dieter Ehlermann, Rocco Basson	15	2008
Olgun Güven, John Kowalski, Wang Chuanzhen	16	2011
Andrzej Chmielewski, Paul Minbiole	17	2013
Mohamad Al-Sheikhly, Zhang Xianghua	18	2016

Two iia Laureates were awarded at IMRP19, one Scientific Laureate and one Business Laureate.

IMRP 19 Scientific Laureate Award

The recipient of the IMRP 19 Scientific Laureate Award was **Maria Helena Sampa** from Brazil.

Dr Sampa obtained her M.Sc. and Ph.D. in Nuclear Technology Applications at IPEN/University of São Paulo, Brazil. From 1976 to 2005 she was researcher and head of Division of Research and Development of Radiation Technology Center at IPEN/CTR where the main activities were to manage and coordinate R&D projects in the field of radiation processing. Maria was one of the founders of RadTech South America and worked at the International Atomic Energy Agency from 2006 to 2011 as Technical Officer in Radiation Processing Technology. During those seven year she has implemented several projects on radiation processing in Member States of IAEA. Dr Sampa was also President of the Brazilian Nuclear Energy Association (ABEN) from 2000 to 2002 and has been involved in professional societies such as American Nuclear Society, Technology Based Business Incubator Center (CIETEC). She received awards in the nuclear field: in 2001 Medal "Carneiro Felipe" received from Brazilian Nuclear Energy Commission (CNEN) and in 2002 Medal "Friends of Navy" received from Brazilian Navy. She has many publications in the field, delivered lectures in different forums and reviewed papers for international journals.

Currently Dr. Sampa is Consultant in radiation processing technology for industry, environment preservation, decontamination of art objects and irradiation facilities for the IAEA, IPEN and CNEN. During the time when she was working in IAEA, she has implemented several coordinated research projects (CRP) recently, including one on-going project, in the field of radiation processing of polymeric materials.

Professor Wilson Calvo collected the IMRP 19 Laureate award for Dr Sampa and passed it to Maria at a celebration at IPEN.

IMAGE CREDIT: E. R. PAIVA / IPEN.

IMRP 19 Business Laureate Award

The recipient of the IMRP 19 Business Laureate Award was **Yves Hénon** from France.

Yves Henon obtained a diploma of agronomy from the prestigious *Institut National Agronomique* in Paris before obtaining a Master of Science in Food Science and Technology from the Louisiana State University. In 1980 he joined the French Atomic Energy Commission (CEA) at the Cadarache Nuclear Research Center working in the Food Irradiation Laboratory where he helped develop the commercial use of food irradiation in France.

After working for the Government for seven years, Yves moved to the private industry where he built and managed gamma irradiators for twenty 20 years. He established facilities for Gammaster in France and Thailand and later worked for Isotron in Malaysia in a regional role. Throughout his time in industry Yves was active and successful in promoting the commercial application of irradiation technologies.

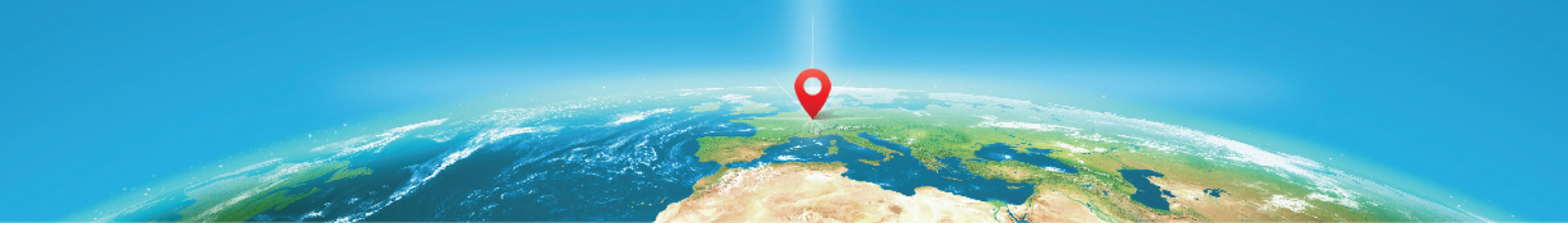
In 2006, Yves established his own consultancy firm specialized in radiation processing first in Singapore then in France. As a consultant he supported the establishment and commercialization of further irradiation facilities. He began supporting the wider irradiation community as a member of the International Irradiation Association team. Yves completed a two-year assignment as food irradiation specialist with the joint IAEA/FAO program in 2014 and before, once again, becoming an important member of the iia team.

Yves had an early interest in Quality Assurance systems and was a strong advocate of ISO standards. He received a National Quality Award from French President Jacques Chirac in 1996. During his tenure with the IAEA, as a technical officer he organized technical meetings and conferences and was involved in many Technical Cooperation Projects. Yves has authored articles and contributed chapters to books on irradiation.

Throughout a career spanning, to-date, almost 40 years Yves has remained a passionate proponent of food irradiation. He has informed, trained and inspired many around the world and remains an invaluable member of the irradiation community. In the lead-up to IMRP 19 Yves chaired the Program Committee where he developed a program to strengthen the links between Business and Science.

Paul Wynne, iia Chairman, presented the award to Yves Hénon.

Next IMRP



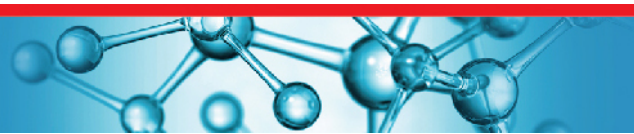
IMRPs are generally held in Asia Pacific, EMEA or the Americas on a rotational basis. This improves access to participants in different areas over time. The table below shows when and where IMRP have been held.

IMRP #	Year	City	Country	Continent
1	1976	Puerto Rico	USA	Americas
2	1978	Miami	USA	Americas
3	1980	Tokyo	Japan	Asia-Pacific
4	1982	Dubrovnik	Yougoslavia	Europe
5	1984	San Diego	USA	Americas
6	1987	Ottawa	Canada	Americas
7	1989	Noordwijkerhout	Netherlands	Europe
8	1992	Beijing	China	Asia-Pacific
9	1994	Istanbul	Turkey	Europe
10	1997	Anaheim	USA	Americas
11	1999	Melbourne	Australia	Asia-Pacific
12	2001	Avignon	France	Europe
13	2003	Chicago	USA	Americas
14	2006	Kuala Lumpur	Malaysia	Asia-Pacific
15	2009	London	United Kingdom	Europe
16	2011	Montreal	Canada	Americas
17	2013	Shanghai	China	Asia-Pacific
18	2016	Vancouver	Canada	Americas
19	2019	Strasbourg	France	Europe

The 20th IMRP should therefore be held in the Asia-Pacific region.

When selecting a location for the next IMRP, the iia Board takes many considerations into account such as:

- Availability of Regional Sponsors prepared to make a financial commitment
- The adoption of radiation processing at the location
- Accessibility of city (proximity to international transit hubs).



- Capacity, quality and cost of recommended venue and hotels
- Local support from iia members
- Support and incentives available from local authorities
- Offer for technical tours
- Anticipated cost and visa requirements for attendees

Proposals for the location of IMRP 20 were reviewed and the iia Board decided to choose Bangkok. MEVEX and STERIS have agreed to be the Regional Sponsors. The meeting will be organized with the cooperation of the Thai Institute of Nuclear Technology. Subject to confirmation, IMRP 20 will take place during the second week of November 2021.

IMRP 20 – BANGKOK, THAILAND – NOVEMBER 2021

The core team of the International Irradiation Association

FROM LEFT: GUSTAVO VARCA, YVES HENON, PAUL WYNNE AND MARTIN COMBEN

Appendices

APPENDIX 1: DIRECTORY OF SPONSORS AND EXHIBITORS

IMRP is the world's largest gathering of organizations that supply radiation processing equipment and services and other irradiation related products. The following list of companies that sponsored and exhibited at IMRP19 serves as a directory of leading suppliers to the irradiation industries.

ADANI Limited

ADANI offers compact EPR (ESR) Spectrometer for scientific and practical purposes and budget-priced Gamma-ray analyzer for the examination of food and building materials. ADANI SPINSCAN X with smart software package for alanine dosimetry is a perfect irradiation / sterilization process control solution for industry and companies providing laboratory testing services.

https://lab.adanisystems.com/

Aerial

Since its creation in 1985, Aerial, an IAEA collaborating center, has been serving the radiation processing industry for dosimetry, training and qualification of irradiation facilities. Aerial's expertise in these areas is internationally recognized. Aerial offers several state-of-the art FDA compliant types of dosimetry equipment: AerEDE, AerODE and DosASAP.

https://www.aerial-crt.com/

BBF Sterilisationsservice GmbH

BBF Sterilisationsservice GmbH can draw on decades of experience in the field of gamma-sterilization. Our tote irradiation system is specialized in the irradiation of medical devices and pharmaceuticals. In addition to standard 25 kGy irradiation, our site is particularly suitable for radiation of temperature and gamma sensitive and products.

https://www.sterixpert.de/en/

BGS Beta-Gamma-Service GmbH & Co. KG

BGS is a specialized service provider for radiation crosslinking and radiation sterilisation. We are second to none in Europe in our mastery of the sophisticated processes involved in optimizing plastics and sterilizing products. BGS has steadily grown into Germany's biggest provider of radiation services and is operating three irradiation centres in Germany.

https://de.bgs.eu/

Buckley Systems International

Buckley Systems Ltd is a leading manufacturer, of precision electromagnets, charged particle beam line systems, and high vacuum equipment used in the Semiconductor Equipment Industry, Display Industry, Medical Therapy Systems, Border Security, Solar Industry and Particle Accelerators for physics research. Committed to serving our customer's needs, providing high quality products.

https://www.buckleysystems.com/

Budker Institute of Nuclear Physics

Budker Institute of Nuclear Physics designed and developed two types of industrial accelerators - DC accelerators "ELV" with energy up to 2.5 MeV (beam power up to 450 kW), and ILU type with energy up to 10 MeV (beam power up to 100 kW). BINP produced 230 accelerators from 1975.

http://www.inp.nsk.su/budker-institute-of-nuclear-physics

CGN Dasheng Electron Accelerator Technology Co., Ltd.

CGN Dasheng is a leading manufacturer and supplier of electron beam accelerators, making its service to the world. CGN Dasheng's e-beams are ranging from 150 KeV to 15 MeV, for commercial use of curing, cross-linking degradation, food irradiation, sterilization, phytosanitary, water treatment, medical waste treatment and NDT.

https://www.cgndea.com/

China Isotope & Radiation Corporation

China Isotope & Radiation Corporation (CIRC) is the holding subsidiary of China National Nuclear Corporation (CNNC) and the largest nuclear enterprise in research and development, manufacturing, distribution and service of nuclear products in China. CIRC is mainly engaged in research and application of radioisotopes and radiation technology, covering radioisotope preparation by nuclear reactor and cyclotron, radiopharmaceuticals, radioactive sources, radiation engineering and processing etc. There are more than 50 production lines capable of supplying over 70 nuclides and 300 kinds of products all together.

http://www.circ.com.cn/html1/folder/1708/202-1.htm

Crosstex International Inc., a Cantel Medical Company

Crosstex International Inc., a Cantel Medical Company, is a leading manufacturer of a wide range of sterilization monitoring products used worldwide. Our comprehensive product line includes Biological Indicators, Chemical Indicators, Incubators, Suspensions, QC Test Suspensions (Growth Promotion) and Sterilization Packaging. We also specialize in Custom Sterilization Indicator Labels.

https://www.crosstex.com/industry-industriallife-sciences

Etigam B.V.

STERILIZATION INDICATORS * chemical process indicators for gamma/e-beam/x-ray, EO gas and steam sterilization, self-adhesive dots or (customized) labels * biological indicators for monitoring sterilization processes spore strips, self-contained BI's and spore suspensions

https://www.etigam.nl/

Far West Technology, Inc.

Far West Technology is a global technology company that applies its skills and expertise to manufacturing innovative scientific products with unique requirements. The company is proud to offer its cost-effective, quality products and services to the medical, physics and environmental health fields in both government and industry.

http://www.fwt.com/

Framatome

Framatome offers individual, customer-oriented solutions for modernization projects to increase capacity and optimize dose distribution for the coverage of the growing global demand for sterilization. Our specialists ensure the long-term operation with services that go far beyond the standard scope.

http://www.framatome.com/EN/home-57/index.html

Gamma-Services Recycling GmbH

Gamma-Service Recycling GmbH is specialized in handling radioactive materials including their international shipment. Our main services are the supply and disposal of radioactive sources from research, medicine and industry, the decommissioning and decontamination of plants, radionuclide laboratories and other facilities as well as the processing of radioactive sources for re-use.

https://www.gamma-recycling.info/en/home.html

GEX Corporation

GEX is a single source provider of a complete range of dosimetry products and services for the radiation processing industry. We serve the complete spectrum of gamma, e-beam, and x-ray radiation process applications, such as medical device sterilization, surface decontamination, the curing of inks and coatings, and food irradiation.

https://www.gexcorp.com/

GEX CORPORATION

Harwell Dosimeters Limited

Harwell Dosimeters Limited supplies both optical dosimeters (dyed PMMA), which darken quantitatively when irradiated and are measured using a spectrophotometer, and Alanine/esr dosimeters which exploit the dose-dependence of the paramagnetic resonance of alanine to provide enhanced precision and accuracy over a wide dose range.

http://www.harwell-dosimeters.co.uk/

Hopewell Designs.

Hopewell Designs provides products and services to government laboratories, nuclear power plants, private industry, medical laboratories and universities throughout the world. These products and services include: • Manual and Automated Irradiator systems, • High dose and self-contained irradiators, • Radiation automation solutions • Radiation shielding and shipping casks • Consulting, training, and service

https://www.hopewelldesigns.com/

IBA

IBA Industrial is a business unit of Ion Beam Application S.A. IBA Industrial develops, installs and maintains solutions for customers in a wide range of markets and applications (Medical Device sterilization, Food sterilization, Wire and Cable Crosslinking, ...). Headquartered in Belgium, IBA group has 1,400 employees and installed systems across the world.

https://www.iba-industrial.com/

HiDORA - High Dose Rate Measurement

HiDoRa is an High Dose Rate measurement tools for ionization beams. The high-power beams can be monitored in real time, and in 2D with the quasi transparent sensor, which features high radiation hardness. The overall dynamic of the system ranges from 1 to 1 000 000. Beams up to 1 MW can be characterized.

https://www.linksium.fr/en/projet/idora/

Institute of Isotopes Co. Ltd.

Manufacturing • Small and high activity Ir-192, Cs-137 and Co-60 sealed sources • Multipurpose commercial irradiators • Research irradiators • Calibration irradiators • Radiation Protection System /hot cells, storage boxes, whole body counters, radiation protection walls, doors, A and B(U) type transport containers Servicing: • Re-encapsulating sources • Radioactive Waste Management • Irradiation test • Irradiation of samples • Morphology studies • Quality analyses • Transportation of radioactive materials

http://www.izotop.hu/?page_id=25

JSC Isotope

JSC Isotope is a 100% owned subsidiary of Rosatom State Corporation, responsible for distribution and marketing of isotope products produced by Rosatom enterprises. On the strength of Rosatom unique production capacities, JSC Isotope offers a wide range of isotope products, including Co-60.

http://www.isotop.ru/en/production/Sterilization/

MEVEX Corporation

Mevex: the e-beam, x-ray, high power, low power, process, software, integration, automation, modelling, applications and irradiation technology company.

http://mevex.com/

NNSA Office of Radiological Security

The National Nuclear Security Administration (NNSA) Office of Radiological Security (ORS) works with government, law enforcement, and businesses to reduce radiological risk by providing world-class security technologies, expertise, training, source recovery, and alternative technology strategies to users of radioactive sources.

https://www.energy.gov/nnsa/national-nuclear-security-administration

Nordion, a Sotera Health company

The Sotera Health companies—Nordion, Nelson Labs, Sterigenics—are your fully integrated, global partners for Cobalt-60 supply and gamma irradiators, lab testing, and sterilization solutions. By delivering safe, high-quality products and services to our customers, we play a critical role in Safeguarding Global Health™.

https://www.nordion.com/

Panel on Gamma & Electron Irradiation

The Panel on Gamma and Electron Irradiation, known as The Panel, is a group of experts with diverse interests in irradiation processing. It meets twice a year and comprises of both suppliers and users of irradiated products and irradiation services, regulatory bodies and consultants.

https://www.irradiationpanel.org/

PTW / VF Metrology

PTW is a global market leader for dosimetry and QA solutions in healthcare and metrology, also operating one of the largest and oldest SSDLs worldwide. As a single-source supplier of state-of-the-art, high-precision metrology equipment, the German company provides turnkey solutions for Beta, Gamma, Neutron and X-Ray calibration laboratories.

https://ptw.de

RadChem Co. Ltd

RADCHEM offers safe and secure solution for isotope applications. Our products and services always customized to offer the best available solution with harmony of the customer demand. We provide isotope contained systems for R&D, industrial and precise metrology purposes. Facility and technology design for feasible application, everything for radiation technology.

http://radchem.hu/

Shanxi Yitaike Electrical Equipment Co. Ltd.

We co-manufacture the ELV type accelerator with BINP, Novosibirsk, Russia. We manufacture irradiation equipment for cable and wires, film and plate. We offer turn-key projects of irradiation centres. Our equipment is characterized by high reliability, high-efficiency, low operation cost and easy maintenance.

http://www.rcelv.com/xen/

SOLSTEO

SOLSTEO is a European leading manufacturer of custom-design EO sterilizers and Air Purification Systems (scrubbers and catalytic oxidizers). We deliver turn-key projects including pre-conditioning, aeration rooms and automatic loading systems. SOLSTEO develops and installs software programs on new EO sterilizers or upgrade software of existing sterilizers. A team of qualified engineers provides technical support, maintenance and validation services.

http://www.solsteo.com/

Sterigenics, a Sotera Health company

The Sotera Health companies—Nordion, Nelson Labs, Sterigenics—are your fully integrated, global partners for Cobalt-60 supply and gamma irradiators, lab testing, and sterilization solutions. By delivering safe, high-quality products and services to our customers, we play a critical role in Safeguarding Global Health™.

https://sterigenics.com/

STERIS

STERIS Applied Sterilization Technologies provides contract sterilization, technical support and laboratory services to companies in the medical device, pharmaceutical, consumer and industrial markets. Through a global network of sterilization and laboratory facilities, the company provides Customers with a technology-neutral service offering using radiation and gas technologies.

https://www.steris-ast.com/

TRAD Test & Radiations
- RayXpert Software

RayXpert is a 3D radiation modelling software developed by TRAD to manage radioprotection projects. RayXpert included: • Import of CAD or 3D modelizing tool • Libraries of materials and radioisotopes • Gamma and Beta decay spectra & Electron/Photon/Neutron continuous spectra • 3D cartography to visualize the doses, the flux and the deposited energies

http://www.trad.fr/

True Indicating LLC

Based in the United States, True Indicating develops, manufactures and distributes a variety of sterilization monitoring products. Radiation product offerings include spore strips, spore suspensions, and Type 1 process indicators, specifically designed for increased shelf life to ensure incidental environmental exposure to UV light does not trigger process color changes.

https://www.trueindicating.com/

Wuxi El Pont Radiation Technology Co., Ltd.

Wuxi El Pont Radiation Technology Co. Ltd. is the leading Chinese company for design, development and manufacturing of electron accelerators from 200KeV to 10MeV and X-ray technology. Our multiple types of under-beam conveyor system can be suitable for surface curing, polymer modification, semiconductor quality improvement, wire and cable, heat-shrinkable materials, tires, film, disposable medical supplies and food irradiation.

http://www.elpont.net/en/

APPENDIX 2: ABSTRACTS OF POSTERS

Technology

POSTER # 3

A SUCCESSFUL COLLABORATIVE PARTNERSHIP TO ASSESS VULNERABILITIES OF INDUSTRIAL IRRADIATORS AND DESIGN SECURITY ENHANCEMENTS TO PROTECT THEM AGAINST RADIOLOGICAL THEFT OR SABOTAGE

Michal Kuca[1], Christian J Hartwigsen[1], Zhu Jun[2], Li Chunsong[2].

[1]Office of Radiological Security, United States Department of Energy/National Nuclear Security Administration, Albuquerque, United States; [2]Beijing SanQiangHeLi Radiation Engineering Technology Co., Ltd (SQHL), Beijing, P.R. China.

Radioisotopes such as Cesium 137 and Cobalt 60 are used in various medical, industrial, and research applications and can be an attractive theft or sabotage target. This work showcases an ongoing collaboration between the In-Device Delay (IDD) program (managed by Sandia National Laboratories for the United States' Department of Energy/National Nuclear Security Administration's Office of Radiological Security) and Beijing SanQiangHeLi Radiation Engineering Technology Co., Ltd, abbreviated as SQHL, (China) to develop security enhancements for SQHL-designed industrial irradiators. These irradiators, like many in the industry, contain millions of curies of Cobalt 60 but have historically been thought to be self-protecting due to the large perceived radiation dose and/or difficulty in breaching the irradiator. This project conducted attack testing which indicated that radiological materials could be nefariously removed from an industrial irradiator quicker and easier with less radiation dose than previously suspected. IDD and SQHL will discuss lessons learned from the project, as well as novel and cost-effective designs to protect SQHL industrial irradiators that may be applicable across the industry. The presented work will illustrate the value of coordination between private and public entities to identify the vulnerabilities of devices that contain high-activity radiological materials and to develop engineered security solutions that help protect the public from the risk of radiological theft or sabotage.

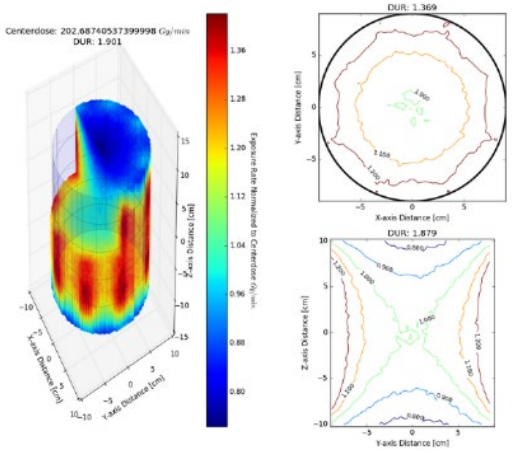
POSTER # 5

MODERN SELF-CONTAINED, DRY-STORAGE IRRADIATORS

Spencer Mickum[1], Robert Rushton[1], Zachary Hope[1].

[1]Research Science, Hopewell Designs, Inc., Alpharetta, GA, United States.

A mainstay legacy irradiation system used internationally for high dose rates activities of cobalt-60 has been discontinued and is no longer supported. In this presentation the design constraints of the legacy system are relaxed for a new design basis that provides a closer link to the legacy system while greatly improving the capabilities of the legacy model. A study into optimizing a vertical chamber travel path irradiator design has been undertaken to modernize the legacy system and introduce a suite of new improvements to self-contained irradiation. Improvements in the overall design eliminate concerns of a high radiation field around the irradiator during transition between operational modes. The study compares a source cavity design over a pass-through shielding drawer to allow for interactions with the irradiation chamber to take place at chest height with no step-up pad. Uniformity within the irradiation chamber and central dose rates are calculated with Monte Carlo simulation. An investigation into the optimal source loading of Co-60 pencils and slugs in varying configurations was undertaken to approach ideal dose uniformity, minimize source reshuffling, and provide onsite in-situ reloading. Furthermore, the present work takes a fresh look at adding a rotational aspect to irradiation of a set of dosimeters and the resultant improved dose uniformity. This work is an ongoing effort to characterize the challenges of utilizing the legacy irradiation systems and improve upon them. Results of the present study show that improvements to operator safety, ease of operation, dose uniformity and resourcing downtime are all attainable through a new design basis that provides a closer link to the legacy system while greatly improving the capabilities of the legacy model.



POSTER # 6

X-RAY IRRADIATOR FOR BIOLOGICAL IRRADIATION TECHNOLOGY

Huaili Qin[1], Guang Yang[1], Hao Shi[1], Liqiang Sun[1], Yanqin Liu[1], Aifeng Liang[1], Yanjie Wen[1], Yonggang Zhou[1].
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Currently, most of irradiating apparatus used in biological field such as sterile insect technique are isotope irradiation instruments, including the self-shielded cobalt-60 and cesium-137 irradiating apparatus. However, the isotope irradiating apparatus is confronted with the problem of decommissioning and potential safety in the world, and the life science research organizations of the world are looking for a replacement device for isotope irradiation instruments. X-ray is mechanical source which has the advantages of stable radiation, high security, and is very suitable as an alternative to isotope irradiation instrument. Through research and related mechanical, electrical, human-computer interaction design, we designed a self-shielding and dual-source X-ray irradiator with a rated tube voltage of 160kV, a pipe current of 75mA and a maximum power of 12kW. And the dose rate and dose distribution in the canister is measured to validate the performance of X-ray irradiator. Dose rate (to water), in the center of an empty canister is about 10.0Gy·min^{-1}. Dose rate at the center of a canister filled with simulation material (density of 0.5g·cm-3) is about 8.0Gy·min-1 at the maximum operating power of the tube (160kV and 75mA). Dose distribution results show that the maximum dose in the canister is 38.9 Gy, the minimum dose is 32.2 Gy, and the dose uniformity ratio is I_{max} / I_{min} = 1.21, which can meet the requirement of irradiation dose uniformity in the technical fields such as SIT (≤1.3). This new type of self-shielding dual-source X-ray irradiator has the advantages of stable radiation, high dose uniformity, and high security, and will provide a new alternative for the field of biological irradiation technology such as SIT.

POSTER # 7

ADVANTAGES OF E-BEAM CROSS LINKING OF CABLES COMPARED TO CHEMICAL CROSS LINKING.

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Electron beam cross linked insulation material can achieve higher operating temperature (melt point) and better electrical (insulating) properties. The same polymer using a different recipe can be crosslinked by both E-beam as well as chemical curing. A series of tests were developed to evaluate the differences in the properties of the different bonds formed as a result of the different during cross-linking processes. An EPDM based compound was cured both by e-beam and by chemical curing. The physical properties, thermal properties and electrical properties of the post processing compound were thoroughly evaluated and compared. The conclusion to our research highlighted the superiority of E-beam cross linking over chemical curing. This paper highlights reports on the tests that were undertaken and the methodologies that were used in the evaluation.

POSTER # 8

TOOLS FOR DESIGN AND SIMULATION OF THE RHODOTRON INDUSTRIAL HIGH-INTENSITY ELECTRON ACCELERATOR AND ITS BEAMLINES

Willem Kleeven[1], Michel Abs[1], Jérémy Brison[1], Eric Forton[1], Jarno Van de Walle[1], Jean-Michel Hubert[1]. [1]R&D, Ion Beam Applications (IBA), Louvain-la-Neuve, Belgium.

The Rhodotron is a compact industrial CW recirculating electron accelerator producing intense beams with energies in the range from about 1 to 10 MeV. RF-frequencies are in the range of 100 to 400 MHz. Average beam powers can range from 10kW to almost 1MW, depending of the specific type of Rhodotron. Main industrial applications are polymer cross-linking, sterilization, food treatment and container security scanning. Recently, RF pulsing was developed to reduce the average wall power dissipation, thus reducing drastically the energy consumption. Pulsing also permits smaller cavities and high energies up to 40MeV, opening the way to applications such as mobile irradiators, or isotopes production by photonuclear reactions, thus offering a compact and high beam duty alternative to linacs. This paper concentrates on some crucial design tools and methods for transverse and longitudinal optics studies, particle tracking with space charge, beam formation studies in the electron gun and dipole magnet design as well as on design aspects of the beamlines that transport electron beams from the Rhodotron to the application.

POSTER # 11

MODULAR FEATURES OF RADIO FREQUENCY ILU ACCELERATORS.

Aleksandr Bryazgin[1,2], Vadim Bezuglov[1], Aleksandr Vlasov[1], Leonid Voronin[1,2], Mikhail Korobeynikov[1,2], Sergei Maksimov[1,2], Aleksey Sidorov[1], Vadim Tkachenko[1,2], Evgeny Shtarklev[1,2]. [1]Budker Institute of Nuclear Physics, Novosibirsk, Russian Federation; [2]Novosibirsk State University, Novosibirsk, Russian Federation.

ILU machines are industrial linear pulse radio frequency electron accelerators that are designing and producing in Budker Institute of Nuclear Physics. A main part in ILU accelerators is an accelerating structure consisting of one or few cavities. Number of cavities and feeding radio frequency generators can be varied to design accelerators with various energy ranges and beam power according to customer's requests. These machines are upgradable. Basic models are ILU-10 (5 MeV, 50 kW) and ILU-14 (10 MeV, 100 kW). A present report describes design possibilities, parameters and restrictions of modular accelerators based on ILU machines.

POSTER # 17

OFFICE OF RADIOLOGICAL SECURITY TYPE B PACKAGES AND TRANSPORTATION SECURITY EFFORTS

John Zarling[2], Temeka Taplin[1], Michael Schultze[3].

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The NNSA's Office of Radiological Security works with domestic and international partners to strengthen transportation security of radioactive materials in the United States and abroad as material is most at risk during transportation therefore these security measures strengthen national security and ensure public health and safety. In 2004, the NRC aligned their regulation with IAEA regulations that phased-out of non-complaint Type B packages and created a shortage of suitable packages category I and II sources. In 2008, NNSA/ORS directed the development of a unique Type B package able to transport a variety of devices from different manufactures, thus alleviating the current shortage of Type B packages. Currently two 435B packages have been constructed using a security-by-design approach which includes inherent security enhancements integrated into the design, thereby providing both safety and security for radioactive material in transit. NNSA/ORS believes in providing additional security measures for radiological shipments above regulatory requirements. These additional security measures are multi-faceted and robust and are not simply limited to just tracking of the conveyance itself. While a shipment's visibility is important, advancements in adding detection measures to packages and vehicles have increased overall transportation security. ORS has certified and constructed internationally compliant Type B packages needed for transportation of category I and II radioactive sources that would have otherwise not been recovered and are in danger of falling out of regulatory control. In conjunction with our international partners, the deployment of these packages and security measures enhance transportation security radiological material transported globally.

POSTER # 18

THE MANUFACTURE AND QUALITY ASSURANCE OF IRRADIATION CO-60 SOURCES IN CHINA

Yuji Yin.

Irradiation and Isotope, CIRC, Beijing, P.R. China.

About 6 to 7 million curies of irradiation Co-60 sources are manufactured each year in China. This presentation provides a brief introduction for the manufacture and quality assurance of CN-101 Co-60 sources, and a comparison with other irradiation Co-60 sources in the world, CN-101 Co-60 sources meet the high-quality requirements and the world safety standards.

POSTER # 32

MOBILE LABORATORY FOR GOLD ORE GAMMA-ACTIVATION ANALYSIS

Mikhail Demsky[1], Andrey Pesterev[1], Alexander Sokolov[2], Vladimir Gostilo[2], Valery Moshkov[3]. [1]CORAD Ltd, St. Petersburg, Russian Federation; [2]Baltic Scientific Instruments, Riga, Latvia; [3]Yangeologia JSC, Batagay, Russian Federation.

The presentation describes design and technical parameters of the mobile laboratory for gold ore gamma-activation analysis. Mobile laboratory is realized based on 8 MeV, 2 kW linear accelerator and its design adapted for two 20 feet shelters, which can be transported by auto truck. Technological regime of irradiation-measurement process is optimized for linear accelerator performance. Registration of the secondary radiation is realized by precise HPGe gamma spectrometer, equipped with analytical software for spectra analysis and elements concentrations calculation. The performance of the system has been simulated and investigated on mobile laboratory prototype, realized on our research workbench [1] for gold ore analysis. Spectra and preliminary results are presented.

1. A. Sokolov, V. Gostilo, M. Demsky, E. Hasikova. Optimization of Industrial Gamma-Activation Assay System for Analysis of Gold and Rare Metals Ores. ALTA Au-2018, p.61-71, Perth, WA. May 19-26, 2018. https://www.altamet.com.au/publications/

POSTER # 33

A NEW PARADIGM FOR E-BEAM IRRADIATORS: A REVIEW OF RECENT INNOVATIVE CONFIGURATIONS

Thomas Servais[1], Gino Massaro[1], Dominique Vincent[1], Jean-Michel Hubert[1], Jeremy Brison[1].
[1]IBA Industrial, Ion Beam Applications, Louvain-la-Neuve, Belgium.

Thanks to emerging technologies and innovative simulation tools, e-beam irradiators are progressing nicely in terms of performance, efficiency, up-time, maintainability, and compactness. These improvements result in higher throughputs, lower cost of ownership and stronger business cases for the end-customer. Initially designed as a standalone accelerator at high energy and high power, the Rhodotron® from IBA has been totally re-invented and is now better integrated in all types of configurations, from a few kilowatts, few MeV, to very high power for X-Ray generation. In 2019, the Rhodotron® installed base counts more than 40 systems, for a total of ca. 4.5MW beam power. In this paper, the IBA team intends to present users' case studies and configurations selected from this renewed catalog of solutions. Applications will cover healthcare, food irradiation, cargo screening, etc., as well as examples of in house/in line processing, and service centers' cases. Recent projects will illustrate the steps from product design to successful businesses, going through product dose mapping, Monte Carlo simulations, irradiator specification, layout and conveyor optimization, and efficient installation and validation. Finally, concepts from the R&D roadmap will unveil a new paradigm for the future of e-beam irradiators at IBA.

POSTER # 37

EXPERIENCE IN RADIATION TECHNOLOGIES INNOVATION AT THE JSC "PUBLIC ENTERPRISE "PODOL'SKKABEL" PLANT

Nikolay Kuksanov[1], Nikolay Gromov[2], Mikhail Gromov[1], Alexander Roikh[2], Rustam Salimpov[1], Mikhail Stepanov[2], Sergey Fadeev[1].
[1]Laboratory of industrial accelerators, Budker Institute of Nuclear Physics, Novosibirsk, Russian Federation; [2]JSC "Podol'skkabel", Podolsk, Russian Federation.

The technology of radiation modification of cable insulation has wide application in the industry. The use of this technology allowed the production of a wide range of cables, wires and heat shrinkable products for different markets: power stations, telecommunications, electronics, oil sector, nuclear power plants, submarines and aviation. In all these industries, high reliability is required both for assembling and for operation in difficult conditions and unusually extreme situations. JSC "PE" PODOL'SKKABEL" was one of the first industrial cable companies that was equipped with electron accelerator in USSR. At that time (45 years ago) the Ministry for Electrical Engineering Industries of USSR ordered the installation of 15 accelerators in different plants for EB treatment of insulation. These accelerators (ELV) were designed and manufactured by the Institute of Nuclear Physics of Siberian Branch of USSR Academy of Sciences. They were intended for long-term and continuous operation under industrial production conditions. The technologies for EB modification of insulation were developed at the All-Union Institute of Cable Industry led by I.P. Peshkov, the Director General and Doctor of Technical Sciences. The accelerators supplied to JSC "PE" PODOLSK'KABEL" were among the first of ELV series accelerators. While in operation, particularly after 2000, there was modernization, i.e. continuous improvement of accelerators and radiation technological process. Recently, we used the most modern equipment and technologies for radiation electron polymer cross-linking. JSC "PE" PODOL'SKKABEL" is now the biggest plant for EB treatment of cable insulation in Russia both for the quantity and variety of cables.

POSTER # 40

DEVELOPING AN ELECTRICAL POWER SYSTEM OF A MOBILE ELECTRON BEAM ACCELERATOR TO TREATMENT OF INDUSTRIAL WASTEWATERS AND EFFLUENTS

Renato Gaspar[1].
[1]Radiation Technology Centre, Instituto de Pesquisas Energéticas e Nucleares (IPEN/CNEN-SP), Belo Horizonte, Brazil.

The treatment of wastewater and industrial effluents by electron beam irradiation is a promising technique, however, not very widespread in Brazilian territory. The design and a construction of a mobile unit containing an electron beam accelerator of 700 KeV and 20kW, by the Nuclear and Energy Research Institute (IPEN) is innovative to demonstrate the effects and positive results of this technology. The aim is to move the mobile unit to several companies with interest in liquid waste treatment and connect to the industry electrical system and start the ionization treatment process through electron beam. The mobile unit's connection to the local electrical system can be a challenge considering the great diversity of voltages and distances involved, as well as the large injections of harmonic content generated by the electron accelerator that can affect sensitive loads in the industrial system. In this work, an analysis was made of the power system of the mobile unit, regarding interruption capacity, selectivity protection and adequate short circuit levels in order to assure a greater reliability in the operation. At the end, the control panel of the mobile unit was tested, simulations and measurements were carried out on the 1.5 MeV and 37.5 kW electron beam accelerator, installed at the Intensive Radiation Technology Center, which demonstrated the necessity of applying of a filter to reduce the measured harmonic distortion.

POSTER # 89

ARCHITECTURAL DESIGN OF A MOBILE IRRADIATION UNIT FOR THE TREATMENT OF INDUSTRIAL EFFLUENTS IN BRAZIL

Fabiana F Lainetti[1], Celina L Duarte[1], Samir L Somessari[1], Francisco E Sprenger [1], Anselmo Feher [1], Maria Helena O Sampa[1], Danilo Fuga[2], Marcos Rodrigues[2], Wilson A Parejo Calvo[1].

[1]Radiation Technology Center, Instituto de Pesquisas Energéticas e Nucleares (IPEN/CNEN-SP), Sao Paulo, Brazil; [2] Development Department , TRUCKVAN Industry, Sao Paulo, Brazil.

The Nuclear and Energy Research Institute (IPEN-CNEN/SP) decided to develop and build a mobile beam irradiation unit for the treatment of industrial effluents. The mobile unit will have 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 Brazil. To implement the project, IPEN-CNEN/SP has been consolidating partnerships with national and international companies. The resources for the development of the unit have been supplied by the Brazilian Innovation Agency (FINEP) and International Atomic Energy Agency, financing the IAEA TC Project BRA 1035 – Mobile electron beam accelerator to treat and recycle industrial effluents. The Institute hired a specialized company – Truckvan – for the unit design and development. Several meetings have been realized with the company and the IAEA experts aiming the compatibility of the design and the exchange of information necessary for the project development. Regarding the mobile lab, several layout options have been developed to better meet the needs of each device and its users. The layout has been discussed with the objective of facilitating the maintenance of the equipment; the well-being and ergonomics of operators; optimization of spacing and also to make compatible the need for the presence of equipment and space for operators. Thus, several studies have been prepared to allow the discussion between the areas involved and to optimize the project, as well as the visualization of the spaces available. In this paper is presented the approach adopted for the architectural design of a mobile irradiation unit in Brazil.

POSTER # 2

PROFICENCY TESTING FOR INTERLABORATORY COMPARISION OF DOSIMETRY SYSTEMS

Sandra Pawlak[1], Diego Martin[1], Pablo Salatino[1], Abel Muñoz[1], Ailin Carreon[1], Juan I Garrido[1].

[1]Dosimetry, National Commission of Atomic Energy, Ciudad de Buenos Aires, Argentina.

An interlaboratory comparison with the requirements of ISO / IEC 17043: 2010, has been planned to give the opportunity to the participants to demonstrate their technical competence and ensure the quality and traceability of their measurements.
The purpose was also to help identify problems related to the performance of personnel, equipment calibration and adequacy of methods used to meet the requirements of the standard. This exercise is developed to evaluate two aspects:
- Part 1: The ability of participants to meet pre-set dose values (target doses).
- Part 2: The ability of the participants to measure doses that were applied. Alanine dosimeters had been irradiated with gamma radiation only.
Part 1: The parameter to be determined is the dose delivered to the dosimeters. The items were irradiated at: 1 kGy, 5 kGy, 10 kGy, 25 kGy.
Part 2: The parameter to be determined is the dose measured by each participant.

From the results obtained in the statistical treatment it was observed that the uncertainty value of some participants should be reviewed. Some of the reported uncertainty values were lower than the reference laboratory. From the results obtained in the statistical treatment, it is observed that the performance of the participants has been very good. No unacceptable results were obtained.

POSTER # 12

POST-IRRADIATION RESPONSE OF ALANINE TAPETAB PACKAGED DOSIMETERS

Deepak Patil[1], Hervé Michel[2], Kyrstan Polaski[1], Claire Frogley[3], David Pymer[3].

[1]STERIS, Applied Sterilization Technologies, Libertyville, IL, United States; [2]STERIS, Applied Sterilization Technologies, Daniken, Switzerland; [3]Harwell, Dosimeters, Didcot, United Kingdom.

Alanine dosimeters have historically been used as a transfer standard dosimeter by national and international standards laboratories. The industrial irradiation market has experienced high demand for delivering dose to meet specifications that are much narrower than historical requirements. This shift to narrower dose ranges resulted in the industrial irradiation industry requiring a higher precision dosimetry system. Alanine pellet dosimeters previously had no physical traceability that allowed them to be tied directly into a process until recent creation and production of an alanine dosimeter package. This poster will examine the response of multiple batches of packaged alanine pellet dosimeters at varying post-irradiation timeframes using both ruby- and manganese-based electron paramagnetic reference material spectrometers.

POSTER # 16

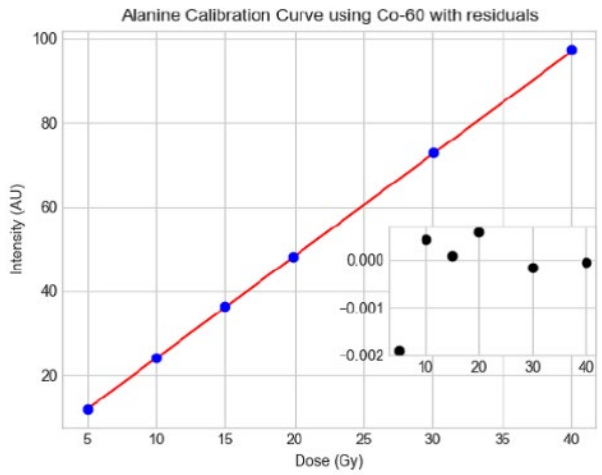
DEVELOPMENT OF A HIGH-ACCURACY ALANINE DOSIMETRY CAPABILITY COVERING THERAPY AND INDUSTRIAL DOSE LEVELS

Malcolm McEwen[1], Iymad Mansour[1], Fatima Hasanain[2], Chris Howard[2].

[1]National Research Council Canada, Ottawa, ON, Canada; [2]Nordion, Ottawa, ON, Canada.

The aim of this work is to develop a new alanine dosimetry capability covering the dose range 5 Gy to 20 kGy with an accuracy better than 1% (k=1). This system will complement those of a number of other national metrology institutes, providing additional redundancy and robustness.

Alanine readout is via a Bruker EMX (Xenon) spectrometer. Reference irradiations are carried out in Co-60, traceable to the Canadian primary standard water calorimeter operated by the NRC. Higher dose irradiations (above 1 kGy) are provided by a Gammacell 220 irradiator maintained by the Nordion dosimetry laboratory, located close to the NRC facility. Investigations have included reproducibility of pellet read-out, comparison of alanine pellet type, and uncertainty in calibration (fitting). The crucial step in accurate alanine dosimetry is measuring low doses (< 100 Gy) to allow the reliable transfer from the absorbed dose primary standard (typically operated at 1 Gy/min). An analysis method was developed, based on the literature, to extract the alanine signal and results are shown in the figure. As can be seen, the rms deviation of the fit is less than 0.2%. No significant difference in the level of noise or reproducibility was seen between different pellet types and the energy dependence for MV x-ray beams was found to be consistent with that reported in the literature (~ 0.5% for x-ray energies up to 10 MV). The overall uncertainty in measuring absorbed dose to water using the alanine system is estimated to be 0.7%. The capability has been successfully developed and comparisons with other alanine systems are currently underway. Initial results give agreement within combined uncertainties, indicating that this new capability is consistent with current standards.



POSTER # 24

DETERMINATION OF DOSE LIMIT FOR A GROUP OF LIF DOSIMETERS WITH RISØ TL/OSL DA-20 UNDER THE STANDARD AND DIFFERENT OPTICAL CONDITIONS OF THE READER

Aleksandar Krleski[1], Margarita Ginovska[1], Hristina Spasevska[1], Sonja Petkovska[2], Ivana Sandeva[1]. [1]Faculty of Electrical Engineering and Information Technologies, Ss Cyril and Methodius University in Skopje, Skopje, Macedonia, The Former Yugoslav Republic of; [2]Radiotherapy, Acibadem Sistina Hospital, Skopje, Macedonia, The Former Yugoslav Republic of.

Risø TL/OSL reader is originally designed for usage in geoarchaeological dating. For a reader to be accepted as suitable for dosimetric purposes, linearity or supra-linearity of the thermoluminescent (TL) response should be observed. This study aims to determine the possible upper readable dose limit for a group of LiF dosimeters. An analysis of TL curves for different groups of dosimeters, LiF:Mg, Ti (MTS-100, MTS-600 and MTS-700) and LiF:Mg,Cu, P (MCP-100, MCP-600 and MCP-700) with usage of U340 and BG39 optical filters is performed. TL characteristics for different doses of beta (90Sr/90Y) radiation (0.3 Gy to 1.1 kGy) were studied. Linearity in the group of LiF:Mg,Cu, P is monitored up to 1 Gy. In group of LiF:Mg, Ti the MTS-700 dosimeter shows the lowest TL intensity using both filters. When using BG39 filter for doses higher than 50 Gy, no normal TL curve with clearly marked peaks is observed. The linearity in this group is monitored up to 50 Gy. Using U340 filter significantly increases the measurement range up to ~ 800 Gy with exception of MTS-700 which has a clear curve at 1.1 kGy. However, the range of ~ 1 kGy is the dose limit because the intensity obtained at this dose enters the limit of the photomultiplier ~ 8.5·106 impulses. The supralinear, corrective part is different for each individual type of both groups and depends on the optical characteristics of the detection system. Usage of different filters makes it possible to increase measurement range. All examined readouts have reproducibility that fits the prescribed standards. TL glow curves obtained with this reader are quite similar with curves obtained with other readers present in literature, regarding their shape and characteristics. Thus, this reader shows potential to be used in dosimetry.

POSTER # 25

ESTABLISHING MEASUREMENT TRACEABILITY FOR LOW ENERGY E-BEAM DOSIMETRY

Seb Galer[1], Peter Sharpe[1], Arne Miller[2], Mark Bailey[2].

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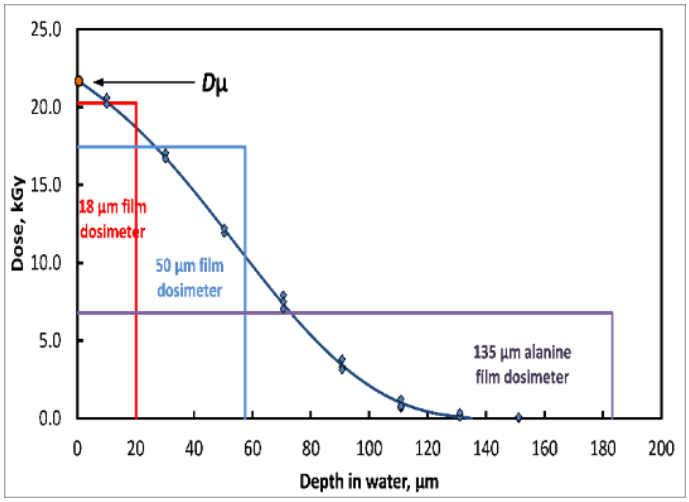
The use of low energy electron beams (70-150 keV) in regulated applications, such as medical device sterilization, requires dose measurements that are traceable to national standards and have a known level of uncertainty. Traceability is established through irradiation of reference and routine dosimeters at the facility of use. Conventional dosimetry techniques are not applicable as large dose gradients will occur in both reference and routine dosimeters using even the thinnest conventional film dosimeter. One suggested solution to this problem is to define the calibration in terms of the dose to water in the first micrometer of material (Dμ, see fig 1), rather than the average dose received by the dosimeter. This enables dosimeters of varying thicknesses to be calibrated using the same quantity and provides consistent measurement results. Determination of Dμ involves an iterative approach (Helt-Hansen et al, 2010) that is difficult to use and hence might impede the practical use of the method. In the present work we introduce a simplified formalism that provides a more direct method for determining Dμ, allowing easier calculation of reference and routine doses in terms of Dμ, and thereby facilitating the calibration that it required for establishing measurement traceability to recognized national and international standards. Traceability of Dμ relies on knowledge of the relative response of dosimeters, such as alanine, irradiated in low energy electron beams and in reference radiation, such as Co-60. Recent developments in primary standards operating in low energy electron beams (Galer et al, IMRP-2016) have provided new data on these relationships, which we use to derive a full uncertainty budget for Dμ with reduced overall measurement uncertainty.



POSTER # 28

RESPONSE OF PE FILMS TO LOW ENERGY ELECTRON BEAM IRRADIATION

Roberto Uribe[1], Omar Al Harbi[1], Zoewendsaongo Nare[1].

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In the past few years low energy electron beam units with energies in the range from 80 to 300 keV have been developed as a convenient and non-expensive alternative for radiation curing of coatings, thin film crosslinking and polymerization, and surface decontamination. In many of these applications the process is controlled by means of the beam parameters and the final properties of the irradiated product, but in applications involving compliance with FDA regulations the determination of the dose received by the irradiated product is a basic requirement. Usually this is obtained through measurement with an appropriate dosimetry system. In the last four years a study to determine the potential use of polyethylene (PE) films as dosimeters in this type of applications has been developed at Kent State University (KSU). The response of the films has been measured by infrared spectroscopy using the attenuated total reflectance (ATR) technique. In this technique the infrared radiation only analyses the chemical changes produced in the surface of the film making this a suitable technique to be used with low penetration radiation beams (e.g. 200 keV electrons). The radiation response of the film has been measured at three different energies in the interval from 100 to 200 keV and compared with the radiation response at higher electron beam energies (3.8 MeV). The results have been analyzed both experimentally and by simulating the absorption of the electrons in the film using the Monte Carlo code Penelope.

POSTER # 35

DOSIMETRY AND MODELLING REFERENCE TRANSFER STANDARD DOSIMETERS – EQUIVALENCE AND FIELD PERFORMANCE STUDY

GARY PAGEAU[1], Shawn Klingel[1], John Logar[4], Arne Miller[3], Peter Sharpe[2].

[1]GEX Corporation, Centennial, CO, United States; [2]National Physical Laboratory, Teddington, United Kingdom; [3]Riso Nutech, Danish Technical University, Roskilde, Denmark; [4]Sterilization Sciences, Johnson & Johnson, Sommerville, NJ, United States.

Many applications in the industrial radiation processing industry, including the sterilization of healthcare products, requires a user to establish a dosimetry system whose dose measurements are traceable to a national standard of dose. This traceability chain can be established by following ISO/ASTM 51261. There are several options for transferring a radiation dose from a national standard of dose to the end user and international treaty agreements call for acceptance of each other's national standards; which are considered equivalent and therefore interchangeable. International comparisons of these standards have been conducted periodically and published every 5-10 years. However, these interlaboratory test results do not reflect how the dose is transferred to an end user and the measurements obtained under actual industrial field conditions. A blind study was performed that included a comparison between suppliers of transfer standard dosimeters. Analysis of the results included cross-chain equivalency comparison between national standard laboratories on the interpretation of dose from a primary standard along with down-chain equivalency comparisons of dose as it is transferred to accredited secondary laboratories and finally with direct comparisons of results of dose transferred and used in routine irradiation processing at end user sites. Results of the study are provided with the analysis of results intended to aid industry understanding of the accuracy and precision, or uncertainty, associated with each step in the dose traceability chain.

POSTER # 36

PERFORMANCE EVALUATION OF IRREVERSIBLE TEMPERATURE INDICATORS IN HIGH RADIATION APPLICATIONS

Gary Pageau[1], Sean Coffman[1], Marcia Dyer[2].

[1]GEX Corporation, Centennial, CO, United States; [2]American Thermal Instruments, Inc., Moraine, OH, United States.

Irreversible temperature indicator labels are used by the radiation processing industry to estimate temperature in the harsh radiation environment that renders electronic temperature measurement apparatus unusable. Reliable temperature estimates are necessary for adjustment of reference dosimeters for temperature influence as well as providing a means of verifying maximum product temperature control limits. Irreversible temperature indicators are thin, flexible, non-toxic, non-liquid filled, non-breakable, single-use devices that can be placed directly onto surfaces and used to estimate a maximum temperature to products and materials. When the Indicator is exposed to the specific temperature, a chemical reacts and the viewing window for that temperature point will display the color change from white to red. The results of a study are presented that compared the actual performance of sets of irreversible temperature indicators that provide visual temperature measurement displays over a temperature range of 27.5°C to 65.0°C (81.5°F to 149.0°F), in 2.5°C increments under actual high dose irradiation conditions against sets of factory controlled non-irradiated reference controls.

POSTER # 39

THE EFFECTS OF PROCESS INTERRUPTION ON HEALTHCARE PRODUCT AND DOSIMETRY SYSTEMS

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In radiation processing, it is common for a process interruption to occur. In this event, product and dosimeters may be exposed to prolonged periods of different temperature without exposure to ionizing radiation. When the process is re-initiated, the product and dosimeters are exposed to ionizing radiation to complete the radiation process. The goal of this experiment is to simulate defined process interruptions that are representative of actual process conditions (downtime, temperature, fractionation, fading) and determine the effects of various combinations of those factors on the dosimeter's response and on product that may promote microbial growth. The experiment consists of an in-depth study on healthcare product, and the response of dosimeters that have been irradiated, stored for a defined period of time and temperature, and then irradiated to complete the process. This study will be performed using Harwell Alanine Tape Tab, Red 4034 PMMA, Amber 3042, and FWT radiochromic film dosimeters. An additional objective of the study is to determine a method to correct the dosimeter's response in the case of irradiator shutdown, while maintaining measurement traceability.

POSTER # 53

TOO MUCH INFORMATION? – THE USE OF MATHEMATICAL MODELLING IN PQ VALIDATION

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Historic dose mapping practices provided a best guess at determining maximum and minimum dose locations during Process Qualifications of individual products. Placement rationales were based on a combination of facility practices, historic information, or set locations based on a grid. Mathematical modelling of dose distribution in products has evolved rapidly over the past few years and now provides a window into what a realistic expectation is for dose distribution. The power of modelling has been to predict doses in areas that may have been previously inaccessible or impossible to measure with dosimeters. The caveat, of course, is that for many processes the measured dose uniformity has severely missed one or both of the maximum and minimum dose regions for a product. This presentation will explore where we go from here: How do you reconcile a process that has been successfully run for decades, with a product that has shown no harm to patients with new information that shows that processing specifications are not being met? How do we need to shift our testing methodologies to properly determine maximum and minimum dose areas and assess their impact to sterility and patient safety?

POSTER # 4

BEST POSTER AWARD

CONTINUOUS ELECTRON INDUCED REACTIVE PROCESSING – A SUSTAINABLE REACTIVE PROCESSING METHOD

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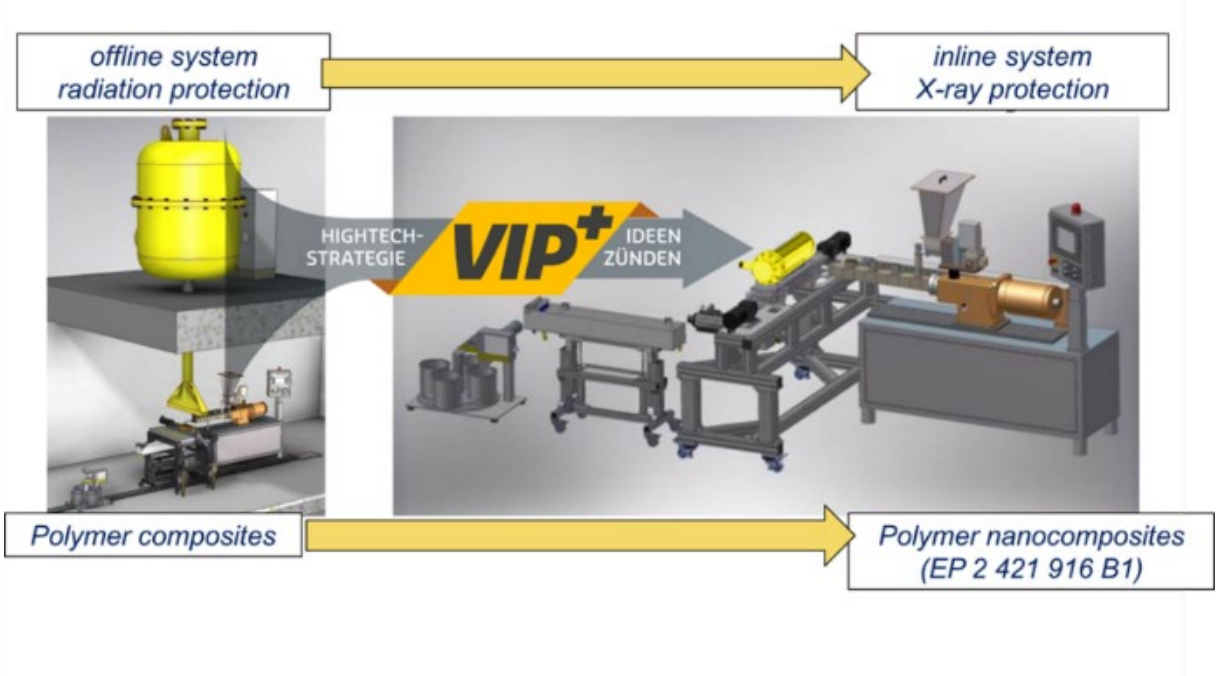
Due to increased requirements on polymer materials, several methods of physical and chemical modification of polymers are used in order fit the property level of different applications. In this sense, the reactive processing is a very powerful tool. It combines the physical and chemical modification of polymers and is used in several applications. In state-of-the-art reactive processing, the chemical reaction is induced by temperature sensitive initiators, but it is difficult to precisely control the desired chemical reaction and to manage the changed viscosity due to the chemical reaction. Nevertheless, it is difficult to analyze and control state of the art reactive processing. Polymer modification with high energy electrons (EB) is used for crosslinking, curing, degrading, grafting, and polymerization of polymeric materials. In contrast to the state-of-the-art reactive processing, EB technology uses the spatial and temporal precise input of electron energy to modify polymers and their compounds. Based on these advantages, the Electron Induced Reactive Processing (EIReP) was developed in order to overcome the disadvantages of state-of-the-art reactive processing. This novel reactive processing method was successfully tested for different polymer compounds. The results suggested that EIReP offers a novel route for preparing various high-performance polymeric materials without any temperature sensitive initiator and chemical additives. Here, the scale up to a continuously working inline demonstrator using a 300 keV electron emitter is shown for the first time. In addition, the main requirements on demonstrator design and first results of testing are presented for a flame-retardant polypropylene nanocomposite.


offline system
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IDEEN
ZÜNDEN
Polymer composites
Polymer nanocomposites
(EP 2 421 916 B1)

POSTER # 13

COMPOSITE MATERIALS HIGH DOSE RADIATION RESISTANCE TESTING

Alexandr Bryazgin[1,2], Vadim Bezuglov[1], Alexandr Vlasov[1], Leonid Voronin[1,2], Mikhail Korobeynikov[1,2], Mikhail Mikhailenko[3], Yuri Pupkov[1], Alexey Sidorov[1], Vadim Tkachenko[1,2], Evgeny Shtarklev[1,2].

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Composite materials – epoxy resin Araldite MY 740, hardened oligocyanurate resin, glass-reinforced resin and carbon-filled plastic – were irradiated with doses up to 500-MGy to determine their mechanical strength dose limits. The tested composite materials are designed for use in space satellites and in accelerating complexes magnet systems. The studies were carried out in Budker Institute of Nuclear Physics using powerful ILU-6 accelerator. Our present report describes irradiation conditions and dose dependence of structure changes and mechanical testing results.

POSTER # 20

METHYLMETHACRYLATE POLYMERIZATION CHARACTERISTIC PROPERTIES UNDER INTENSE PULSE ELECTRON BEAM IMPACT

Alexandr Bryazgin[1,3], Vadim Bezuglov[1], Alexandr Vlasov[1], Leonid Voronin[1,3], Mikhail Korobeynikov[1,3], Alexey Sidorov[1], Vadim Tkachenko[1,3], Evgeny Shtarklev[1,3], Mikhail Mikhailenko[2], Boris Tolochko[2].

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Methylmethacrylate polymerization under intensive pulse electron beam impact was studied using powerful ILU-6 accelerator. Results of the studies showed polymerization process instability – some samples in one lot can show zero polymer content even at dose of 100 kGy. The polymerization process was carried out at various dose rates and with or without magnetic shielding of the samples. Samples heating by electron beam and magnetic shielding made for stable reaction run. Influence of magnetic fields generated by electron beam can be possible reason for reaction instability. Electron beam generated by radio frequency accelerator ILU-6 has thin nanosecond component stipulated by accelerating radio frequency harmonics. This component has a same order of magnitude as characteristic time of radical interactions.

POSTER # 31

STUDY OF PROPERTIES IN PAINTS OF ACRYLIC EMULSIONS WITH AQUEOUS CELLULOSIC DISPERSIONS PROCESSED AND TREATED BY ELECTRONS' BEAM, ASSOCIATED WITH THE CONCEPTS OF ICA AND CIRCULAR ECONOMY

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According to the Brazilian Coatings Manufacturers Association (2018), decorative paints accounted for 83.3% of the volume of all paints produced in Brazil (2017). In 2016, this segment grossed USD 2,352 million and this shows the relevance of the sector, in addition to the Brazilian market, is one of the five largest in the world. The aim of this project was to propose the application of the concepts of Life Cycle Assessment (LCA) and Circular Economy in a premium acrylic emulsion paint and to improve the properties of this paint by means of the addition of aqueous dispersions of cellulosic waste processed by an electron beam. The methodology used was a case study, which consisted of the preparation from 5% to 10% dispersions of industrial cellulosic waste in water, processed with an electron beam in absorbed doses from 5 kGy to 50 kGy. Among the main results obtained are the minimization of environmental impacts and the identification of opportunities to improve environmental performance throughout the product life cycle. In addition, the maintenance and improvements of properties of the premium acrylic emulsion, such as appearance, specific mass, coating power, color, solids content, pH, biodegradability, besides the possibility of cost reduction. It is concluded that the research represents an innovative business opportunity by joining the paint and paper segments in a sustainable way (economic, social and environmental) by reusing the cellulosic waste dispersed in aqueous solution treated by electron beam and introduced to enhance the paint in the technical cycle, as recommended by the circular economy within the principles of regenerative and restorative process.

Metodology (Experimental)

a) Researches samples preparation

Figure 1 – Separate samples to initiate research activities

Results and Discussion

The results were determined according to Abrafati's QSP [12]. An interesting result obtained was the wet coating power of the paint [4], according to Table 1

Tabela 1 - Wet coating power of the paint [4],

Name	Wet coating power (%)				
	CP01	CP02	CP03	Results	Specifications
Control sample	95,69	95,43	96,24	95,79	≥ 90 %
FCN 5%RC 5kGy	94,20	94,41	88,93	92,51	≥ 90 %
FCN 5%RC 50kGy	95,65	94,04	90,76	93,48	≥ 90 %
FCN 10%RC 5kGy	93,88	91,23	94,79	93,30	≥ 90 %
FCN 10%RC 50kGy	93,25	96,06	95,35	94,55	≥ 90 %

POSTER # 44

PREPARATION OF BEECHWOOD/POLYMER COMPOSITES USING THE METHOD OF LYOPHILIZATION AND GAMMA IRRADIATION

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The beechwood is primarily used in building and furniture production. By the mid-19th century, beechwood was considered of lesser quality compared to other types of trees. With the development of wood protection technology (mating, impregnation) beechwood is becoming a valuable raw material. The improvement of beechwood properties, as well as its conservation, can be achieved by impregnation with monomers or polymers. The improvement of the characteristics depends largely on the polymer loading into the wood. In order to achieve better loading of the polymer, the wood was first lyophilized to remove as much moisture as possible. The lyophilized wood species were submerged in various monomer solutions. We used solutions of different concentrations of styrene and butyl methacrylate in methanol. After 24 hours in the solution, the samples were dried and then irradiated with different doses and radiation dose rates. The weight of the samples was measured before and after this procedure. Based on the weight differences, we determined which of the monomer solution is most suitable for making beechwood/polymer composites. Also, the most appropriate dose of radiation as well as the dose rate is determined.

POSTER # 51

POLYMER ELECTROLYTE MEMBRANES FROM PRE–IRRADIATION INDUCED GRAFT COPOLYMERIZATION ON ETFE

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Polymer electrolyte membranes (PEM) are a key component in many fuel cells and in redox flow batteries (RFB). So far in most applications Nafion membranes are utilized. In search of alternate membrane materials various approaches are pursued. One of them is the radiation-induced activation of polymer films and subsequent graft copolymerization [1]. In this contribution the preparation of PEMs in a three-step process is reported: Firstly, commercially available fluoropolymer films, e.g., poly(ethylene-co-tetrafluoroethylene) (ETFE), are activated via electron beam treatment. Secondly, graft co-polymerizations with functional methacrylates, *e.g.,* hydroxyethyl methacrylate and glycidyl methacrylate, are performed. Then, the functional groups are sulfonated yielding the final PEM. Alternately, co-polymerizations may be carried out with acrylic acid and hydroxyethyl acrylate, and subsequently the material is phosphonated to yield proton conductivity. The impact of the ETFE activation and especially the adsorbed dose on the grafting process, and consequently the performance of the PEM is addressed. In order to reduce cross-over in vanadium redox flow batteries and to enhance the mechanical stability, polymerizations is carried out in the presence of crosslinkers. The electrical performance of the resulting membranes is evaluated by electrochemical impedance spectroscopy and in fuel cell and vanadium redox flow battery (VRFB) tests. Stable electrochemical performance directly indicates membrane stability under typical VRFB conditions [2].

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POSTER # 52

BEST POSTER AWARD

COMPARISON BETWEEN GOLD NANOPARTICLES SYNTHESIZED BY RADIOLYSIS AND BY EGCG-DRIVEN GOLD REDUCTION

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Radiolytic synthesis and phytochemical-driven gold reduction for the generation of nanoparticles are successful examples of Green Chemistry applied for nanomaterials [1, 2, 3]. This study consists on the comparison between these two green approaches, their characterization regarding hydrodynamic size (assessed by dynamic light scattering), stability over time, optical properties (analysis of their absorption spectra from 250 to 1000 nm) and toxicity to living organisms (Zebra fish embryos (Danio rerio)). The nanoparticles were synthesized radiolytically by mixing: Au 1 mM; polyvinyl pyrrolidone (PVP) 0.5%; AgNO3 6 x 10-5 M; propan-2-ol 0.2 M and acetone 0.06 M (for the generation of isopropyl radicals). A dose of 15 kGy (5 kGy h-1, 60Co source was applied. The EGCG-functionalized nanoparticles were synthesized by mixing Au 1.6 mM with EGCG 0.8 mM in phosphate buffer, for 2 hours. The particles were successfully synthesized with both protocols, with plasmon resonance band peaks ranging from 520 nm to 535 nm. The polydispersity was relevant only for the radiolytic protocol. One month after the synthesis, there was no significant size alteration in the radiation synthetized particles, while some aggregation could be observed for the EGCG-particles. Regarding the toxicity, it was not possible to find the IC50 for any of the nanomaterials, but a mild toxicity was observed for the EGCG-nanoparticles. There was no toxicity at all for the radiolytically synthesized material. In conclusion, these green methods of nanoparticle synthesis generate particles with good control of size and optical properties, especially via reduction by EGCG. The stability and toxicity results, however, were more promising for the radiolytically synthesized gold nanoparticles.

POSTER # 84

RADIATION CROSSLINKED PROTEIN-BASED NANOCARRIERS: TOWARDS THE DEVELOPMENT OF NANO-RADIOPHARMACEUTICAL AND NANO-CHEMOTHERAPEUTIC AGENTS

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Nanoparticles have been proven useful as drug carriers due to their size, surface, and kinetics advantages, as well as ease of functionalization with targeting, imaging, and therapeutic moieties. Special attention has been paid to the use of protein-based nanoparticles due to inherent advantages of protein, including biodegradability, biocompatibility, and availability for conjugation of ligands or drugs. In this work, we address the synthesis of protein-based nanocarriers crosslinked by radiation, using albumin as a globular protein and papain as a therapeutic enzyme, as well as loading of potential drugs of interest. After synthesis, radiation crosslinked nanopapain and nanoalbumin of 8 and 26 nm, respectively, were used. Regarding nano-radiopharmaceuticals, the nanocarriers were directly radiolabeled with ^{99m}Technetium (^{99m}Tc), and the radiochemical evaluation and radiochemical stability were assessed by high-performance liquid chromatography. Radiochemical yield was established around 87.3±0.9 % for ^{99m}Tc-nanopapain and about 90±0.8% for ^{99m}Tc-nanoalbumin, with a shelf-life stability of 6 hours. Biodistribution in animals was also approached in this work. As for the nano-chemotherapeutic agent, paclitaxel (a model taxane) was encapsulated by the sonication method. Nanopapain-paclitaxel and nanoalbumin-paclitaxel held 96% and 85% encapsulation efficiency, respectively, while values around 75% were identified for the native and irradiated samples. In conclusion, the nanocarriers that were developed offered superior loading ability regarding paclitaxel encapsulation and radiolabelling with ^{99m}Tc if compared to the controls. Thus, the results provided experimental evidence of the relevant potential of the systems as nano-radio- and nano-chemotherapeutic agents.

POSTER # 87

Y-IRRADIATION SYNTHESIS OF MAGNETIC IRON OXIDE NANOPARTICLES IN THE PRESENCE OF DIFFERENT DEXTRAN POLYMERS

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Magnetic iron oxide nanoparticles (NPs) have applications as sensor, as contrast agents for MR imaging, in drug delivery and for hyperthermia cancer treatments. Gamma irradiation is an attractive and ecologically friendly technique for the synthesis of magnetic nanoparticles at room temperature. It has the advantage of inducing electrons and other reducing species homogeneously through the sample. Unlike radiolytic synthesis of noble metal NPs, the radiolytic synthesis of iron oxide NPs is much less investigated. One of the reasons is the very complex iron oxide chemistry that produces numerous phases. Besides, magnetic NPs have a high tendency for agglomeration and due to these reasons various polymers are used that act as dispersants and stabilizers of magnetic NPs in suspensions as well as growth and surface modifiers. Herein, we studied the influence of gamma irradiation dose, dose rate, pH and type of dextran polymers on the magnetic iron oxide NPs synthesized using gamma irradiation. In order to achieve reducing conditions upon gamma irradiation iron (III) chloride alkaline aq. solutions were purged with nitrogen in the presence of 2-propanol. Since ferrous ions (Fe2+) that formed upon g-irradiation of iron(III) precursor (in the form of Fe(OH)2 and Green Rust intermediate phases) are highly susceptible to oxidation, the final product depend not only on the g-irradiation parameters, but also on the process of product isolation. In the presence of positively charged DEAE-dextran polymer the irradiation with dose of 36 kGy resulted in formation of very small spherical sub-stoichiometric magnetite NPs, whereas at higher dose (130 kGy) the magnetic d-FeOOH nanodiscs were obtained. On the other hand, irradiation with 130 kGy in the presence of negatively charged dextran sulfate resulted in formation of mixed phases such as a-FeOOH, d-FeOOH and iron (III) hydroxide sulfate. By admixing glycerol in irradiated suspensions reduced intermediated phases such as Fe (OH)2 and Green Rust were captured thus confirming that γ-irradiation generated reducing conditions. In addition, we quantitatively determined the concentration of Fe2+ produced in irradiated suspensions by spectrophotometric technique (using 1,10-phenanthroline and ferrozine) as well as by redox titration using potassium permanganate and compared these results with the amount of Fe (II) in isolated powders. Besides, the synthesized magnetic NPs were used for decolorization of methylene blue, a cationic organic dye which is used in color staining of domestic objects and in industry and the removal of which from industrial wastewater is a major concern.

POSTER # 92

E-BEAM INDUCED MODIFICATION OF THE ELECTRICAL AND CATALYTIC PROPERTIES OF COPPER NANOTUBES BASED COMPOSITE MEMBRANES

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Currently, the use of ionizing radiation is one of the most effective ways to modify the properties of nanoscale materials. A significant number of publications are devoted to the study of changes in the structural, optical and conductive characteristics of metallic nanostructures, including composite materials based on polymer track membranes and metallic nanotubes [1,2]. In this work, we studied the effect of the e-beam on the catalytic properties of composites based on copper nanotubes and PET track membranes (pore density 4*107 ion-2, pore diameter 420 nm). The deposition of copper NTs was performed by the method of chemical template synthesis according to [3], after which the samples were irradiated with 5 MeV electrons in the range of 50–250 kGy. The morphology of the surface of the composites before and after irradiation was investigated by scanning electron microscopy. An analysis of the structure of the irradiated samples by X-ray diffraction showed that with an increase of the irradiation dose up to 250 kGy, there is an increase in the degree of crystallinity of the samples by 20% compared with the initial composite, the phase composition of the samples remains unchanged. Changes in the conductivity properties are also observed: in the range of 0-150 kGy, the resistance of the samples increases due to a change in the crystal lattice of the samples. The effect of electron irradiation on the catalytic properties of the composites was studied using p-nitrophenol hydrogenation as an example: the reaction rate constant and the degree of p-nitrophenol conversion were determined for 5 consecutive test cycles.

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POSTER # 94

TECHNICAL INNOVATION AND IMPROVEMENT OF PE-XC FLOOR HEATING TUBES - HIGH THERMAL CONDUCTIVE PE-XC FOOR HEATING TUBES

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"High Thermal Conductive PE-Xc Floor Heating tubes" is a new floor heating material that has been successfully developed based on PE-Xc tubes. By adding thermal conductive fillers into the composite material, the thermal conductivity of the composite material is improved. The thermal conductive filler has good dispersing ability in the composite material, so the tube material has excellent mechanical properties and thermal conductivity. When undergoing an irradiation process, the molecular structure changes from a linear structure to a three-dimensional network. At the same time, the thermoplastic material is changed into a thermoset material, which can further improve the performance of the tube. The thermal conductivity of "High thermal conductivity PE-Xc tubes" are twice that of ordinary PE-Xc tubes. The resistance to temperature of "High thermal conductivity PE-Xc tubes" goes from 70°C to 120°C and the resistance to pressure is increased. The useful life of High thermal conductivity PE-Xc tubes is 70 years. In conclusion, "High thermal conductivity PE-Xc tubes" have better thermal conductivity, faster thermal dissipation, and higher heat resistance. They save more energy and are more environmentally friendly than other ordinary polyethylene tubes.

POSTER # 10

IMPACT OF IONIZING RADIATION ON BIOACTIVE COMPOUNDS OF OLIVE WASTES

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In Portugal, the olive oil industry produces more than 600000 ton of wastes containing a significant amount of phenolic compounds such as hydroxytyrosol, tyrosol, secoiridoids derivatives, phenolic acids and flavonoids. These compounds can be used as food bioactive compounds, while being considered undesirable for the environment. Ionizing radiation can degrade higher molecular compounds into lower molecular ones [2], which could contribute for the treatment of recalcitrant compounds as well as for the enhancement of important bioactive compounds. The objective of this work was to evaluate the impact of ionizing radiation on the phenolic compounds of olive pomace. The irradiation experiments were carried out at room temperature in a Co-60 semi-industrial facility (absorbed doses: 5-20 kGy; dose rate: 16 kGy/h). The characterization of the phenolic profile in the extracts of olive pomace and the identification of the radiolytic products were carried out by HPLC-DAD-ESI/MS [3]. The antioxidant activity of irradiated and non-irradiated samples was measured by DPPH radical scavenging activity. The major phenolic compounds present in olive pomace extracts were hydroxytyrosol, verbascoside and quinic acid. The concentration of hydroxytyrosol, quinic acid and other phenolic compounds in the extracts increased significantly at 5 kGy of gamma radiation. Gamma radiation also induced a slight increase (15%) on the antioxidant activity, probably promoted by the increase of the concentration of these compounds. This output is very important since these compounds can present health benefits as anti-inflammatory, antimicrobial, antitumor and antioxidant properties that could be used as natural ingredients in food industry after isolation and purification.

POSTER # 22

DETECTION OF IRRADIATED COMPONENTS IN MIXTURES OF HERBS AND SPICES BY THERMOLUMINESCENCE

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Treatment of food with ionizing radiation is used for reducing the number of harmful microorganisms and toxins, delaying ripening and preventing sprouting. Thermoluminescence is one of the physical methods for detection of irradiated food containing minerals. When minerals are exposed to ionizing radiation, they accumulate energy by which some electrons move to excited energy states. When returning to ground state, some of them remain trapped in the crystal lattice. When exposed to heat, trapped electrons are released and recombination with holes occurs, resulting in emission of photons, thus a luminescence signal is obtained. Thermoluminescence analysis is done twice for each sample. The first measurement is done after isolation of minerals and detection of the signal. The second measurement is done after exposing the sample to a certain dose of ionizing radiation and detecting the signal for the second time. By these measurements two glow curves are obtained, which give the dependence of the thermoluminescence intensity on temperature. Glow ratio gives the ratio of the maximum intensity from the first and the second measurement. Magnitude of glow ratio and shape of glow curves can identify the sample as irradiated or unirradiated. Thermoluminescence measurements for this study are done on mixtures of irradiated and unirradiated food samples. Low content of irradiated material could still be detected by thermoluminescence, making it a useful method for detection of small contents of irradiated ingredients in food.

POSTER # 38

PHYTOSANITARY IRRADIATION: DOES MAP CREATING A LOW OXYGEN ENVIRONMENT THREATEN TREATMENT EFFICACY?

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Modified atmosphere packaging (MAP) used to preserve fruit quality during export creates a low-oxygen environment that may reduce the efficacy of phytosanitary irradiation treatment. For the first time, studies were conducted on irradiation efficacy under realistic conditions using infested fruit, actual MAP bags and approved irradiation doses. In Thailand, 'Nam Dok Mai' mangoes infested with oriental fruit fly third-instar larvae and placed in CF1 (8.6% O2), FF5 (9.6% O2), or H34M (7.2% O2) commercial MAP bags were treated with gamma radiation at 0 (control), 30, 60, 90, 120, and 150 Gy. The use of MAP on infested mangoes significantly increased mortality of oriental fruit fly after irradiation treatment. Therefore, MAP acted as an additional stressor rather than providing radioprotection in irradiated oriental fruit fly. Large-scale confirmatory testing of 35,000 oriental fruit larvae treated at 150 Gy in mangoes with H34M MAP bags produced no survivors to the adult stage. In Hawaii, 'Rainbow' papayas infested with third instar larvae of melon fly were placed in Ziploc storage bags, Xtend PP61 bags or Xtend PP53 bags and irradiated at 50 Gy; Ziploc storage bags (1-4% O2) increased survivorship to adult from 14 to 25%, whereas Xtend PP61 bags (3-8% O2) and Xtend PP53 bags (11-15% O2) did not. In large-scale tests, 9,000 melon fly and 3,800 Mediterranean fruit fly larvae infesting papayas in Ziploc bags (1-4% O2) were irradiated at 150 and 100 Gy, respectively, with no survivors to the adult stage. MAP should not compromise the efficacy of the internationally approved 150-Gy generic radiation treatment for tephritid fruit flies or the 100-Gy radiation treatment for Mediterranean fruit fly. Regulatory restrictions on MAP may be an impediment to commercial use.

POSTER # 45

INSECTICIDAL ACTIVITY OF NANOCOMPOSITE BASED FILMS CONTAINING ENCAPSULATED NANOEMULSION BASED ON ESSENTIAL OILS IN COMBINATION WITH Γ – IRRADIATION: IN VITRO AND IN SITU EVALUATIONS

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Plant essential oils (EOs) are known to have insecticidal properties and may have practical application in the management of stored product pests. The rice weevil, *Sitophilus oryzae* is a pest of stored and packaged grains such as rice.

The fumigant toxicities of eight individual essential oils (basil, cinnamon, eucalyptus, mandarin, oregano, peppermint, tea tree and thyme) and one binary combination (thyme and oregano) were investigated. Their activity was confirmed ranging between 4-42% with EOs (0.75%) loaded biopolymeric films during 10 days of incubation. Mortality percentage was significantly higher when treated with the chitosan-based films, showing around 40% mortality after 10 days of storage as compared to 20 and 30% for samples treated with PLA and MC based films, respectively.
In addition, the percent mortality increased to 95% mortality at day 10, when active chitosan-based film was combined with 300 Gy gamma radiation.

These results show that bioactive films containing EOs have the potential to control pests and extend shelf life in stored food products.

POSTER # 48

IDENTIFICATION OF IRRADIATED PLANT MATERIALS COMMONLY USED IN THE PRODUCTION OF SPICES, HERBS AND DIETARY SUPPLEMENTS BY PHOTOSTIMULATED LUMINESCENCE SPECTROSCOPY.

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The Food Safety Modernization Act requires food facilities to conduct hazard assessments and if a hazard is reasonably likely to occur, they must put in place preventive measures to control the hazard. Pathogens are reasonably likely to occur in some plant materials used in the production of spices, herbs and dietary supplements. Manufactures may choose to irradiate their products to control this hazard for those products for which there is a regulation allowing for their treatment. Currently, there are no reliable methods to determine if a product has been irradiated for verification of compliance with the Act. The use of Photostimulated Luminescence Spectroscopy (PSL) to detect irradiated spices was demonstrated in the early 2000's (EN 13751:2009 Detection of irradiated food using photostimulated luminescence). This paper presents data on the use of PSL for detecting irradiation in a variety of plant-derived materials. Over 60 plant materials commonly used in the production of spices, herbs and dietary supplements were investigated. The PSL procedure could determine irradiated plant materials from non-irradiated plant materials for a limited number of products that were investigated. For most of the plant materials, PSL could distinguish irradiated from non-irradiated products. However, for others this technique was not able to identify the irradiated products from the non-irradiated products. For a few products that were known to be non-irradiated, the technique gave a false positive response. A summary of the results will be presented providing data on the limitations of this technique to identify irradiated plant materials as well as the results of a single laboratory validation.

POSTER # 49

GAMMA IRRADIATION OF ANTIOXIDANTS TRIS (NONYLPHENYL) PHOSPHITE (TNPP) AND IRGANOX 1076 IN POLYETHYLENE FOOD CONTACT MATERIAL

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Pre-packaged food such as bagged lettuce that is pre-cut, and ready-to-eat are convenient to consumers. Demand for pre-packaged food is expected to increase, along with consumer expectations of obtaining safer food. Use of food irradiation technology may increase to meet the market demands. Before marketing irradiated pre-packaged food, the food packaging materials must be FDA approved for irradiation. The list of approved packaging materials for irradiation contains very few modern materials. To evaluate the food packaging material for safety, information on the chemical changes that occur after irradiation treatment is required. Additives present in polymeric food contact materials form radiolysis products when exposed to irradiation. In this study, we determined the concentration and identity of some of the radiolysis products of two antioxidants, TNPP and Irganox 1076, when irradiated at doses applicable to food. Polyethylene resin containing TNPP and Irganox 1076 were irradiated at 0.5 - 20 kGy. The antioxidants and their radiolysis products were extracted from the resin using accelerated solvent! extraction. The extracts were analyzed using liquid chromatography with mass spectrometry (LC-MS and LC-MS/MS) detection. The concentration of the antioxidants decreased as the irradiation dose is increased. For Irganox 1076, a 64% decrease from 312 ppm was observed at 4 kGy. The major radiolysis product was an oxidized form of Irganox 1076 corresponding to the loss of two hydrogens. For TNPP, a 97% decrease from 1595 ppm was observed at 4 kGy. The major radiolysis products were tris(nonylphenyl) phosphate, followed by nonylphenol. Eight other minor compounds were tentatively identified as radiolysis products of TNPP.

POSTER # 59

STERILIZATION OF LIQUID FOOD PACKAGES BY RADIATION

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In order to determine the lowest radiation dose to reach the 10^{-6} SAL and the highest tolerance dose for microorganisms, six types of liquid food packages from two manufacturers were eluted by membrane-filter procedure. The microorganisms were counted, classified, purified and cultured to be made into suspensions in same concentration. The suspensions were irradiated from 0.5 to 3kGy with a dose increment of 0.5kGy. The microorganisms were counted and the D_{10} value was determined. The lowest radiation dose necessary to reach a SAL of 10^{-6} SAL was calculated by SD= D10（logN0-logN）. Physical properties were tested between the lowest radiation dose up to 70kGy, which determined the highest acceptable dose for the products. The results showed that the minimum dose necessary was 24.75kGy, and the highest acceptable dose was 70kGy.

POSTER # 60

A STUDY OF RADIATION MUTANT PERILLA FRUTESCENS VAR. CRISPA FOR FUNCTIONAL FOOD APPLICATION

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About 165 lines of radiation-induced mutant *P. frutescens* var. *crispa* were screened for their anti-inflammatory activities. Among those screened, the mutant ("Antisperill") having the highest inhibitory activity on NO production in LPS-treated RAW264.7 cells were selected. The enhanced anti-inflammatory activity seemed to be due to the increase in isoegomaketone (IK) content (Fig. 1). We confirmed anti-arthritic effects of Antisperill in collagen antibody-induced arthritis (CAIA) in Balb/c mice (Fig. 2). Mice treated with Antisperill developed less severe arthritis than the control CAIA mice. They showed significantly improved arthritic score, paw volume, and paw thickness compared to the control CAIA mice from days 3 through 7. In human body application test, the group taken Antisperill showed significant improvement compared to placebo group in pain, rigidity, and joint function. Taken together, Antisperill treatment delays the onset of the arthritis and alleviates the manifestations of arthritis in animal model and human body. This study carries an important meaning in that it contributes to enhancing therapeutic possibilities for radiation mutant resources.

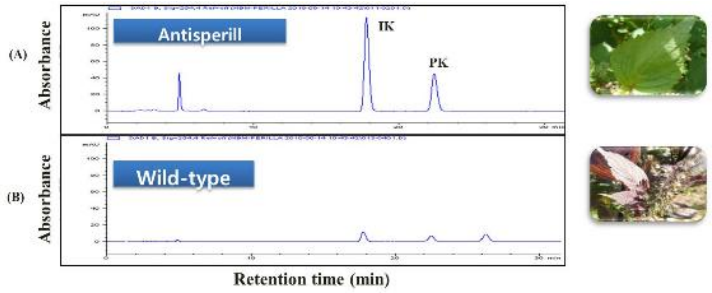

Figure 1. HPLC chromatograms. (A) Antisperill (radiation mutant) and (B) wild type

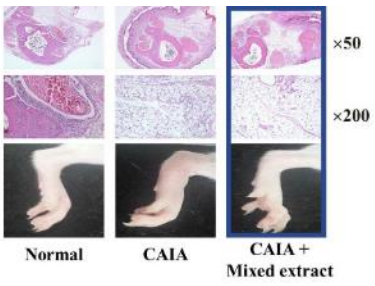

Figure 2. Anti-arthritic activities of mixed extract from radiation mutant "Antisperill" in collagen antibody-induced arthritis

POSTER # 62

EFFICACY OF LOW ENERGY ELECTRON BEAM ON MICROBIAL DECONTAMINATION OF SPICES

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Electrons with energies of 300 keV or lower have the potential to decontaminate the surfaces of various types of food products with minimal loss of quality. The aim of the work being presented was to determine the effectiveness of the process when applied to naturally contaminated food samples. Black pepper, white pepper and allspice samples were irradiated using electron beam at energy of 300 keV and 9 MeV to confirm the inactivation of bacteria on the surface. Total aerobic bacteria were counted before and after irradiation and bacterial species were determined by MALDI Biotyper, a microbial identification system based on MALDI-TOF mass spectrometry. The range of applied low energy electron beam in food products was estimated based on depth-dose profile of electron beam and density of samples. The beam was able to penetrate over a depth of about 300 μm, however the highest dose was on the surface. Non-irradiated white pepper and allspice carried 10 and 4 species of bacteria, respectively. They are all considered to be forming spores on grains of spices. The dominant species was *Bacillus subtilis*. In non-irradiation black pepper twelve species of bacteria were found and 5 species survived after the irradiation with low energy electron beam. Among them *Cronobacter sakazaki* dominated (63.3 % of total count after irradiation), which was recognized as a radiation resistant species. The reduction in total number of bacteria for food samples irradiated with high energy electron beam was comparable with that of the low energy electron beam process if estimated doses delivered on the surface were equivalent.

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POSTER # 63

ESTABLISHING ELECTRON BEAM FACILITIES AND COORDINATING THE SUPPLY CHAIN FOR PHYTOSANITARY TREATMENT AND DISTRIBUTION OF MEXICAN IMPORT COMMODITIES

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Electron beam (eBeam) processing is the U.S. Department of Agriculture's preferred method of phytosanitization. Given the volume of Mexican produce that requires phytosanitary treatment for entry into the United States, electron beam technology can play a major role. Currently, only one electron beam facility (located in the United States) is offering this processing capability. Conflicts in the objectives of the produce Distributor and the potential eBeam Service Provider have prevented the construction of additional facilities. To date, there has not been a detailed economic and supply chain analysis of the requirements for adopting this technology for treating Mexican produce. This paper demonstrates how the distributor's and the eBeam Service Provider's objectives could be coordinated by the eBeam Services Provider's strategic decisions on the facilities' locations and capacities, which determine whether the distributor uses the new facilities and, if so, the routes he travels. We show that cooperation can increase total profits by an average of 8.6%. We detail how the Distributor can motivate the eBeam Services Provider to make the appropriate sacrifices to increase the supply chain's overall profit. These results are robust to all business parameters tested.

POSTER # 64

IMPACT OF IONIZING RADIATION ON BRAZILIAN MACADAMIA (MACADAMIA INTEGRIFOLIA) NUTS AND THE CAKE RESULTING FROM THEIR LIPID EXTRACTION

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Native from Australia, the macadamia (*Macadamia integrifolia*) started to be commercially produced about 4 decades ago in Brazil. Macadamias constitute the edible seeds with the highest content of monounsaturated fats. The extraction of macadamia oil is commonly performed by cold pressing; however, the process presents low extraction yields, generating partially defatted meal as a byproduct, which can be subjected to further processing to increase the yield of oil extraction. Fumigants like propylene oxide are commonly used in the USA to reduce microbial populations in bulk raw almonds and others. Nevertheless, it is identified as probable human carcinogen. Ionizing radiation appears as a good alternative. Different authors already investigated some effects of gamma irradiation on various types of nuts. In the present work, results on the impact of gamma irradiation on Brazilian macadamia nuts and the residual cake after pressing are presented. Radiation treatment (doses up to 10 kGy) reduced yeast and mold bioburden as well as aerobic mesophilic bacteria below admissible maxima. Also, elements like calcium, selenium, magnesium or manganese were analyzed by neutron activation analysis (NAA) on both kinds of samples and it was found that there are important differences in the nutritional contribution coming from nut and cake.

POSTER # 66

EXPERIMENTAL-PRODUCTION RADIATION TREATMENT PROCESS FOR AGRICULTURAL PRODUCTS OF PLANT ORIGIN AT THE GAMMA-FACILITY 'GUR-120': CURRENT STATE AND OPTIMIZATION PROSPECTS

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The purpose of the work was to determine the optimal radiobiological indicators of the experimental-production process of radiation treatment, providing microbiological safety and increase the shelf life of plant products.

The research methodology was the following:

- To obtain the distribution of γ-radiation absorbed doses in agricultural products with different density using engineering calculation techniques and experimental data;

- To optimize the radiation treatment modes for different volumes of agricultural products, ensuring its uniform irradiation;

- To study the radiosensitivity of microorganisms present in spices, dried herbs, dried and fresh vegetables;

- To evaluate the radiation sterilization effectiveness for raw and finished products;

- To develop and conduct approbation of technological regulations for plant products radiation sterilization.

The application of different dosimetry techniques allowed obtaining new data on the basic «dose-effect» relationship for bacteria, fungi and yeasts under irradiation with dose rates in the range of 0.3 to 1.2 kGy/h and doses from 0.03 to 10 kGy.

The developed processing technologies of agricultural plant raw materials irradiated by isotopic sources with relatively small dose rates is optimal, but when the initial contamination of products is high, the destruction of microorganisms is incomplete and the required quality level cannot be achieved and it is then necessary to increase the applied dose.

POSTER # 67

SHELF LIFE EXTENSION OF DRIED SHRIMP USING ELECTRON BEAM AND PACKAGING TECHNIQUES

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Dried shrimp is a commercially important preserved marine product for both national and international trade. It can be eaten as a snack or used as an ingredient in various kinds of dishes in South East Asian. Products currently available usually contain a chemical preservative to prolong the shelf-life and to maintain microbial quality but chemicals are not well perceived by consumers but they also pose a health risk to certain individuals sensitive to the preservative. While the products without preservative can be kept only 14 days, we developed dried shrimp without preservative with extended shelf-life at room temperature using electron beam irradiation. Halophiles and microbial content of the products in vacuum-packed samples were studied before and after irradiation following 15, 30, 60 and 90 days of storage at room temperature (~ 25-30°C). The effects of electron beam irradiation on the physico-chemical properties including sensory characteristics were also investigated. It was found that microbial numbers were reduced in a dose-dependent manner after irradiation but color fading also increased with dose. Microbial quality was maintained at least 60 days at 3 kGy and 90 days at 8 kGy of storage. Ammonia levels in all samples were less than 1 ppm but gradually increased and reached 1 ppm after 60 days of storage. The combination of electron beam irradiation and vacuum packaging has contributed in improving the microbial quality and an extended shelf-life of dried shrimp. This effectiveness is expected to fulfil a growing demand for healthy dried shrimp and other food products.

POSTER # 69

IDENTIFICATION OF IRRADIATED PLANT FOOD SUPPLEMENT INGREDIENTS BY ESR USING SAMPLE PRE-TREATMENT WITH ALCOHOLIC EXTRACTION

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European Directives require labelling of irradiated food and checks at the commercialization stage. EN 1787 method, based on Electron Spin Resonance (ESR) technique, is applicable to detect irradiated products containing cellulose but its effectiveness is limited by the storage conditions and the complexity of the ESR spectra of some matrices. The results reported by Ahn et al. (2014) indicated that the alcoholic extraction enhances the radiation induced signal and improves the identification of some irradiated spices. This study aimed to verify the efficacy of this procedure to detect irradiation in Plant Food Supplement (PFS) ingredients. To this purpose samples of *Camellia sinensis, Ginkgo biloba, Silybum marianum, Vaccinium myrtillus, Cinnamomum verum, Zingiber officinale, Curcuma longa* were selected. Irradiation was performed by using a low-energy X-ray irradiator with a dose rate of 15 Gy min-1. To verify the efficacy of the alcoholic extraction not irradiated and irradiated (5, 10 kGy) samples were analyzed before and after the treatment. The extraction was performed following the procedure described in Ahn et al. (2014). ESR measurements were carried out at room conditions with the recording parameters indicated in the EN 1787 Standard. The preliminary results showed a general decrement of the signal intensity which was often associated with the disappearance of the spurious signals. As a consequence, the spectra obtained allowed an unambiguous detection of the irradiated samples. Further analysis, including an interlaboratory test, are in progress to confirm these findings.

Ahn J.J., Sanyal B., Akram K. and Kwon J.H. Alcoholic extraction enables EPR analysis to characterize radiation-induced cellulosic signals in spices. J. Agric. Food Chem. 2014, 62, 11089−98.

POSTER # 70

EFFECT OF GAMMA-IRRADIATED MANILA CLAM PORRIDGE WITH HESPERIDIN ON QUALITY CHARACTERISTICS AND IN VIVO IMMUNOMODULATORY ACTIVITY FOR STERILIZED PATIENT FOOD

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The objectives of this study were:

- To investigate the optimal doses of gamma irradiation for the production of Manila clam porridge (MP) as a hygienically safe sterilized patient food, and

- To evaluate the effect of MP with hesperidin, which selected for improving immune activities, on immune-suppressed model mice using gamma irradiation.

Gamma irradiation reduced the number of aerobic microorganisms and sterility was obtained at at 3 kGy. *B. cereus*, yeast, fungi, and *E. coli* were not detected. Gamma irradiation did not affect the pH, color, or moisture content except the fatty acid content and viscosity of MP. In the sensory evaluation results, all items except odor showed a preference toward normal (4 point) or more until 3 kGy.
C57BL/6 male mice were fed orally MP (4 g• kg^{-1}•day^{-1}) substituted with 20% normal diet or normal diet for 4 weeks, and then exposed to gamma irradiation at 4 Gy followed by the oral administration of hesperidin (150 mg•kg^{-1}) for one week. The group fed an irradiated was compared to the control group fed with a normal diet. White blood cell counts in the combined treated group with both MP and hesperidin were significantly higher, whereas DNA damage to splenocyte in the combined treated group was significantly lower ($p<0.05$). Furthermore, the concentrations of serum cytokines, especially interleukin-1β and tumor necrosis factor-α, in the combined treated group exhibited significant differences from those in the irradiated control group, indicating protective and inflammatory lowering effect of the combined treatment on immune cells in mice damaged by gamma irradiation. This study showed that gamma irradiation would be a suitable way for hygienically safe sterilized patient food and combined treated with hesperidin could help to improve radioprotective effect of patients.

POSTER # 71

RADIATION TREATMENT OF FISH PRESERVES: COMPARISON OF THE EFFECTIVENESS OF VARIOUS TYPES OF IONIZING RADIATION

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The aim of the work is to compare the effectiveness of gamma, bremsstrahlung and electron radiation at various doses for the radiation pasteurization of fish preserves. Samples of fish preserves in hermetically sealed jars consisted of pieces of herring fillet in oil filling with or without addition of spices. Irradiation was carried out in gamma facilities of different activities and in accelerators (electron energy from 2.5 to 10 MeV) in electron and X-ray bremsstrahlung modes. The absorbed doses were 0.5, 1.5, 3.0 and 6.0 kGy. The samples were examined immediately after irradiation then after 30, 45, 90 and 180 days. The number and types of micro-organisms (MALDI TOF mass spectrometry) were analyzed. The decrease in microbial contamination of fish preserves after irradiation at all facilities at doses from 3 to 6 kGy reached almost 100%. For the low-activity gamma-ray units, the duration of the irradiation process was critical; The effectiveness of antimicrobial treatment on the electron accelerator decreased with increasing electron energy and dose rate in the beam. The use of an electronic accelerator in the regime of X-ray bremsstrahlung increased the time of irradiation. The use of electron accelerators with an electron energy of more than 5 MeV should be applied with strict limitations on the maximum absorbed dose not exceeding 6 kGy. The organoleptic, physical and chemical quality parameters of fish fillet and oil filling did not change during 30-45 days of storage.; The metabolic activity of microbiota survived after irradiation (mainly yeast-like fungi - *Candida zeylanoides*) significantly decreased.

POSTER # 72

POTENTIAL OF NUCLEAR MAGNETIC RESONANCE (NMR) SPECTROSCOPY IN THE DETECTION OF IRRADIATED FOODS

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Ionization enables to prepare foods with a longer shelf life. In Europe, the process is strictly regulated and the treatment of a product by ionization must be mentioned on its packaging. In this context and given the potential of this technology to reduce food waste, the detection of irradiated foods is an important issue for fraud and control aspects. However, if the techniques implemented today can detect most irradiated foods, some specific matrices are more problematic to analyze. This work aims to test the ability of NMR spectroscopy to detect irradiated foods. Three matrices were considered: paprika, nutmeg and flax seeds. Irradiation of the former two is easily characterized by conventional detection techniques but the latter is much more complex to analyze with these same techniques. Samples of paprika powder, nutmeg and flaxseed were irradiated at increasing doses (from 0.5 to 20 kGy) with e-beams of 2.2 MeV. The apolar fraction of these products was selectively extracted using CDCl3. The extracts were analyzed by 1H NMR with a 9.4 Tesla spectrometer. The spectral fingerprints obtained were compared with those of non-irradiated samples using multivariate statistical approaches. Results show that NMR is capable of detecting ionized paprika and nutmeg powders at doses as low as 0.5 kGy. If this technique could not estimate the dose received by these products, it highlighted for paprika the successive appearance and disappearance of a neo-formed compound as the dose increased. Concerning nutmeg, a potential marker of product integrity was observed. Finally, a preliminary model of the dose received by flaxseed samples was established based on their complete 1H NMR spectra. These results open new perspectives in the use of NMR as a complementary technique to detect irradiated foods.

POSTER # 73

DEVELOPMENT OF A DOSE SUBSTANTIATION METHOD INVOLVING USE OF A NON-PATHOGENIC SURROGATE FOR SALMONELLA THAT CAN BE USED IN SPICES AND RELATED PRODUCTS

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The objective of this study was to develop a method for substantiation of a 6 kGy dose for achieving a 5-log reduction in salmonella using an appropriate surrogate. Three spice seasonings having some degree of variation in product composition were selected for this study. The surrogate organism used was *Enterococcus faecium* NCIMB 2699 which is a non-pathogenic surrogate for Salmonella. This organism was initially developed by the Almond Board of California for thermal processes and later adopted by the spice industry for other microbial reduction processes such as ethylene oxide and irradiation. After procuring from NCIMB, U.K. the organism was enriched in luria broth and incubated at 37°C for 24 hrs. The enriched broth was isolated on nutrient agar medium and inoculated into sterile talc. The inoculated talc was further mixed with the spice seasoning samples to obtain a count of minimum 10^6 cfu/g. The inoculated product was packed into paper pouches of 50 grams each and 10 such samples of each seasoning were prepared. The product samples were placed at a validated stationary position inside a batch irradiator and irradiated to a dose of minimum 6 kGy. The samples were analyzed for the count in surrogate post irradiation. The results are in figure 1. The variation of surrogate counts in the untreated samples is attributed to the inherent anti-microbial properties of a particular spice ingredient. This exercise could demonstrate a 5-log reduction in salmonella surrogate across a variety of spice seasonings. This methodology can be adopted by the irradiation industry for substantiating a dose selected for eliminating salmonella in other similar products

Product	Untreated	Log of Untreated	Treated (Average)	Log of Treated	Log Reduction
Seasoning A	7.0×10^6	6.845	< 10	1	5.845
Seasoning B	5.0×10^7	7.698	< 10	1	6.698
Seasoning C	1.91×10^6	6.281	< 10	1	5.281

POSTER # 78

ANALYSIS OF COLOR AND TEXTURE IN TAGETES PATULA L. PROCESSED BY IONIZING RADIATION

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Tagetes patula L. (French marigold) is used in culinary preparations to enrich both sensory and nutritional qualities. The main objective of edible flowers use in gastronomy is to add beauty and flavor. The color and texture attribute represent the most important criteria of their quality. However, edible flowers are highly perishable products and new approaches are required to improve their conservation and safety. Irradiation treatment is a method that can be used for the extension of shelf life of perishable commodities and ensuring food safety. The purpose of this study was to evaluate the physical properties of color and texture in *T. patula* flowers submitted to gamma and electron beam irradiation (0.5, 0.8 and 1.0 kGy) against non-irradiated samples (control). A colorimeter and a texturometer were used to analyze samples of orange T. patula. The physical characteristics of the irradiated samples were not significantly different from the control sample. Irradiation is an option to preserve the quality of edible flower petals.

POSTER # 79

EFFECT OF IONIZING RADIATION ON TRADITIONAL AND BACON "FAROFAS"

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Cassava in Brazilian industry has a wide variety of uses and its products and by-products are widespread throughout the country. Spiced "farofa" present daily in the meals of Brazilians" is one of these by-products and is the result of the addition of condiments during its preparation. Ionizing radiation be an alternative for technological improvement and to prolong the shelf life of the product. The effects of ionizing radiation on the moisture, color, pH and water activity (aw) were evaluated in bacon farofa (BF) and traditional farofa (FT)). The samples were obtained from the São Paulo-SP trade. They were irradiated in the electron accelerator of IPEN / CNEN-SP Radiation Technology Center at 1, 5 and 10 kGy. The tests were carried out on the first, 15th and 30th day of storage. The results demonstrated that irradiated FB and FT samples showed pH acid level throughout the storage period irrespective of dose increase. It was observed that there was no significant difference in the results in relation to the doses of ionizing radiation applied in the water activity. The following values were found on the 30th day of storage for FT sample 0.37 ± 0.01; 0.42 ± 0.01; 0.45 ± 0.00; 0.44 ± 0.00 at doses 0 kGy, 1 kGy, 5 kGy, 10 kGy, respectively. In the colorimetric analysis, it was observed that on day 30 of storage the BF sample had no significant difference indicating that the yellowish staining remained stable throughout the experiment at all doses applied. At 30 days of storage, the samples of FB and FT presented moisture between 90 and 92 %. It was concluded that the radiation doses applied did not significantly alter the studied parameters.

POSTER # 80

ENTERIC PATHOGEN SURROGATES FOR THE VALIDATION OF A NEW RADIATION PROCESS FOR SEEDS DECONTAMINATION

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Sprouts and spices are increasingly involved in outbreaks of gastrointestinal illness in USA and Canada as well as in Europe. Irradiation is a very effective technique for seeds microbial decontamination (e.g. Salmonella enterica and Escherichia coli O157:H7). The use of high-energy electron beam (HEEB) permits seeds decontamination, but with the risk of inhibiting their germination. A new process implementing a low energy electron beam (LEEB) (200 KeV) can limit the radiation impact to the seeds surface, where contamination is found. However, the implementation of LEEB process for seeds decontamination requires validation. In this respect, the joint Aérial - Bühler project focused on the identification of suitable Salmonella and Escherichia coli O157:H7 surrogates for *in situ* validation of seeds decontamination by both high- and low-energy electron beam irradiation process. The impact of seeds nature (Alfafa, coriander, fennel and wheat) and electron beam energy (2.5 MeV and 200 keV) on the radiation resistance of Salmonella, E. coli O157:H7 and surrogate candidates were investigated. Our purpose for this presentation is to present the rational for surrogate's selection and the methodology to carry out their inoculation in real conditions (at industrial level) including a sieving step. The main results on the radiation resistance of selected surrogates will also be presented, demonstrating that both, HEEB and LEEB process can lead to D10 values of some strains of surrogates higher than those of the target pathogens. Some nonpathogenic strains evaluated in this study could be used as surrogate for pathogenic E. coli and Salmonella to validate LEEB irradiation. This will be an effective strategy to enhance the microbiological safety of seeds.

POSTER # 85

EVALUATION OF THE HURDLE TECHNOLOGY USING ANTIMICROBIAL EFFECTS OF SPICE ESSENTIAL OILS, HEATING, IRRADIATION TO CONTROL THE BACILLUS SPORES

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Since bacterial spores show resistance against various sterilization treatments it is important to investigate the inactivation mechanism of spores for individual sterilization methods in order to establish appropriate hurdle technology as a method for effectively sterilizing the spores in foods while preserving their quality. Bacterial spores develop into vegetative growth through germination and outgrowth stages, which begins when contacting germination-inducing agents to the germinating receptor located in inner membrane of the spores. When bacterial spores are damaged by a bactericidal stress, these stages may be inhibited which eventually leads to cell death. Currently little knowledge is available on the process of cell death and the presence or absence of injured bacteria which are viable but non detectable as survivors. In this study, we focused on the development of *Bacillus subtilis* spores and examined where is a critical point of inactivation with heating and gamma irradiation from cobalt-60. These results suggest that damages to *B. subtilis* spores are different between gamma rays and 98°C heat treatment, and damage is mainly caused to genomic DNA with gamma rays while the germination system of the spore seemed to be affected by heating at 98°C.

POSTER # 93

SURVIVAL OF E. COLI O157:H7 IN IRRADIATED APPLES AND THEIR JUICE

Anuradha Prakash, Dielle Fernandes.

Chapman University, USA.

Escherichia coli 0157: H7 can contaminate dropped apples used for juicing via manure or irrigation water and attach to the flesh of the apple through bruises and wounds where surface sanitizers are not effective. The goal of this project was to determine the survival of Escherichia coli O157: H7 in whole apples used for juicing, as well as the juice, following irradiation up to 1 kGy. Whole apples were punctured to simulate wounds which were then inoculated with an outbreak strain of E. coli O157: H7 and subject to gamma irradiation at doses up to 1 kGy. The D-value of the E. coli O157:H7 strain was 334 Gy indicating that irradiation at 1 kGy would result in a 3 log reduction of this pathogen. Contaminated apples were also stored for 3 weeks in cold temperatures during which E. coli survived but did not grow. The inoculated apples were juiced, and the juice was stored up to 72 h. There was no change in counts of E. coli in the juice from the control apples, but irradiation at 800 Gy reduced counts by 3 logs, and these cells did not survive the 72 h storage. Sensory testing of juice treated at 800 Gy indicated that consumers could tell the difference from the control juice, due mostly to greater sweetness of the juice from irradiated apples. These results show that E. coli O157:H7 can easily survive in bruised apples and in the juice made from them. Irradiation can provide significant lethality of E. coli in apples and juice conferring a greater level of safety without negative effects on sensory quality.

POSTER # 41

THE EFFECT OF GAMMA IRRADIATION PROCESS INTERRUPTION ON MICROBIAL RESISTANCE OF G. STEAROTHERMOPHILUS

Fatima Hasanain.

Nordion, Ottawa, ON, Canada.

Sterilization process monitoring and control is key to product safety in the healthcare industry. ISO/AAMI 11137-1, addresses the importance of monitoring and documenting radiation process parameters to ensure products have been processed according to specifications with no reference/information describing the effect of process interruption on the microbial resistance to radiation. When a sterilization process is interrupted and restarted, standards generally state that the two doses delivered on either side of the interruption are cumulative. That is the case to radiation effects on materials/products. It was desired to better understand if multiple doses delivered with a process interruption are likewise cumulative to microbial inactivation. The main objective of this study is to:

- Investigate the effect of gamma sterilization process interruption on the radiation resistance of G. s*tearothermophilus* in both a wet and a dry state

- Ensure sterility and product safety in the healthcare industry.

This presentation will highlight the cumulative dose study performed at Nordion collaboratively with Nelson Laboratories to determine the effect of radiation process i$. The study will provide the healthcare industry with the necessary know-how and tools to effectively control the safety of healthcare products when process interruptions occur.

POSTER # 46

TARGETING OXIDATIVE STRESS MOLECULES AMELIORATES EXCESSIVE PRODUCTION OF RADIATION-INDUCED INFLAMMATORY CYTOKINE

Remigius Ambrose Kawala[1,2], Fatuma Jumapili Ramadhani[1,2], Byung Yeoup Chung[1], Hyoung-Woo Bai[1,2], Jin Kyu Kim[1,2].

[1]Research Division for Biotechnology, Advanced Radiation Technology Institute (ARTI), Korea Atomic Energy Research Institute (KAERI), Jeongeup, Korea; [2]Radiation Biotechnology and Applied Radioisotope Science, University of Science and Technology (UST), Daejeon, Korea.

The early excessive release of inflammatory cytokines induced by ionizing radiation may cause diseases whose inhibition provide radioprotection. Researchers investigated the key molecules responsible for the excessive production of cytokine during radiation exposure. The present study determined the key cytokine genes of skewed M1 macrophages that contribute to macrophages-IR responses. The result from microarray and PCR showed increased levels of proinflammatory cytokine genes and downregulation Atp5h gene that detected the cytosolic DNA. The results indicate that the effect of increased proinflammatory genes is minimally caused by compromised DNA rather the other released early molecules. To ascertain this, expression of Dclre1c that may be required for the repair of complex DSBs induced by radiation tolerated only in less than an hour. Interestingly, the results also showed early upregulation of Gbp7 a molecule responsible for the promotion of oxidative killing. The induction of this gene is correlated with the early release of Lcn2 and HO-1 and late release of Gpx2 which suggest that the increased responses of IR are associated with oxidative stress, in particular the increased ROS. In conclusion, the study showed that the IR-induced responses are propagated by the signals related to ROS and targeting these signals may provide novel radioprotection.

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POSTER # 47

BEST POSTER AWARD

CANCER DRUGS MODIFIED BY GAMMA RADIATION SHOWED ENHANCED EFFICACY IN CANCER TREATMENT

Remigius Ambrose Kawala[1,2], Fatuma Jumapili Ramadhani[1,2], Byung Yeoup Chung[1], Hyoung-Woo Bai[1,2].

[1]Research Division for Biotechnology, Advanced Radiation Technology Institute (ARTI), Korea Atomic Energy Research Institute (KAERI), Jeongeup, Korea; [2]Radiation Biotechnology and Applied Radioisotope Science, University of Science and Technology (UST), Daejeon, Korea.

Incrementally modified drug (IMD) is a new technique that provides a structural modification for drugs with low efficacy to a cancer patient. In this study, ionizing radiation (IR) was used to modify the structure of Kenalog (Kenalog-IR) and showed potential enhanced efficacy for the treatment of various cancer. The compounds generated by IR were tested for their anticancer activity in melanoma cancer cells. Treatment with these compounds induced inhibition of cell proliferation as assessed by 3-(4,5-Dimethylthiazol-2-Yl)-2,5-Diphenyltetrazolium Bromide (MTT) assay and induced apoptotic cell death associated with intrinsic mitochondria pathway. The induction of this pathway was associated with the activation of caspase-related molecules in concentration and time-dependent manner. Interestingly, the induction of this molecules was associated with excessive production of reactive oxygen species (ROS) without affecting the cell cycle arrest. Taken together the findings in this study provide an evidence that apart from a chemical modification of IMD, the IR might quest a potential arm in IMD and therefore provide potential candidates for the treatment of various types of cancer.

POSTER # 61

DEVELOPMENT OF RADIATION COMPATIBLE EPDM COMPOUND FOR HEALTHCARE APPLICATIONS.

Chantara Thevy Ratnam[1], Pairu Ibrahim[1], Sivanesan Appadu[1], Mahathir Mohamed[1].

[1]Radiation Processing Division, Malaysian Nuclear Agency, Kajang, Malaysia.

Radiation processing represents a minor yet significant technology in healthcare applications. In the healthcare industry, irradiation has two main applications: sterilization of medical devices, cosmetics and herbs on one hand and the treatment of polymeric materials to modify their biomedical and other desired properties on the other hand. Ethylene–propylene rubbers (EPDM) and polypropylene (PP) are widely used in various medical applications that often require radiation sterilization. Under irradiation EPDM is found to crosslink to a considerable extend. However, PP degrades when irradiation is carried out in air although it crosslinks in an inert atmosphere. In this study, the radiation compatibility of thermoplastic elastomers based on ethylene-propylene diene terpolymer (EPDM) / polypropylene (PP) were investigated. The PP/EPDM blends with mixing ratios of 70/30, 50/50/ and 30/70 were prepared in a laboratory internal mixer at 180°C and a rotor speed of 50 rpm. The blends were irradiated by using a 3.0 MeV electron beam (EB) machine at doses up to 100 kGy in air and room temperature. The samples were characterized for tensile properties, gel fraction, thermal and morphological properties. The development of the gel content formed in irradiated blends proved that the increase in EPDM concentration generated an increasing insoluble fraction. The glass transition temperatures of the studied EPDM /PP blends indicated that the compatibility of the EPDM/PP blends improved upon irradiation. The scanning electron micrographs of the fracture surfaces of the irradiated blends show evidence consistent with the above contention. Thus, the experimental results clearly indicated that cross-linking in the EPDM and compatibilization of PP and EPDM phase simultaneously occurr upon irradiation.

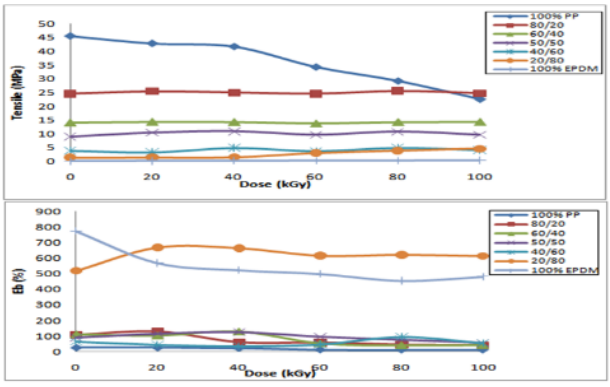


Figure 1 : Effect of irradiation on the Ts of PP, EPDM and PP/EPDM blend

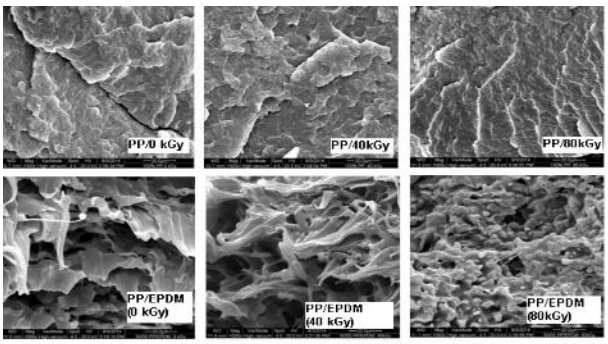


Figure 2 : Effect of irradiation on the fractured surface of PP and 50/50 PP/EPDM blend

POSTER # 68

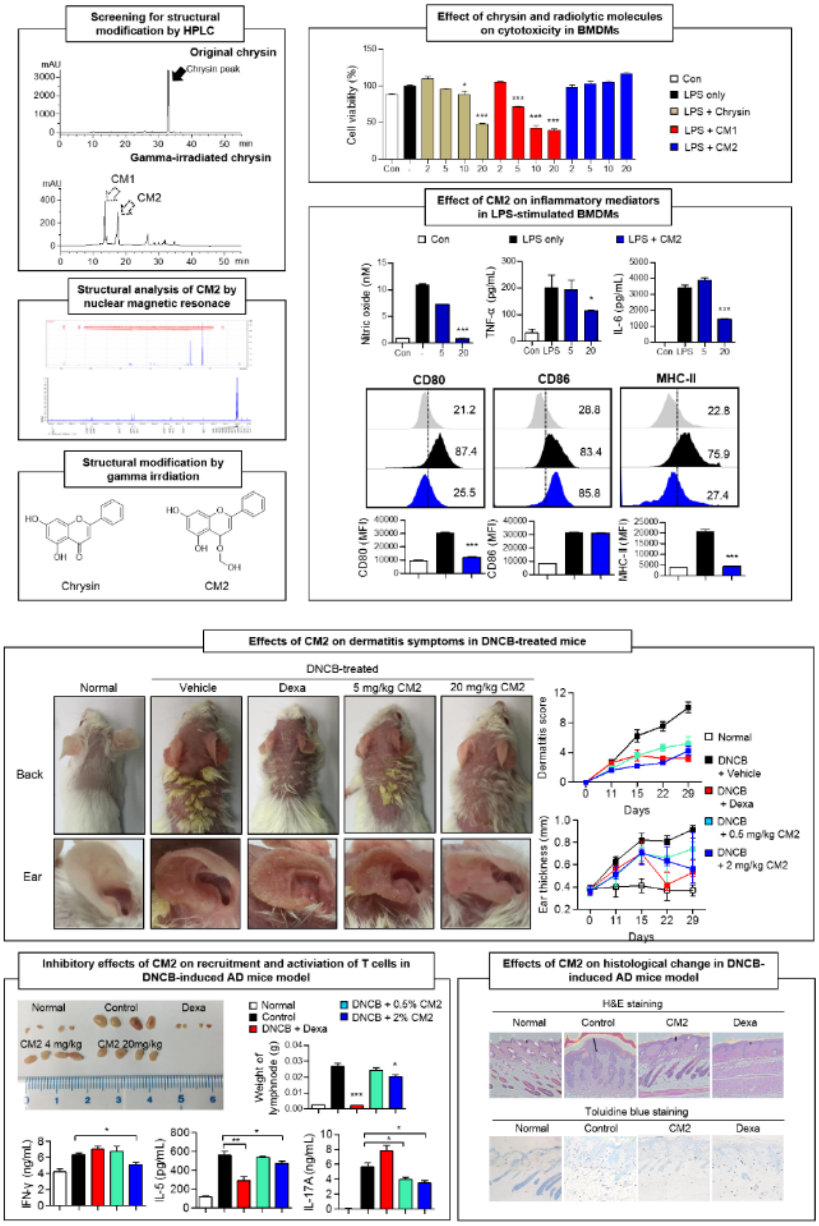
DEVELOPMENT OF NOVEL ANTI-ATOPIC DERMATITIS CANDIDATE FROM PROPOLIS-DERIVED CHRYSIN USING GAMMA IRRADIATION

Eui-Baek Byun[1], Ha-Yeon Song[1], Dongho Kim, Woo Sik Kim[1], Dae Seong Choi[1], Beom Su Jang[1].

[1]Biotechnology, Advanced Radiation Technology Institute, Korea Atomic Energy Research Institute, Jeongeup, Korea.

Chrysin is a well-known anti-inflammatory compound derived from propolis. However, high dose uptake of chrysin can lead to toxic effects, including cell death and injury in organs. Irradiation technology can be applied to reduce toxicity and to enhance physiological properties of natural molecules because their ionizing energy causes structural modification through oxidation-reduction reaction in functional group of compounds. The main objective of this study was to reduce toxicity of chrysin through structural modification and to evaluate the therapeutic effect of anti-atopic dermatitis in order to develop novel candidates. Chrysin was irradiated at dose of 100 kGy and the irradiation process led to the transformation of the chrysin structure into two radiolytic compounds (CM1 and CM2). Purified CM2 revealed lower cytotoxicity than intact-chrysin in bone marrow-derived macrophages (BMDMs). Treatment of CM2 strongly inhibited lipopolysaccharide-induced inflammatory mediators, e.g., overexpression of nitric oxide, inflammatory cytokines, and surface molecules in BMDMs. Furthermore, application of CM2 emulsion effectively attenuated dermatitis symptoms, including clinical signs, infiltration of inflammatory cells into dermis in the 2,4-dinitrochlorobenzene-induced atopic dermatitis (AD) mice model.

In conclusion, irradiation induced the production of a new molecule (CM2) from chrysin, which exhibited lower cytotoxicity and stronger anti-inflammatory effect than original chrysin in in-vitro and in-vivo model. These findings suggest that CM2 can be attractive candidate for treatment of AD.


Screening for structural modification by HPLC
Original chrysin
Chrysin peak
Gamma-irradiated chrysin
CM1
CM2
Structural analysis of CM2 by nuclear magnetic resonace
Structural modification by gamma irrdiation
Chrysin
CM2
Effect of chrysin and radiolytic molecules on cytotoxicity in BMDMs
Cell viability (%)
Con
LPS only
LPS + Chrysin
LPS + CM1
LPS + CM2
Effect of CM2 on inflammatory mediators in LPS-stimulated BMDMs
Nitric oxide (nM)
TNF-α (pg/mL)
IL-6 (pg/mL)
CD80
CD86
MHC-II
21.2
87.4
25.5
28.8
83.4
85.8
22.8
75.9
27.4
CD80 (MFI)
CD86 (MFI)
MHC-II (MFI)
Effects of CM2 on dermatitis symptoms in DNCB-treated mice
DNCB-treated
Normal
Vehicle
Dexa
5 mg/kg CM2
20 mg/kg CM2
Back
Ear
Dermatitis score
Ear thickness (mm)
Days
Normal
DNCB + Vehicle
DNCB + Dexa
DNCB + 0.5 mg/kg CM2
DNCB + 2 mg/kg CM2
Inhibitory effects of CM2 on recruitment and activiation of T cells in DNCB-induced AD mice model
Normal
Control
Dexa
CM2 4 mg/kg
CM2 20mg/kg
DNCB + 0.5% CM2
DNCB + 2% CM2
Weight of lymphnode (g)
IFN-γ (ng/mL)
IL-5 (pg/mL)
IL-17A (ng/mL)
Effects of CM2 on histological change in DNCB-induced AD mice model
H&E staining
Normal
Control
CM2
Dexa
Toluidine blue staining

POSTER # 74

CONSIDERATIONS WHEN CHANGING RADIATION SOURCES AND LOCATIONS; GUIDANCE FOR THE INDUSTRY

Bryce Telford[1], Wendy Wangsgard[2], Martel Winters[2], Kevin O'Hara[3].

[1]Radiation, Nelson Laboratories, a Sotera Health company, Broadview Heights, OH, United States; [2]Nelson Laboratories, a Sotera Health Company, Broadview Heights, OH, United States; [3]Sotera Health, Broadview Heights, OH, United States.

With increasing costs, and changes in technology it is becoming more common to change from one radiation source or irradiator to another. There are items that need to be considered and evaluated when making such a change. When undertaking such an evaluation items such as packaging configuration, biocompatibility, and maximum dose of the product should be considered. Depending on the source change being considered additional testing may be required. These considerations and different requirements will be outlined and evaluated to provide clarification and guidance. This includes information from ISO 11137-1 Section 8.4; Discussion of maximum acceptable dose between sources; Transfer of verification dose or sterilization dose; and consideration for water in its liquid state.

POSTER # 75

SELECTION OF ALTERNATE STERILITY ASSURANCE LEVELS FOR METHOD VD_{MAX}

Wendy Wangsgard, Martell Winters.

Nelson Laboratories, Salt Lake City, UT, United States.

The Association for the Advancement of Medical Instrumentation (AAMI) Radiation Working Group is in the process of developing new guidance for healthcare products sterilized following the VDmax method. The document is Technical Information Report (TIR) 76, Sterilization of Healthcare products — Radiation — Substantiation of a selected sterilization dose at a specified sterility assurance level: Method VDmax^SD-S. This guidance will expand on the established methods utilizing a spreadsheet that allows for determination of a verification dose for a range of sterilization doses and sterility assurance levels (SAL). The average bioburden can range from 0.01 to 10^6, sterilization doses can range from 3 to approximately 36 kGy, SALs from 10^-6 to 10^-3, SIPs from 0.01 to 1.0 and verification doses for 10, 30 or 90 healthcare products. Examples and guidance will be provided showing when the use of this TIR is beneficial and considerations for selecting the number of samples to be used in the test of sterility.

POSTER # 76

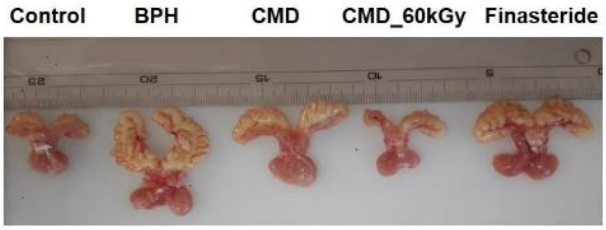
GAMMA IRRADIATION ENHANCED THE EFFICACY OF NATURAL MATERIALS IN IMPROVING AND TREATING PROSTATIC HYPERPLASIA

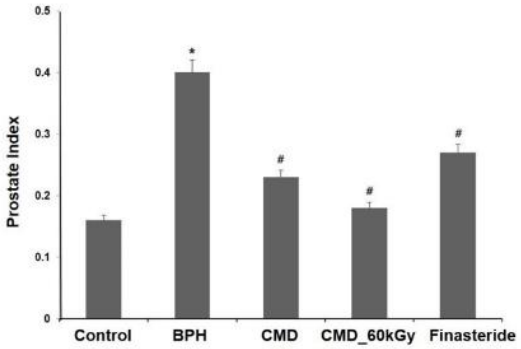
Mi-Jin Kwon[1], Cheng-Bi Choi[2], Gay-Won Lee[3], Kwan-Soo Kim[4], Kwang-Hoon Kim[4], Soo-Jin Kim[4], Haneul Choi[1], Ji Hee Sung[1], Young Ho Cho[3], Young-Min Yoon[1], Chen Hao[5], Ju-Woon Lee[1].

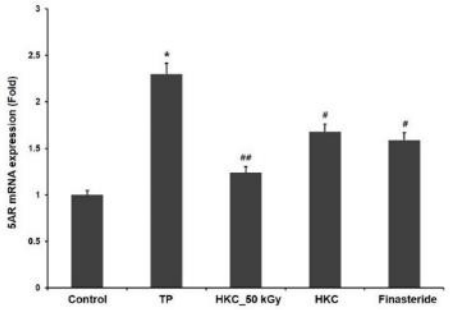
[1]Division of Efficiency Evaluation of Biomolecules, PSA Co., Ltd, Daejeon, Korea; [2]Department of Food Science and Technology, Yanbian University , Yanji, P.R. China; [3]Department of Pharmaceutics and Biotechnology, Konyang University, Daejeon, Korea; [4]Greenpia Technology Inc., Seoul, Korea; [5]Sichuan Institute of Atomic Energy, Sichuan, P.R. China.

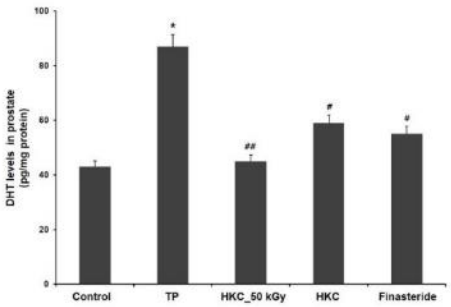
Benign prostatic hyperplasia (BPH) is one of the most common disease of mankind. The management of BPH has two goals, to reduce the bother of the symptoms, and to prevent or delay the progression of BPH related symptoms. In this study, the extracts of two natural products, *Rhodiola sachalinesis* (HKC) and *Asparagus cochinchinensis* (CMD) were gamma irradiated. Irradiation resulted in an improvement of the treatment effect of prostatic hyperplasia.

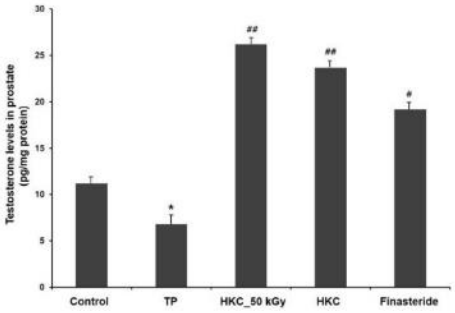
Experimental animals (7-week-old male SD rats) were divided into normal control and experimental groups. Experimental groups received subcutaneous injection of 20 mg/kg of testosterone propionate (TP) to induce BPH. The enhancing inhibition of prostate size and DHT concentration was found in 50 kGy irradiated HKC fed group. As well, 50kGy irradiated HKC fed group showed more significant reduction in 5-AR mRNA expression and testosterone concentration tend to increase. Based on these results, we next examined the therapeutic effect of HKC on hypertrophy of the prostate by first inducing enlargement of the prostate gland and then feeding it. Both HKC and 50kGy irradiated HKC fed group had a prostatic index close to that of normal control group. In the 60kGy irradiated CMD group, not only the prostate size was close to that of the control group, but also the testosterone and DHT levels were similar to those of the control group. Therefore, we expect to be able to develop more functional materials by gamma irradiating natural extracts as they lead to improvement and treatment of prostatic hyperplasia. We now need to identify the metabolic mechanism taking place.

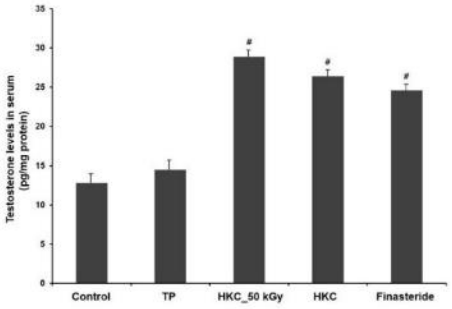

Control
BPH
CMD
CMD_60kGy
Finasteride


Prostate Index
0.5
0.4
0.3
0.2
0.1
0
Control
BPH
CMD
CMD_60kGy
Finasteride


5AR mRNA expression (Fold)
Control
TP
HKC_50 kGy
HKC
Finasteride


DHT levels in prostate (pg/mg protein)
Control
TP
HKC_50 kGy
HKC
Finasteride


Testosterone levels in prostate (pg/mg protein)
Control
TP
HKC_50 kGy
HKC
Finasteride


Testosterone levels in serum (pg/mg protein)
Control
TP
HKC_50 kGy
HKC
Finasteride

POSTER # 77

DIRECT STRUCTURAL CHANGE FROM SALIDROSIDE TO TYROSOL BY GAMMA IRRADIATION

Ji Hee Sung[1], Haneul Choi[1], Cheng-Bi Cui[2], Kwan-Soo Kim[3], Kwang-Hoon Kim[3], Soo-Jin Kim[3], Gye-Won Lee[4], Young Ho Cho[4], Young-Min Yoon[1], Chen Hao[5], Ju-Woon Lee[1].

[1]Division of Efficiency Evaluation of Biomolecules, PSA Co., Ltd, Daejeon, Korea; [2]Department of Food Science and Technology, Yanbian University, Yanji, P.R. China; [3]Greenpia Technology Inc., Seoul, Korea; [4]Department of Pharmaceutics and Biotechnology, Konyang University, Daejeon, Korea; [5]Sichuan Institute of Atomic Energy, Sichuan, P.R. China.

Interest in radiation molecule conversion technology has increased and it has become a new physical process without heat or chemical treatment. When a solvent such as water absorbs radiation energy by radiation, it forms radicals, which can react with target molecules to synthesize or decompose new materials. This study was started by studying the color change induced by gamma irradiation on extracts of *Rhodiola sachalinesis*. Salidroside (S) and its metabolite p-tyrosol (T) are two major phenols in the *Rhodiola sachalinesis*. Salidroside and tyrosol have excellent anti-inflammatory and antioxidant activity but the amounts present in natural products are extremely small, and the synthesis process is complicated, which limits their use in industry. In this study, we have investigated that S and T are separated from the ionization energy generated by the radiation conversion technique. As the dose of gamma irradiation increases, the concentration of S originally existing decreases, but T increased gradually, and newly generated T was confirmed by standard addition HPLC method. In addition, this phenomenon appears to be different depending on the pH condition, and this is thought to be due to the difference in degree of radical generation activated in the solvent. Based on the results of this study, it was shown that radiation technology can be used as a biodegradation, modification, or synthesis tool. In addition, the radiation trans-conversion technology will be developed as a core technology for enhancing competitiveness as an economical bio-functional material discovery and development technology compared with existing methods.

POSTER # 81

THE USING OF AAMI TIR IN RADIATION PROCESSING OF BIOLOGICS AND TISSUE-BASED PRODUCTS

Yiling Shen[1], Yue Zhang[1], Wenquan Sun[2].

[1]test and analysis center, Beijing Research Center for Radiation Application, Beijing, P.R. China; [2]Beijing Ruijian Biomedical Co., Ltd, Beijing, P.R. China.

The dose setting methods described in the ISO 11137 series Sterilization of Healthcare products—Radiation, Parts 1-3, were developed in the context of medical devices, and do not address the unique issues associated with biologics/tissues. These unique issues might potentially involve every aspect of a radiation sterilization validation, routine processing and maintenance of the sterilization process. The paper analyses some of the issues in establishing a sterilization dose for these particular products.

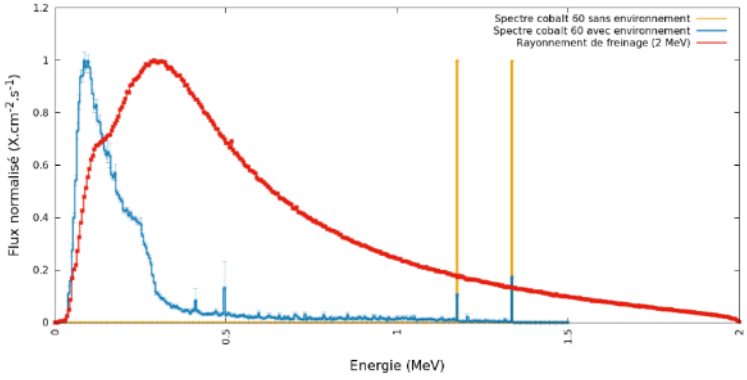
POSTER # 15

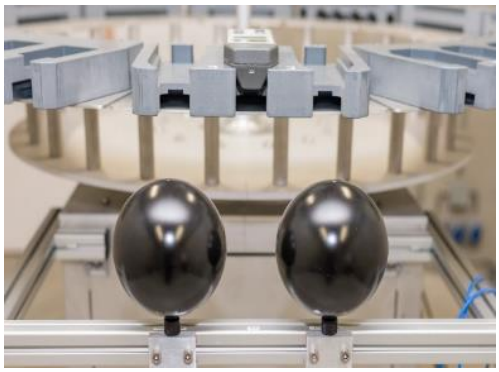
CALIBRATION OF RADIATION SURVEY METERS USING THE BRAKING RAYS OF AN ELECTRON BEAM

Gabriel Dupont, Arnaud Chapon.

ATRON Metrology, Cherbourg, France.

ATRON has developed an innovative method to calibrate radiation survey meters through large ranges of energy and dose-rate [1]. It consists in using the braking rays produced by an electron beam as calibration source instead of a radioactive source [2]. The production rate and reliability of the process are much better than the standard method. It is also safer for workers and environment, and the shape of the calibration X-spectrum is fairly representative of the typical one experienced in nuclear power plants, as shown on figure 1. Braking rays are generated by interaction of an electron beam in a Ta target. The beam is delivered by a HVE Singletron accelerator which allows to produce mono-kinetic electrons with an energy set to a value between 200 keV and 3.5 MeV. Another strong challenge comes from the large range of dose rate through which we have to calibrate radiation survey meters: it goes from 0.1 µSv/h to about 100 Sv/h. It is allowed by the wide range of current, from 10 pA to 1 mA. ATRON has developed the full calibration chain including a carousel divided into twelve sectors on which radiation survey meters are placed on templates and in front of which are two calibrated ionization chambers, as shown on figure 2. The response of the radiation survey meters are read by a camera above and compared to the ambient dose equivalent rate measured by the two chambers. This method is the result of three years of research done in partnership with the CNRS/LPCCaen and the CEA/LNHB laboratories.





References:

1. Vérification de l'étalonnage de radiamètres au moyen d'un accélérateur d'électrons, A. Chapon, J.-M. Bordy, SFRP (2015).
2. Reference radiation fields for radiation protection – Definitions and fundamental concepts, ISO 29661.

POSTER # 34

PRESERVATION AND PROTECTION OF CULTURAL HERITAGE ARTEFACTS BY GAMMA IRRADIATION IN CROATIA – GAMMA RADIATION TREATMENT OF COMMON FUNGI ON SELECTED CULTURAL HERITAGE OBJECTS

Katarina Marusic[1], Maja Segvic Klaric[2], Ana Dumbovic[3], Irina Pucic[1], Branka Mihaljevic[1].

[1]Laboratory for Radiation Chemistry and Dosimetry, Ruđer Bošković Institute, Zagreb, Croatia; [2]Faculty of Pharmacy and Biochemistry, University of Zagreb, Zagreb, Croatia; [3]Croatian Conservation Institute, University of Zagreb, Zagreb, Croatia.

Cultural heritage (CH) objects of organic origin are susceptible to degradation due to activity of various biological agents. The gamma irradiation method has already been proved to be non-destructive and a very effective method in saving CH objects. A CH object should be considered as a complex system with a lot of interfaces. Therefore, in the process of its protection, the interdisciplinary approach is necessary where, besides microbiological analysis, the impact of irradiation on the CH object components must be studied. Depending on radiation sensitivity of fungi 2 - 10 kGy is needed for fungal decontamination but lower doses can ensure satisfactory reduction of bioburden. However, for CH objects consisting of sensitive natural polymers it is crucial to apply the minimal dose which is still effective against bio-deteriorating agents but does not affect the physical and chemical properties of the object. In this work paper was used as the model system. The samples were inoculated with particular fungal species including primary (Aspergillus and Penicillium species), secondary (Cladosporium and Alternaria species) as well as tertiary colonizers (Fusarium species). After irradiation at the Radiation Chemistry and Dosimetry Laboratory of the Ruđer Bošković Institute, plate count method was applied to determine the number of viable fungi and proper irradiation doses and dose rates that eliminate fungi, respectively. Impact of gamma irradiation on physico-chemical properties of the paper was performed by colorimetry and FTIR. This work will present a systematic overview of the required minimal doses for radiation treatment of the most common and specific microorganisms found on paper as based material of CH artefacts.

POSTER # 42

FACILITATING INTERNATIONAL OUTREACH AND EDUCATION ON ELECTRON BEAM AND X-RAY TECHNOLOGIES

Malika Taalbi[1], Suresh Pillai[2].

[1]National Nuclear Security Administration, Department of Energy, Washington, DC, United States; [2]National Center for Electron Beam Research, Texas A&M University, College Station, TX, United States.

While cobalt-60 has been an industry mainstay for medical device sterilization and radiation processing, it also presents risks regarding the security of the radioactive material in use. We know that terrorists have intent to acquire and use radioactive materials in a dirty bomb. Machine-based ionizing radiation technologies, such as electron beam and X-ray, can be suitable replacement technologies for the use of cobalt-60 without the related security requirements. There is a need for broader knowledge transfer about these technologies, however, in order to support outreach about irradiation options and to identify potential advantages and disadvantages for specific stakeholder needs. This includes technology capabilities, costs of technology acquisition and operation, material validation, and infrastructure requirements. Furthermore, this information should be discussed in the context of specific needs relative to the region and/or country. Knowledge transfer can occur across multiple delivery platforms, including specialized educational programming, technical consultations, enhancement of educational curricula, and social media messaging. There are ample opportunities for national and international agencies, non-governmental organizations, international financing, and educational institutions to be closely involved in these activities. As an example, NNSA and NCEBR are coordinating on a regional electron beam technology workshop to be hosted in Argentina in March 2019 to include multiple stakeholders around South America. Continued efforts by the radiation processing community to provide open information about the availability of technologies will support all stakeholders making an informed choice about their radiation processing methods.

POSTER # 43

NEW RECYCLING PROCESS BY THE COMBINATION OF RADIATION PROCESSING AND MECHANICAL SHEAR FOR BUTYL RUBBER

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Plastics and rubbers cover a rising proportion of urban and industrial solid wastes and consequently, their impact on the environment is a severe concern. Rubbers exhibit a slow decomposition due to their chemical structure weather resistant as well to enzymatic degradation and to microorganisms. Rubber recovering is hampered by its insolubility caused by crosslinked structures. Besides, this tridimensional structure causes various problems for material recovering and reprocessing. Just 8% to 12% of polymeric residues are thermoplastic polymers; remaining are elastomers especially post consumption tires. It is relevant to emphasize that the crosslinking is essential for practical use of rubber and this process is worldwide known as the vulcanizing process, discovered by North American Charles Goodyear. The implementation of new technologies in order to reduce polymeric residues, acceptable from the environmental viewpoint and at an effective cost proved to be a great problem due to inherent complexities for polymers reuse. Ionizing radiation has the capacity to change the structure and properties of polymeric materials. Butyl rubbers have been used in wide scale within a variety of applications such as tires spare-parts and diverse artifacts. A major effect of high energy photons, such as gamma rays in butyl and halo-butyl rubbers is the creation of free radicals accompanied by changes in mechanical properties. This work aims to the development of processes of controlled degradation (de-vulcanizing) of butyl rubber in order to characterize their availability for modification and changes of their properties. Experimental results obtained showed that butyl rubbers irradiated at 25 kGy and further sheared can be used as the starting point for mixtures with pristine rubber.

POSTER # 58

IRRADIATION-INACTIVATED BACTERIAL CELLS ARE INTACT AND METABOLICALLY ACTIVE: THE CASE FOR DEEPER UNDERSTANDING OF THIS STATE

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The morphological, transcriptomic, and metabolomic states of irradiation-inactivated bacterial cells are intriguing. Contemporary studies are documenting that though these cells are incapable of replicating, they are structurally intact, and possessing very defined transcriptomic and metabolomic signatures. The cells are metabolically active with similar ATP levels as compared to unirradiated (control) cells, distinct electron transport patterns, capacity to help propagate specific bacteriophages and with defined metabolite accumulation patterns. Specific metabolites accumulate within the cells at specific time points post irradiation. What is intriguing is that the metabolic activity persisting in irradiation-inactivated cells for defined periods of time post irradiation occurs even after the genomic DNA undergoes extensive "shredding". DNA fragmentation analysis confirms the shredding of the genomic DNA. These metabolically active yet non culturable (MAyNC) bacterial cells have significant value as killed vaccines with strong antigenic and immunogenic properties. Studies in my laboratory have demonstrated that these vaccine formulations can be administered intra-muscularly, orally and *in ovo* in poultry and mice to protect against the pathogen, *Salmonella*. The MAyNC state of irradiated bacteria having protective abilities opens up new opportunities for foods and beverages fortified with defined inactivated pathogens that are primed at optimal metabolomic and transcriptomic states. These medicinal foods can be consumed prophylactically as well as therapeutically. However, developing this next generation of foods with therapeutic properties requires a deep understanding of the optimal structural, transcriptomic, proteomic, and metabolomic states of inactivated bacterial cells.

POSTER # 90

GAMMA BIOCIDE TREATMENTS FOR CULTURAL HERITAGE

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Biodegradation is the first kind of decay that affects organic materials of natural origin in cultural collection. What can curators and conservators do with pest infestation, for instance when xylophagous insects are eating wooden sculpture, or when fungi such as rot or mold are damaging mummies or archives? To manage such calamity, they must evaluate a balance between benefits and drawback of the different possible processes, in order to find the best compromise regarding the conservation issue. In this balance, advantages of biocide treatment by gamma irradiation are various. It is a contactless technology that meets well the concept of minimum intervention for curative conservation of cultural heritage, hoping to keep the goods in a state as near as possible it was at the origin before treatment, within the required efficiency assuring that the biodegradation process will stop. The possibility to treat by mass, through packaging if appropriate, and the absence of other associated heat effect or residue in processed materials are two other expected features. But beyond that, it is definitively its reliability, besides its efficiency, which distinguishes gamma irradiation from other competing biocide technologies mostly based on diffusion processes. However, and despite some resounding success, gamma irradiation is still of limited use in the field of cultural heritage conservation. Actually, if such denoted "nuclear" process can scare the less scientific among curators, the reluctance due to the fear of the so-called side effects, i.e. the induced effects that ionization may have on irradiated material, is more rational. Indeed, harmlessness cannot be retained as absolute, as it cannot with any process (even anoxia) that is required to be active, in this case to kill biodegrading species. One cannot ask at the same time to be completely inactive. Material behavior under irradiation has been widely investigated in many areas (nuclear, space, medical, etc. ...). To evaluate a potential risk, many studies were also done in the field of heritage. Finally, considering the operating doses, the current knowledge allows gamma biocide treatment of cultural heritage artefact to be presented as almost innocuous for a broad range of materials.

POSTER # 91

EXTRACTION OF MOLYBDENUM FROM SPENT CRACKING CATALYSTS

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Catalyst is a substance that changes the rate of a reaction. In the petroleum industry the commonly catalysts are used for Fluid Catalytic Cracking (FCC) and Hydro Catalytic Cracking (HCC), which one applied in a specific stage. These catalysts are used to facilitate the molecular chains cracking which will generate a mixture of hydrocarbons. However, the catalyst gradually loses its activity, either by changing its original molecular structure or by its contamination from other petroleum molecules. The application of ionizing radiation (high-energy electron beam and gamma rays) over these spent catalysts was studied to contribute the extraction of metals or rare-earths of high added-value. Tests conducted with FCC catalysts were used the techniques of 60Co irradiation and electron beam (EB) and had as a subject the extraction of Lanthanum; meanwhile with HCC catalysts the irradiation used was electron beam and had as a subject the extraction of Molybdenum (FIG.1). EDX characterization was performed on a Shimadzu EDX-720/800HS and X-ray diffraction on a Rigaku MultiFlex.

FIGURE 1 – RADIATION-THERMAL TREATMENT PROCESSING ON SPENT HCC CATALYST FROM UPPER ZONE: ALUMINA CRUCIBLE AND CRYSTAL FORMED AFTER ELECTRON BEAM IRRADIATION.

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