



9th NAARRI International Conference

NICSTAR - 2026

**Radiation Applications:
Diverse, Mature and Sustainable**

March 9-12, 2026

Westin Convention Centre, Powai, Mumbai.

Organised by:



**National Association for Application of
Radioisotopes and Radiation in Industry
(NAARRI), Mumbai**

**Souvenir
&
Abstract Book**



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(NAARRI), Mumbai**

**Souvenir
&
Abstract Book**

NICSTAR 2026
Souvenir & Abstract Book

Edited by

S. Sabharwal, S. K. Malhotra, H. J. Pant, Ashutosh Dash

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A. K. BALASUBRAHMANIAN

अध्यक्ष

CHAIRMAN




Message

I offer my compliments to National Association for Application of Radioisotopes and Radiation in Industry (NAARRI) on the occasion of its Golden Jubilee.

It is indeed a pleasure to note that as a part of its Golden Jubilee celebrations, NAARRI is organizing 9th International Conference, NICSTAR-2026 on the theme “Radiation Applications: Diverse, Mature and Sustainable” during March 9-12, 2026. I understand that NAARRI, since inception in 1976, has been promoting peaceful applications of radioisotopes and radiation technologies in a variety of areas. NAARRI and AERB are having a long association in facilitating and promoting safe use of radiation technologies for the benefit of mankind. I recall that in 2017 NAARRI published a book titled ‘Safety, Security and Regulations in Handling Radiation Sources’.

I am sure that NICSTAR-2026 will go a long way in facilitating developers, stake holders and regulators of these technologies to discuss and share their rich experiences during the conference.

Wishing you all very fruitful deliberations during NICSTAR-2026.


(A. K. Balasubrahmanian)



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MESSAGE

First and foremost, I congratulate all the members of National Association for Application of Radioisotopes and Radiation in Industry (NAARRI) for achieving the milestone of its Golden Jubilee. Completing fifty fruitful years is definitely a moment for celebration for any organisation.

It is heartening to note that NAARRI is organizing its 9th International Conference, NICSTAR-2026 on the theme "Radiation Applications: Diverse, Mature and Sustainable". Non-power applications of Atomic Energy are contributing immensely towards economic and societal development of various countries in the world. Nuclear Power Corporation of India Ltd. (NPCIL), takes pride in providing Cobalt-60 which is an important radiation source for applications in a variety of fields like health-care, agriculture, industry, radiation processing etc.

I am sure that NICSTAR-2026 will provide a common platform to the scientists, technologist, academicians, scholars and entrepreneurs for discussing the latest developments and future prospects in the field. I wish fruitful deliberations to all the participants of NICSTAR-2026.

Place: Mumbai.

Date: 09.02.2026.

(Bhuwan Chandra Pathak)

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Date: 31-12-2025

MESSAGE

It is a matter of great pride that National Association for Application of Radioisotopes and Radiation in Industry (NAARRI) is celebrating its Golden Jubilee and as part of this, is organizing its 9th International Conference, NICSTAR-2026 on the theme "Radiation Applications: Diverse, Mature and Sustainable" during March 9-12, 2026 at Westin Convention Centre, Powai, Mumbai.

Applications of radioisotopes and radiation technologies are contributing to a great extent to the sustainable development all around the world. With my earlier experience with research reactors, I can vouch that the radioisotopes produced in the research reactors of BARC have helped the researchers and developers of these technologies with wide applications in the field of health-care, food security, industry and pollution abatement etc. At IGCAR, we are deeply involved in interaction of radiation with matter and non-destructive testing using radiation.

I wish NICSTAR-2026 a grand success and fruitful deliberations to all the participants.

(C.G. Karhadkar)



From the Desk of the Vice Chancellor, KIIT Deemed to be University



Message

It is heartening to note that the National Association for Application of Radioisotopes and Radiation in Industry (NAARRI) is celebrating its Golden Jubilee and, as part of the commemorative programme, is organising the 9th NAARRI International Conference, NICSTAR-2026 on the theme “Radiation Applications: Diverse, Mature and Sustainable” at Mumbai during March 9–12, 2026. Radioisotopes and radiation technologies, with applications spanning healthcare, industry, agriculture and food safety, radiation processing of materials, radiation polymerisation, water resource management, and pollution abatement, have been making significant contributions to human welfare while also supporting sustainable economic growth across nations. I am confident that NICSTAR-2026 will provide a comprehensive platform for in-depth deliberations on the latest developments in this vital domain.

Inspired by the visionary ideals of Dr. Achyuta Samanta, hon’ble Founder of KIIT Deemed to be University, which strongly emphasise the application of science and technology for societal good, it is a matter of immense pride to recall that NAARRI organised the National Seminar ASAR-2025 at our campus last year. The association with the NAARRI team was a truly enriching experience. With NAARRI’s rich legacy and long-standing expertise, I am certain that NICSTAR-2026 will be a resounding success.

I wish all the participants highly fruitful deliberations and a rewarding academic experience during the conference.

A handwritten signature in blue ink, appearing to read 'Saranjit Singh', written in a cursive style.

(Prof. Saranjit Singh)
Vice Chancellor



NATIONAL ASSOCIATION FOR APPLICATION OF RADIOISOTOPES AND RADIATION IN INDUSTRY

(NAARRI)

(REGD.NO. BOM-76/78 G.B.B.)

President

Dr. Shyam K. Shrivastava
Director, Oncology,
MGM Hospital, Navi Mumbai



Message

I am elated to announce that NAARRI, having rendered five decades of distinguished service, now advances towards the milestone of its Golden Jubilee. This momentous occasion is to venerate the stalwarts who sculpted this organization and imparted a clear trajectory to its course. This occasion also serves as a poignant reminder to commemorate those who nurtured NAARRI to its present eminence. The occasion grants us the privilege to assess our accomplishments and contemplate the challenges that lie ahead.

I am glad that as part of the Golden Jubilee, NAARRI is poised to organise 9th NAARRI International Conference NICSTAR-2026 on 'Radiation Applications: Diverse, Mature, and Sustainable' to be convened during March 9-12 at Westin Convention Centre, Powai, Mumbai, India.

In recent decades, the realm of Radiation technology has witnessed phenomenal growth in India, interweaving itself into the tapestry of our daily lives and profoundly enhancing our quality of life.

NICSTAR 2026 will feature talks by leading scientists, technocrats and professionals in areas of radiation processing, health-care, radiation technology, industrial diagnostics and radiation safety & security.

I am decidedly of the opinion that NICSTAR-2026 shall furnish its delegates with an invaluable forum for sharing their experiences, success and new novel discoveries with each other. I avow with unwavering conviction that NICSTAR-2026 destined for a resounding success, largely due to the Board of Trustees & Executive Committee of NAARRI, the Organising and Scientific Programme Committees and various other committees of NICSTAR 2026, and the dedicated volunteers who have toiled tirelessly to ensure its resounding success.

I seize this opportune moment to offer my heartfelt congratulations to all the awardees poised to be conferred with various NAARRI Awards during this venerated conference. Finally, I wish all the participants of NICSTAR-2026 for profoundly productive deliberations.

Dr. Shyam K. Shrivastava



NAARRI

NATIONAL ASSOCIATION FOR APPLICATIONS OF RADIOISOTOPES AND RADIATION IN INDUSTRY

(NAARRI)

(REGD.NO.BOM-76/78G.B.B.)

P.J. Chandy

Hon. Secretary



It gives me immense pleasure to welcome the esteemed participants to the 9th NAARRI International Conference NICSTAR-2026 on Radiation Applications: Diverse, mature & sustainable NICSTAR-2026 is a very special event of our NAARRI and is making an important milestone of its Golden Jubilee completing 50 years of its dedicated service to the society. On this momentous occasion, I pay my humble and respectful homage to the visionary founders, particularly, Dr. V. K. Iya the doyen of isotope programme in our country and also the founder President NAARRI who charted a definite course for its future.

Since its inception in 1976, NAARRI has been promoting peaceful use of Atomic Energy and program aimed at promoting applications of radioisotopes and radiation. It has been serving as an effective interface between the Department of Atomic Energy and users of radioisotope and radiation. Its activities over the last 5 decades have earned for it a unique place in the Asia Pacific region as a leading professional body engaged in promoting applications of radioisotope and radiation. In pursuance of its objectives, NAARRI had been organising training courses for industrial isotope radiography, management induction programmes designed to suit specific industrial sectors, programme aimed at radiation safety objectives, regular workshops, seminar, national and international conferences. The international conferences organised by NAARRI have become notable events in the global stage, known for its thematic diversity engaging discussion and exceptional presentation. It is rare to witness a gathering of medical professionals, nuclear engineers, physicists, chemists, microbiologist, nuclear safety experts, conservation scientists & business leaders from around the world gathering under one roof.

The present international conference NICSTAR 2026, the 9th in the series is the natural outcome of NAARRI's continuing effort to review and record the latest advancement in the field of Radiation Technology. The organising committee of NICSTAR has worked hard to present a vibrant scientific program with excellent professionals from research institution, industry and government organization to share their rich experience with the participants. Its rich scientific program of 40 invited lectures and about 100 contributed presentation covers the entire gamut of application in isotope and radiation. It is heartening to note that, almost 25% of the invited speakers are women scientists, highlighting the important role being played by them in using nuclear science and technology.

We are quite sure that, NICSTAR -2026 will provide an ideal platform for fruitful interaction and the rich experience shared by the experts will benefit the participant immensely.

I wish the participants a very productive conference with exciting and encouraging discussion so that we can ensure a safe, diverse, mature and sustainable radiation applications.

PJ Chandy



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9th NAARRI International Conference

NICSTAR-2026

RADIATION APPLICATIONS: DIVERSE, MATURE AND SUSTAINABLE

March 09-12, 2026, Westin Convention Centre, Powai, Mumbai, India

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The National Association for Applications of Radioisotopes and Radiation in Industry (NAARRI) is pleased to present its 9th international conference NICSTAR-2026 during March 09-12, March 2026 at the Westin Convention Centre, Mumbai

The theme for NICSTAR-2026 is "Radiation Applications: diverse, mature and sustainable" is appropriate as the global radiation industry continues to change rapidly and we will cover important topics related to Gamma and Electron beam radiation processing, Nuclear medicine, Industrial diagnostic technologies, among others. Eminent delegates and speakers, both, from overseas and India will make presentations in their respective fields. The platform is expected to provide entrepreneurs, academicians and researchers excellent opportunities to reflect upon and assess current trends and future prospects for our industry

During the conference, it is also planned to celebrate a milestone, NAARRI's golden jubilee, held off to coincide with NICSTAR-2026; the Association was conceived in 1974, by our founder President, the late Dr. V K Iya, Director of the Isotope Group, BARC, considered as the doyen of the Radioisotopes programme in India. A host of senior and super seniors who have been associated with NAARRI are expected to join in the celebrations

We are grateful to all the invited speakers and participants; local and international sponsors: Aerial, AGROSURG Irradiators, CGND, EECI, Friend's Industries, Gamma Sources Recycling Gmbh, IBA, INNOMET, JSC Isotope, MICROTROL, Molecular Cyclotron, NORDION, Raditech Hydromatics, Samrudhdi Health Equipments, Symec Engineers, Universal Medicap, Wuxi El Pont, and several others for their continued and valuable support to make the conference vibrant

The successful organisation of NICSTAR-2026 required the organising team to work tirelessly over the past year or so and put together a comprehensive programme ; my thanks to honorary members of the several committees who have devoted valuable time under the able leadership of our President, Dr. S. K. Shrivastava and the untiring enthusiasm and efforts of Dr. Sunil Sabharwal and Dr. H. J. Pant of the Scientific Committee, and Shri P J Chandy, our Hon. Secretary. I am grateful to all and these efforts I am confident will result in the grand success of NICSTAR-2026



Vikram Kalia



Editorial

With profound pleasure, we extend a cordial welcome to each participant gracing the 9th NAARRI International Conference NICSTAR-2026 on 'Radiation Applications: Diverse, Mature, and Sustainable' with their esteemed presence. We extend our sincerest gratitude to each of you for embellishing this conference with your presence, particularly amidst your demanding itineraries.

NICSTAR conferences, organized by NAARRI, have emerged as pre-eminent conferences internationally through their thematic breadth, stimulating discourse, and impeccable presentations pertaining to radiation applications. It is seldom to see a congregation of medical doctors, nuclear engineers, physicists, chemists, microbiologists, nuclear safety and security experts, businessman and industrial professionals from across the globe convened within the ambit of a single conference. The NICSTAR-2026 scientific programme committee has striven hard to curate a resplendent and intellectually stimulating programme, featuring esteemed experts across diverse fields, to foster perspicacious discourse and the exchange of profound knowledge, thereby surpassing participant expectations. The programme, encompassing 36 invited talk, 8 oral renditions, and 100 contributed papers presented as posters across four days, serves as a testimony to this conference's significance. Our appreciation and gratitude extends to the invited speakers and poster presenters for the expeditious submission of their abstracts, to the reviewers for their exemplary cooperation in assessing the contributed abstracts and to the Publication Committee for their unwavering efforts ensuring timely printing. We posit that the printed compendium of the abstracts will enhance the understanding of presentations at NICSTAR- 2026, thereby fostering new vista of knowledge, research and technology pertaining to radiation application.

The editorial team extends its profound gratitude to the Organizing Committee of NICSTAR-2026 for their unwavering trust and support in sculpting the scientific programme. We have endeavored to curate an exquisite and enriching scientific programme for our esteemed participants. Kindly accept our sincere apologies for any inconvenience experienced prior to, during, or following the conference. We convey to all participants our expectations for a remarkably productive conference.

Sunil Sabharwal

Chairman, Scientific Committee

Swapnesh Malhotra

Chairman, Publication Committee

Harish Jagat Pant

Convener, Scientific Committee

Ashutosh Dash

Convener, Publication Committee

Tribute to Late Dr. V K Iya, Founder Father of NAARRI



16 September 1927 - August 10, 2024

Thanks to Dr. Homi Bhabha, India embarked upon the nuclear energy programme very early. Being very close to Pandit Jawahar Lal Nehru, in July 1948, he wrote to the Prime Minister “.... In next couple of decades atomic energy would play an important role in the economy and the industry of countries and if India did not wish to fall even further behind the industrially advanced countries of the world, it would be necessary to take more energetic measures to develop this branch of science. An immediate objective should be the setting up of a small atomic pile.” He established the AEET (Atomic Energy establishment, Trombay) in 1954. After his untimely passing away, it was renamed BARC (Bhabha Atomic Research Centre), the first nuclear research reactor in Asia, was conceptualised by Dr. Bhabha, became operational in 1956 and started producing radioisotopes for applications in agriculture, healthcare and industry.

In 1976, the late Dr. V K Iya, then Director Isotope Group, BARC, established NAARRI (National Association for Application of Radioisotopes and Radiation in Industry) which is now celebrating its golden jubilee. As and when any radiation technology application in agriculture, healthcare or industry matured at the DAE, it was transferred to the private sector and made available for commercial application. The Board of Radiation and Isotope Technology (BRIT) was carved out of BARC as an independent unit of the DAE in March 1989 and since then, it has been promoting and spearheading isotope applications and radiation technology across industry, healthcare, research and agricultural sectors. The production of radioisotopes, which began at the research reactor APSARA, received a boost with the commissioning of research reactors CIRUS and DHRUVA. Later, production of Cobalt-60 was initiated in power reactors. Dr. Iya is widely regarded as the founding father of the Indian programme on radioisotopes and allied areas. He was given the DAE Homi Bhabha 'Lifetime Achievement Award'. Today, in most reputed private hospitals, there is a Department of nuclear medicine; there are more than 30 private industries sterilising medical devices and hygienising bioburden in food ingredients with Cobalt 60 source produced in DAE's reactors. These plants sterilise several thousand cubic metres of medical devices annually. It is estimated that the number of persons engaged in these activities for societal benefit are far greater than the number employed for generating nuclear power.



On the occasion of Golden Jubilee and 9th International Conference of NAARRI NICSTAR-2026, let us all remember Dr. Iya and pay him homage for his immense contribution to the field of Radioisotopes and Radiation. I congratulate and compliment NAARRI for instituting 'Dr V K Iya Memorial Award', a befitting tribute to this great son of India.

Anil Kumar Anand

Former colleague of Dr. V. K. Iya and
Former Chairman, Board of Trustees, NAARRI
Former President, NAARRI



Late Dr. V. K. Iya with other dignitaries in a NAARRI Programme in Kerala



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NAARRI Lifetime Achievement Award

Shri A. N. Nandakumar

A.N. Nandakumar has done Ph.D in Physics from University of Mumbai. He joined Bhabha Atomic Research Centre in 1968. He has worked in the fields of Radiation shielding, Safety in medical, industrial & research applications of radiation, Transport of radioactive material and Calculation of radiation dose received in normal and emergency conditions. He represented India in many Technical Meetings of the International Atomic Energy Agency (IAEA).



He served as Head, Radiological Safety Division, Atomic Energy Regulatory Board (AERB). He worked in the International Atomic Energy Agency, Vienna as a Safety Specialist. He retired in 2006 and continues to provide Consultancy to AERB and IAEA. He has participated in the preparation of safety codes and safety guides on industrial applications of radiation published by AERB and IAEA. He has served as faculty in many training programmes on radiation safety in India and abroad organized by BARC and IAEA.

He was the Alternate Member Secretary of the Crisis Management Group of DAE from 1988 to 2004. He has served as faculty in numerous training programmes in India and abroad on topics related to radiation safety and also in the Basic Training on CBRN emergencies conducted by NDMA in various venues in India. He has experience in handling radiation emergencies and has imparted training on the topic in India and abroad.

He was associated with NAARRI since its inception. He has participated in various programmes of NAARRI, for example, served as faculty in training programmes, contributed articles to NAARRI bulletin and edited the proceedings of NAARRI annual conferences. His sustained interest in the NAARRI activities has developed into a strong bond.

He has published over 65 scientific and technical papers in national / international scientific journals and conference proceedings.



Dr. V. K. Iya Memorial NAARRI Award

Dr. N. Sivaprasad

Dr N Sivaprasad retired as Senior General Manager, Board of Radiation and Isotope Technology (BRIT). He did his post doctoral work in the University of Alberta, Canada. Dr. N. Sivaprasad has made significant contributions to the use of radioisotopes in medicine. In BRIT, he led a team of scientists in research & development and production of Radiopharmaceuticals, Radioimmunoassay kits and Labelled Compounds & Biomolecules. During his service in BRIT he was responsible for the establishment of ^{99m}Tc Generator production plant and Radio analytical laboratory for food analysis & certification.



His major contribution was development of radioimmunoassay (RIA) kits and the indigenization of radioimmunoassay (RIA) reagents and kits for various hormones and drugs. He along with his team developed a novel production method for magnetisable microcrystalline particles with mixed ferrite core, which was used as a separation system in radioimmunoassay. The new technology of production and the new product enabled the development of many radioimmunoassay kits. His work on radioimmunoassay of drugs such as theophylline, clonidine and phenytoin are notable examples of his work, in extending the applications of radioisotope in medicine.

In the area of radiopharmaceuticals, he was responsible for a new radiation synovectomy agent based on ^{32}P samarium phosphate, which resulted in low cost product for treatment in arthritic patients. He was responsible for the indigenous development and production of ^{14}C urea capsules for the diagnosis of H. pylori. Dr. Sivaprasad successfully managed and executed a multidisciplinary contract research project on the development and production of ^{131}I iodine labelled monoclonal antibody for clinical trial.

Currently Dr Sivaprasad is the President of Indian Pharmaceutical Association (Maharashtra State Branch) and Visiting Professor for Medical Physics in Mangalore University. He played a key role in establishing the Centre for Application of Radioisotope and Radiation Technology (CARRT) in Mangalore University. He is also the Technical Advisor to Ganti Radioisotope Laboratories Vijayawada which produces ^{131}I based radiopharmaceuticals.

As a member of Expert Committee on radiopharmaceuticals of Indian Pharmacopoeia commission, he contributed significantly in the inclusion of radiopharmaceuticals in the Indian pharmacopoeia. He has also been serving as a member of Bureau of Indian Standards Committee for Horology, and Maharashtra FDA's Price Monitoring & Resource Unit (PMRU).



NAARRI Golden Jubilee Award

Shri PJ Chandy

Shri PJ Chandy has been associated with National Association for Application of Radioisotope and Radiation in Industry (NAARRI) right from its inception in 1976 and is its longest serving Secretary. Through his relentless, dedicated efforts and with his visionary outlook, NAARRI which had a humble beginning attained the present glorious and unique place as a leading organisation, devoted to application of radioisotopes and radiation, not only in Asia pacific region but also globally. He started the nationwide public awareness campaign about the impact of radioisotopes and radiation on the lives of people. These programmes also helped in eradicating misconceptions about radiation from the minds of general public. NICSTAR series of international conferences is his brainchild. Through his efforts, Shri Chandy has been successful in putting NAARRI on the world map of Radioisotopes and Radiation arena.



Shri Chandy began his career in the isotope group of Bhabha Atomic Research Centre, BARC and later joined Board of Radiation and Isotope Technology (BRIT). He has made impressive contributions in the field of sealed sources equipment and their applications. Some of the systems developed by him are industrial gamma radiography cameras, lab scale and panoramic batch irradiators. These brand products of BRIT are being widely used by R&D institutes and industry in the country and abroad.

Through his initiative and in collaboration with CMC Vellore, a dedicated blood irradiator was designed, developed and manufactured in the country as an import substitute. It plays an important role in inhibiting T lymphocytes proliferation thereby preventing Graft versus Host disease (GvHD) in immune deficient patients. After a series of tests and certifications from the regulators, deployment of these radiators was initiated in the Indian market. Presently, more than 75 such blood radiators are in use at different reputed hospitals in India.

On the occasion of its Golden Jubilee, NAARRI considers It a privilege to bestow upon Shri PJ Chandy with the Golden Jubilee NAARRI Award.



Shri R.G. Deshpande Memorial NAARRI Award

Dr. Satyendra Gautam

Dr. Satyendra Gautam is an Outstanding scientist and visionary leader in the field of Food Science and Technology, whose contributions to research and national initiatives in utilizing nuclear energy for food security are truly remarkable. Since joining the prestigious Training School Program at the Bhabha Atomic Research Centre (BARC) in 1994, he has emerged as one of the foremost experts in food irradiation and nuclear applications for enhancing food security. He currently holds the position of Head of the Food Technology Division at BARC, Mumbai, while also serving as Senior Professor and Convener of the Board of Studies for Life Sciences at Homi Bhabha National Institute. His postdoctoral research at Rutgers University, New Jersey, USA, further cemented his status as a trailblazer in the field.



Dr. Gautam has led several high-profile research projects, including serving as Chief Investigator in Coordinated Research Projects with the International Atomic Energy Agency (IAEA), and recently representing India at the IAEA Scientific Forum (2024) in Vienna. His presentation on "Atoms for Food" highlighted India's cutting-edge advancements in nuclear technology aimed at ensuring food safety and sustainability. A Fellow of the Maharashtra Academy of Sciences, Dr. Gautam has also contributed to key scientific panels of the Food Safety and Standards Authority of India (FSSAI).

With 153 peer-reviewed journal papers to his name and the co-authorship of the influential book *Food Security by Radiation: The Unreasoned Fear of Irradiated Food*, Dr. Gautam has earned numerous accolades, including the prestigious DAE Homi Bhabha Science & Technology Excellence Award and multiple DAE Group Achievement Awards. His work exemplifies the power of translating pioneering research into transformative technologies that have a profound impact on both India's economy and the global food security landscape.



Shri R.G. Deshpande Memorial NAARRI Award

Dr. Sharmila Banerjee

Dr. Sharmila Banerjee is a distinguished scientist and leader in radiopharmaceutical chemistry and nuclear medicine, with significant contributions to research, clinical translation, and national radiopharmaceutical programmes. She has served as Head of the Radiation Medicine Centre and the Medical Cyclotron Facility at the Bhabha Atomic Research Centre (BARC), Mumbai and as Deputy Chief Executive of the Board of Radiation and Isotope Technology (BRIT). She served as Senior Professor and member of the Board of Studies at Homi Bhabha National Institute. She has also held positions as Professor of Nuclear Medicine and Project-in-charge for the Radiological Research Unit, at Advanced Centre for Treatment, Research and Education in Cancer (ACTREC), Tata Memorial Centre. Since 2018, she has been serving as the Chairperson of the Radiopharmaceutical Committee of the Department of Atomic Energy, Government of India, and is a member of the joint quality control committee of the International Atomic Energy Agency and World Health Organization on radiopharmaceutical products.



She has served as an IAEA expert in international technical cooperation missions and represented India in several IAEA-sponsored coordinated research projects. She has also undertaken IAEA-sponsored expert missions at the Korean Atomic Energy Research Institute, China Institute of Atomic Energy and the National Nuclear Energy Agency of Indonesia.

Dr. Banerjee has authored over 250 international publications, review articles, book chapters, and IAEA technical reports and serves on editorial boards of international journals. She is the recipient of the DAE Homi Bhabha Science & Technology Excellence Award, multiple DAE Group Achievement Awards, the Homi Bhabha Memorial Oration Award from the Society of Nuclear Medicine India, the Acharya P.C. Ray Memorial Oration Award, Distinguished Woman Scientist Award from the Women's Graduate Union, ASET Colloquium recognition at Tata Institute of Fundamental Research, the Marie Curie Memorial Award and the prestigious Fellowship Scroll from the Indian College of Nuclear Medicine, for her outstanding contributions to nuclear medicine.



NAARRI Entrepreneur Award

Shri Subhasis Bhattacharya

Shri Subhasis Bhattacharya is a Mechanical Engineer who began his professional career in the field of Industrial Hydraulics, subsequently expanding his expertise into material handling systems and process automation. Building on this strong engineering foundation, he developed specialized competence in Radiation Processing Technology, special-purpose machinery, conveying systems, industrial hydraulics and pneumatics, and automation solutions.



He entered the field of radiation technology in 2002 and played a pivotal role in Commissioning India's first private radiation processing plant in Kolkata in 2004.

In 2010, he successfully commissioned India's first multipurpose commercial radiation processing plant with a split-type source frame, marking a major technological milestone in the country's radiation processing sector. In 2014, he further demonstrated large-scale industrial capability by achieving a throughput of 20 tons per hour in potato irradiation, establishing the commercial viability of high-capacity food irradiation.

Mr. Bhattacharya has also commissioned radiation processing facilities abroad, including a plant in Bangladesh and, most notably, a **2 MCi design-capacity multipurpose gamma irradiation plant in Iran. These international projects reflect his expertise in system design, execution, and compliance with stringent safety and regulatory requirements.

He has made significant contributions to the development of safety interlock and security systems for gamma irradiators, driven by continuous innovation and engineering excellence, thereby enhancing operational safety, system reliability, and regulatory confidence.

Shri D. S. Lavale

Shri Lavale is mechanical engineer, BARC training school product. He joined Isotope group of BARC and later worked in BRIT. He was type casted as a projects man and in that identity, he built the required infrastructure for Isotope Group and BRIT. Subsequent to his superannuation he is working in the industry and is establishing Electron Beam Machines for Polymer cross linking application. His best-known projects are Isomed which help development of single use disposable medical devices industry, RPP, Vashi which encouraged Industrial operators to establish such plants, today nearly 40 plants are built and many more are coming up, about 22 nos Electron Beam machines are installed in Industry in wire and Cable industry.



His overall work can be seen as a pioneering one; NAARRI on its part is benefited by including these applications, with confidence, in its awareness program.



NAARRI Institutional Award

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The Company initially offered only Ethylene oxide (EtO) sterilisation services however, in view of changing market trends, MICROTROL commissioned its 1st Gamma Radiation Sterilisation (GRS) facility at Bengaluru in 2006 and second in Bawal (Haryana) in 2020. The GRS facilities bear a special focus to customer needs, convenience and offers flexibility and can process Medical Devices, Packaging Material, Nutraceuticals, Ayurvedic, Herbal Products, Spices & Condiments, Pharmaceutical and Cosmetic raw materials and other products. The facility regularly processes products in a wide range of doses, from 2 to 125 kGy (Kilo Gray)

To diversify its portfolio, the Company installed and commissioned its 1st Electron Beam facility in Bangalore, a 10 MeV/10 kW LINAC in 2024 which helps adding new products/ services into its basket.

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In recognition of their immense contribution to the sterilisation and hygienisation industry, NAARRI bestows upon them with NAARRI Institutional Award.



NAARRI Young Technocrat Award

Dr Dhiren Kumar Sahoo

Dr Dhiren Kumar Sahoo who has completed his graduation in Mechanical Engineering from Utkal University, Odisha and PhD from Indian Institute of Technology, Mumbai is from the 44th Batch of BARC Training School. He brings over 24 years of extensive experience in the research, design, and application of radiation technology for industrial and societal benefits and currently overseeing the Radiation Technology Development Programme in Board of Radiation and Isotope Technology (BRIT).



Dr Sahoo has been actively involved in translating advanced radiation science into practical technologies that support industry, food safety, and public welfare. He has made significant contributions to the field of industrial radiography by conceptualizing, designing, and developing a range of advanced radiography systems and equipment, including the COCAM-120, ROTEX-I, COCAM-120(W) and COCAM-A etc. These equipment are being widely deployed for non-destructive testing and industrial inspection, ensuring structural integrity, quality assurance, and safety across critical sectors such as power, infrastructure, and manufacturing. His innovations have enhanced operational reliability, radiation safety, and cost-effectiveness in radiographic practices.

In addition to industrial radiography, Dr. Sahoo has played a key role in the development of a Low Temperature Irradiator (LTI) designed to improve the shelf life, safety, and export quality of marine products through controlled irradiation. This initiative will not only reduce post-harvest losses by increasing shelf-life but also strengthen the seafood processing industry.

Dr Sahoo has also led the design and development of specialized radiation transportation casks for the safe and secure movement of radioactive materials in the public domain. These casks are engineered in compliance with stringent safety standards, ensuring radiation shielding, structural robustness, and regulatory adherence during transport.

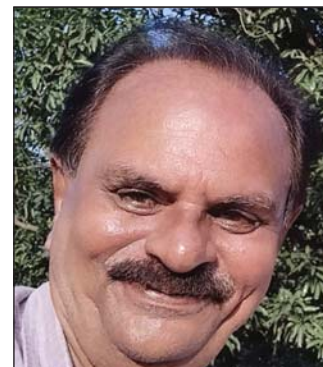
Dr Sahoo is widely recognized for his technical leadership, innovation-driven approach, and unwavering commitment to the peaceful and productive applications of radiation technology. His work continues to contribute significantly to industrial advancement, public safety, and national development.



NAARRI NICSTAR 2026 Award

Shri Swapnesh Kumar Malhotra

Shri Swapnesh Kumar Malhotra, currently Vice President of NAARRI has been involved in its activities for many decades in various capacities. He has been an integral part of the organising teams of all the editions of NICSTAR. He has also been spearheading the public awareness activities of NAARRI and is a popular speaker on topics related to power and non- power applications of Atomic Energy. Shri Malhotra superannuated from Department of Atomic Energy in 2015 after a distinguished service of about four decades. After retirement, he was awarded the coveted Raja Ramanna Fellowship of DAE and was also appointed as Secretary, Atomic Energy Education Society, an autonomous unit of DAE. He has delivered more than 500 scientific lectures and has authored a chapter in the book 'India Culture of Science' published in 2014 on the occasion of 101st Indian Science Congress and another chapter in a book titled 'Bridging the communication Gap in Science and Technology Lessons from India' published by Springer in 2017. He is recipient of many awards for science communication and is Fellow of Indian Science Writers Association and Indian Society of Analytical Scientists.



Mr. K. S. S. Sharma

The NAARRI – NICSTAR 2026 Award has been conferred upon Mr. K S S Sharma, honouring his outstanding professional services and dedicated support towards the activities of NAARRI. His significant contributions have greatly influenced the success of NICSTAR 2026. Mr. Sharma is a radiation technologist by profession. He served BARC and BRIT for thirty-six years, specialising in the field of radiation processing and irradiation technologies. Since 2020, he has been associated with Microtrol Sterilisation Solutions Pvt. Ltd, Mumbai continuing his commitment to advancements in his field of interest.





NAARRI NICSTAR 2026 Award

Dr. Sunil Sabharwal

Dr. Sunil Sabharwal. Worked with the International Atomic Energy Agency. IAEA. EA Vienna during 2011-2018 as radiation processing specialist. Before joining IAEA. He worked at Bhabha atomic research centre. For 33 years. He led the programme of development. Demonstration and deployment of applications of radiation technology using electron beam accelerators for polymer processing. And environmental applications. Dr. Sabharwal was also a professor at Homi Bhabha National Institute. India and Mumbai University. To guide scientists and technologists for PhD degrees, he has. Published over 170 research papers in international journals. He has received a number of awards and honours related to development of radiation technology applications. Dr. Sabharwal. Has been contributing to NARI international conferences particularly. In shaping their scientific programs. In view of. His contributions and achievements.



Dr. Harish Jagat Pant

Dr. Harish Jagat Pant, obtained his M.Sc Degree in Physics from H.N.Bahuguna Garhwal University, Srinagar Garhwal, Uttarakhand in 1985 and joined erstwhile Isotope Division, Bhabha Atomic Research Centre (BARC), Mumbai in 1988 after graduating from the 31st Batch of BARC training school. He obtained his Ph.D degree in Physics from Mumbai University in 2000. After joining BARC in 1988, Dr. Pant was engaged in development and application of radioisotope-based techniques for industrial and environmental applications. He has developed a number of radioisotope techniques and applied the same in various industries in India. He published more than 130 papers in international journals and contributed 8 book chapters in different books. Dr. Pant superannuated from BARC in May 2024 and was holding the post of Head, Isotope and Radiation Application Division at BARC, Mumbai at the time of superannuation. Dr. Pant is currently the Joint-Secretary of NAARRI and has been contributing immensely in promoting the applications of radioisotope technology in India and in organization of various programmes of NAARRI including NICSTAR-2026.





NAARRI NICSTAR 2026 Award

Dr. Ashutosh Dash

Dr. Ashutosh Dash is ex- Head, Radiopharmaceuticals Division, BARC and Senior Professor HBNI and ex-Raja Ramanna Chair, BARC. His areas of research are: radioisotope production, production and development of brachytherapy sources, development of radionuclide generators for medical applications and separation methodologies for clinically useful radionuclides. He has been actively involved in the development and application of radiolabelled molecular probes for diagnostic and therapeutic uses, especially for management of cancer. He has published over 290 papers in peer reviewed journals, guided 7 PhD students and he is the author of the Book “Radiopharmaceuticals for Therapy (Published by Springer-Verlag).



Shri Pravin Kumar

Shri Pravin Kumar after joining Board of Radiation and Isotope Technology (BRIT) in 1991, contributed significantly in handling of various types of radioactive materials i.e. Co-60, Ir-192, Cs-137, neutron sources etc. As DGM (Scientific Officer/H), Sealed Sources & Logistics, he is responsible for planning, fabrication, supply of different types of sealed sources containing Co-60, Ir-192, Cs-137 etc. to various users for different types of applications (Irradiators, Radiography, Teletherapy, check sources etc.). He is also responsible for management of disused sources containing different types radionuclides after it's useful life.



Shri Pravin Kumar is recipient of the “Scientific & Technical Excellence Award 2012” by Department of Atomic Energy, India. He had also received “Group Achievement Award” for his contributions in different types of assignments several times.

He is closely associated with the activities of NAARRI for many decades and has been convenor of Local Arrangement Organising Committee NICSTAR 2026.



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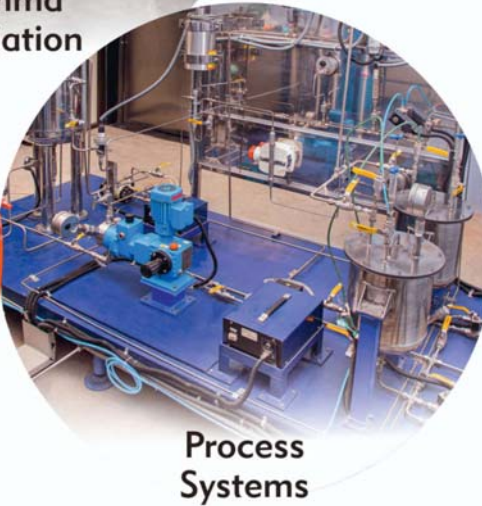


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Beam Intensity	400mA	100mA	80mA	80mA	80mA	60mA 80mA	50mA	40mA	34mA	20mA	2mA 4mA 6mA
Beam Power	80KW	50KW	64KW	80KW	96KW	90KW 120KW	100KW	100KW	100KW	100KW	20KW 40KW 60KW
Shielding Type	Self-shielded	Self-shielded / Semi-self-shielded / Non-self-shielded				Semi-self-shielded / Non-self-shielded		Non-self-shielded			
Application	Curing	Cable, Film, Tire	Cable, Film, Tire	Cable, Film, Tire	Cable, Film, Tire	Cable, Heat-shrink Tube, Sheet	Cable, Heat-shrink Tube, Sheet	Cable, Heat-shrink Tube, Sheet	Heat-shrink Chip, Tube	Cable, Heat-shrink Tube, Chip	Food & Medical Sterilization and Disinfection

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We have sold more than 600 sets of accelerators in total, with our domestic market share ranking among the top two for consecutive more years. Taking a proactive approach to overseas expansion, our products have been successfully exported to numerous countries including the United States, Japan, South Korea, India, Turkey, Romania, Russia, Indonesia, Mexico, Vietnam, Thailand, Tunisia, and Honduras. We provide strong equipment and technical support for global irradiation application scenarios such as medical sterilization, material modification, printing curing and radiation grafting, as well as for nuclear technology research and development.

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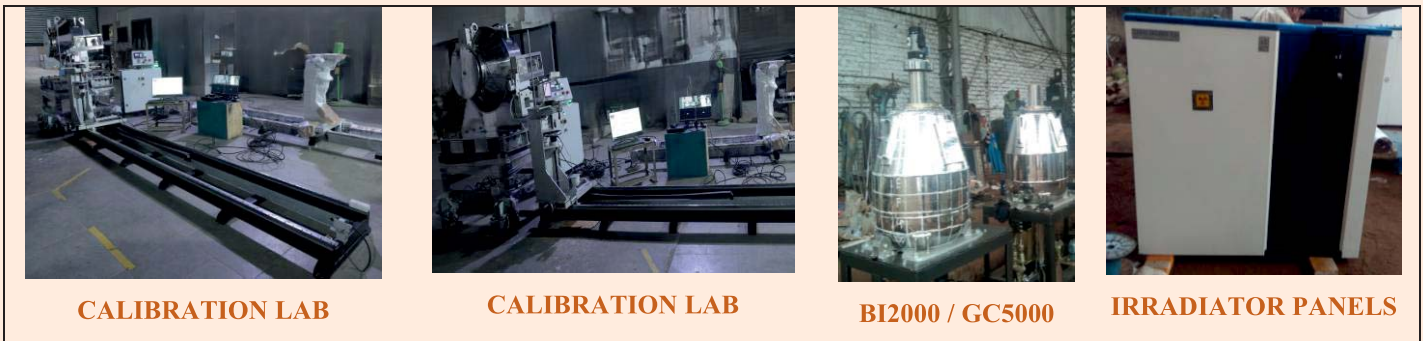
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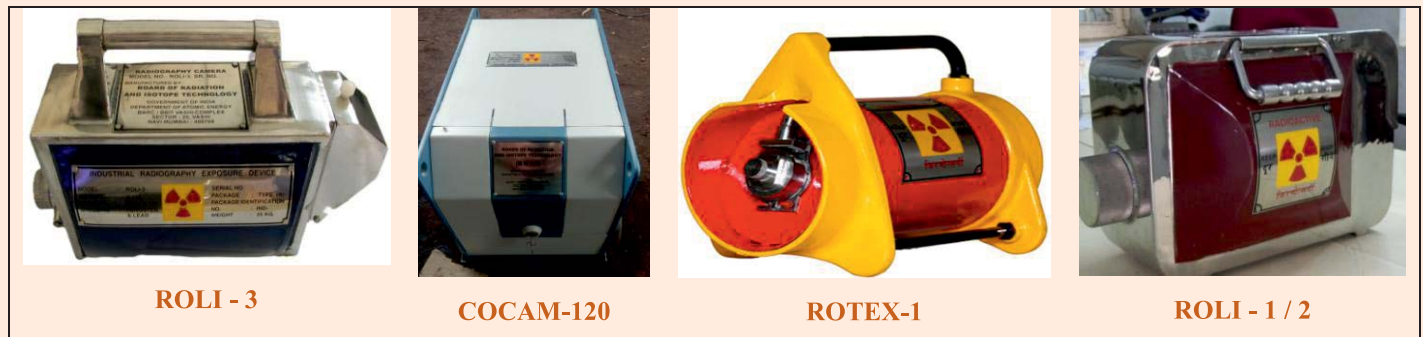
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* Ir.192 / Co.60 based Tungsten / Lead Shielded Industrial Gamma Exposure Devices for Radiography



* Radioactive Material Storage/Transportation/Waste Storage Casks: BLC 100, BLC 200, ARTC, HTC etc.

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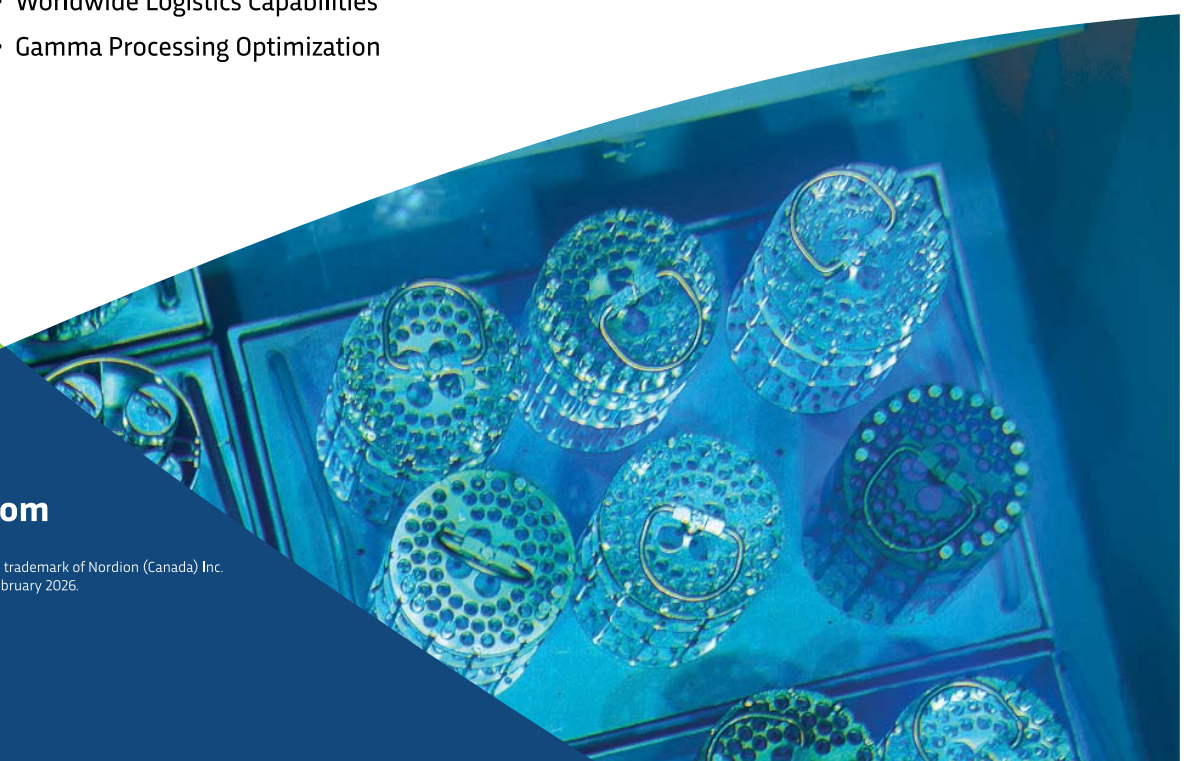
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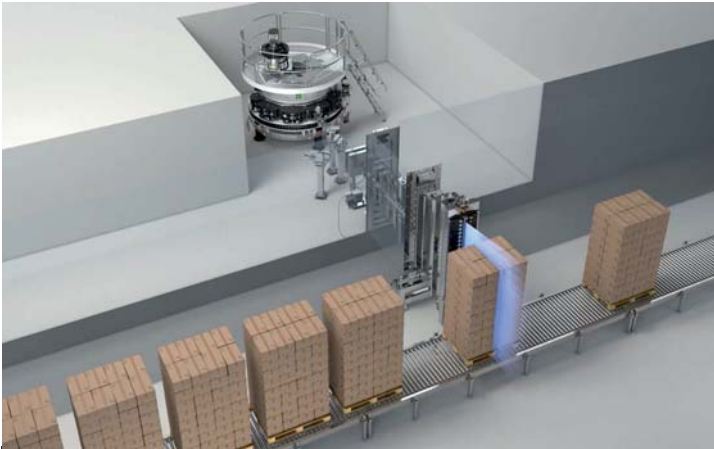
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Radiographic Examination: <ul style="list-style-type: none"> Linear Accelerator Cobalt-60 Iridium-192 Portable X-Ray (upto 300kV) CR/DR (On Demand) 	Ultrasonic Examination: <ul style="list-style-type: none"> Conventional PAUT (On Demand) TOFD (On Demand) 	Magnetic Particle Examination: <ul style="list-style-type: none"> Yoke (Visible & Fluorescent) Prod (Visible & Fluorescent) 	Up-gradation of Castings Shot/Sand Blasting (On Demand) Heat Treatment (On Demand)
		Liquid Penetrant Examination: <ul style="list-style-type: none"> Solvent Removable (Visible & Fluorescent) 	Final Inspection: <ul style="list-style-type: none"> Third-Party



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- GC-5000, GC-1200 (for research purposes)

BLOOD IRRADIATORS

- BI-2000 (for irradiation of blood to prevent T-GVHD)



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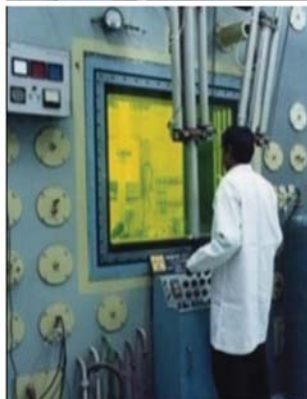
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- Accelerators based Radiation Processing Plants
- Medical Accelerators for Radiotherapy
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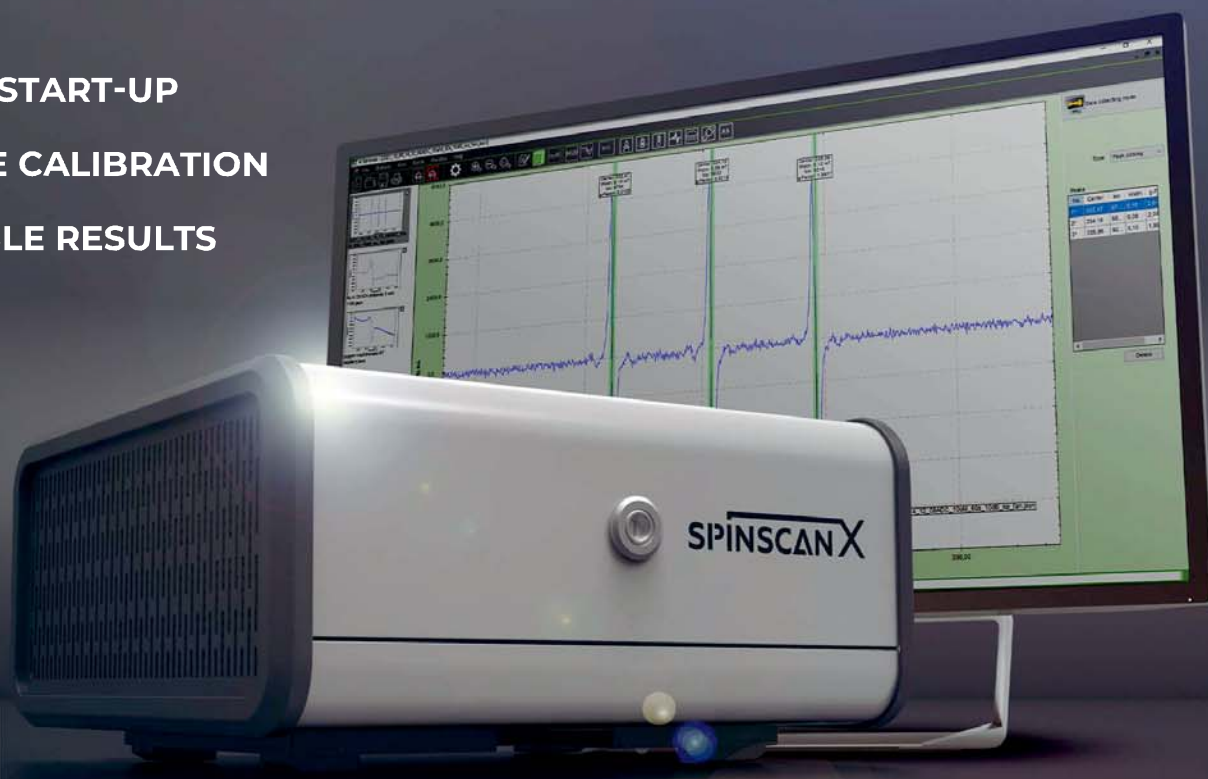
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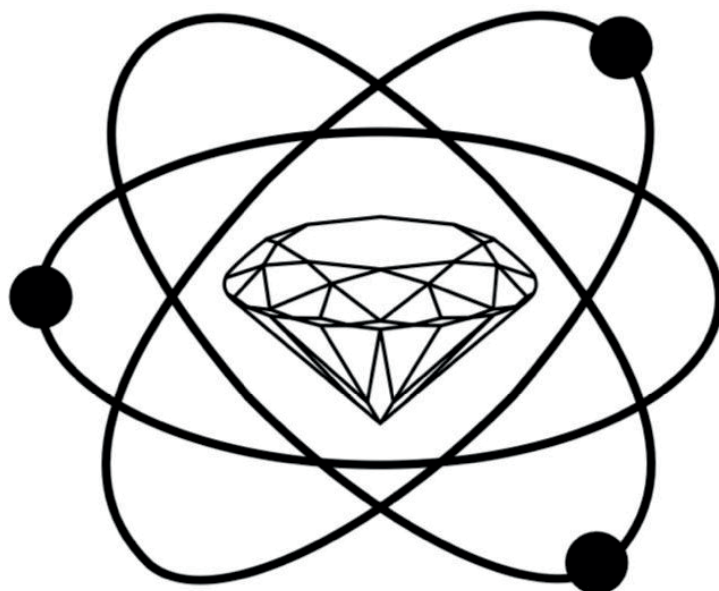
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Keynote Address & Invited Talks



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KN	Safety Regulation of Radiation Applications: Challenges, Approaches and Way Forward Dinesh Kumar Shukla Former Chairman, Atomic Energy Regulatory Board, Anushaktinagar, Mumbai, India
IT 1	Radiation Technology: Driving Sustainable Industrial and Environmental Innovations BumSoo Han, Korean Association for Radiation Application, 18F, Seoul-Forest IT Valley, 77, Seongsuil-ro, Seongdong-gu, Seoul, Republic of Korea
IT 2	A Strategic Investment Opportunity- Private Multi-Purpose eBeam Technology Centers in India: A Suggested Framework for Technical, Financial, and Market Feasibility Analysis Suresh Pillai, USA National Electron Beam Research Center, Texas A&M University, College Station, Texas, USA 77845
IT 3	Radiation-induced polymerization: towards industrial materials with higher performance using greener curing methods Xavier COQUERET Institut de Chimie Moléculaire de Reims, CNRS UMR 7312 Université de Reims Champagne Ardenne, 51100 Reims, France
IT 4	Self-Reliance in Personnel Monitoring of External Radiation Exposure Dr. Balwinder Sapara Radiological Physics & Advisory Division, Medical Group Bhabha Atomic Research Centre, Mumbai, India-400 094
IT 5	Preserving the Past, Powering the Future: Innovative Radiation Approaches for Cultural Heritage Katarina Marusic, Branka Mihaljevic Ruder Boskovic Institute, Bijenicka cesta 54, HR-10000 Zagreb, Croatia
IT 6	Sustainable disinfection of Cultural Heritage materials using gamma radiation Prof. (Ms) Alessia Cemmi, 1 ENEA Nuclear Department (NUC), Casaccia Research Center, Rome, Italy 2 Sapienza University, Department of Biology and Biotechnologies, Rome, Italy
IT 7	Developing NORM database for addressing Public Concerns P. Padma Savitri Environmental Monitoring and Assessment Division, Bhabha Atomic Research Centre, Visakhapatnam India
IT 8	The evolution, status and future of global radiation processing MARTIN COMBEN, International Irradiation Association, 5 The Business Quarter, Eco Park Road, Ludlow, SY81FD, UK
IT 9	Innovation of Electron Accelerator and Industrial Applications ZHANG YANG CGN Dasheng Electron Accelerator Technology Co., Ltd. Pingwang Town/Suzhou City, China



IT 10	Harnessing Electron Beam Capabilities: Aerial's Vision for the Future of Radiation Processing Florent KUNTZ, Aerial CRT, 250 rue Laurent Fries, F 67400 Illkirch – France
IT 11	Application Scenarios for the Self-Shielding Electron Accelerator and the Prospect of EB-Irradiation Curing Y. ZHANG, China Wuxi El Pont Radiation Technology Co.,Ltd.Wuxi, China
IT 12	High-energy industrial electron accelerators ILU type. A.A.Bryazgin Budker Institute of Nuclear Physics, 11, Lavrentev av., Novosibirsk, Russia 630090
IT 13	Applications of Ga-68 based radiopharmaceuticals: Clinical Update Dr K. Agrawal Additional Professor and Head, Dept. of Nuclear Medicine All India Institute of Medical Sciences (AIIMS),Bhubaneswar Dean, Indian College of Nuclear Medicine Contact No: 00-91-8195930013
IT 14	Novel radionuclides for medical applications in theranostics: perspectives and challenges. Renata Mikolajczak Radioisotope Centre POLATOM, National Centre for Nuclear Research (NCBJ), Otwock, Poland
IT 15	Novel ²²⁵ Ac-labeled Antibody for Targeted Alpha Therapy of Pancreatic Cancer Cathy S. Cutler Isotope Research and Production Department, Brookhaven National Laboratory, Upton, NY
IT 16	Medical Cyclotrons: A Viable Business Model M.R.A. Pillai Molecular Group, Puthuvype, Ernakulam, Kerala 682 508
IT 17	Strategies to Promote the Adoption of Electron Beam Worldwide Kristin Jade Hirsch U.S. Department of Energy/National Nuclear Security Administration/ Office of Radiological Security Washington DC, 20585
IT 18	Leveraging Regional Partnerships to Promote the Adoption and Expansion of Advanced Alternative Technologies Ms. Katie Larsen U.S. Department of Energy/National Nuclear Security Administration/ Office of Radiological Security, Washington D.C. USA 20585
IT 19	Equivalence Studies of Alternative Technologies: Electron Beam (eBeam) vs Cobalt-60 Kurt Lauer Housh, U.S. Department of Energy/National Nuclear Security Administration Office of Radiological Security, Washington D.C. USA 20585



IT 20	When Modeling and Dosimetry Meet to Empower Accelerated Adoption of eBeam and X-ray Technology Randy Schwartz Pacific Northwest National Laboratory, Richland, Washington, USA 99354
IT 21	Development of high power industrial Linac for radiation processing at RRCAT Dr. R.S. Sandha Raja Ramanna Centre for Advanced Technology, Indore 452013, India
IT 22	Security During Radioactive Source Reloading at Gamma Irradiation Facilities Mr. Michal Kuca Sandia National Laboratories Albuquerque, USA
IT 23	Radiation processing for various purposeful applications Sanjay Rajput and Mukul Das Shriram Institute for Industrial Research, 19, University Road, Delhi-110007, India
IT 24	Sediment dynamics investigation using radiometric methods Dr. Patrick Brisset International Society for Tracers and Radiation Application (ISTRA) c/o Austrian Society for NDT (ÖGfZP) Jochen-Rindt-Str. 33 1230 Wien Austria
IT 25	The Evolution of Safety in Industrial Gamma Radiography Jake Bourn (VP/GM - QSA Global), USA
IT 26	Radioisotope based power sources Dr. Ajay Singh Technical Physics Division, Physics Group Bhabha Atomic Research Centre Mumbai-400085, India
IT 27	Radioactive Particle Tracking Technique and It's Application in Industrial Process Systems Rajesh Kumar Upadhyay Department of Chemical Engineering and Technology, IIT (BHU) Varanasi Varanasi- 221005, India
IT 28	Feasibility study of a Dual-Mode 7–10 MeV Electron Beam and X-ray Accelerator for Industrial Applications in Jordan Eng. Mohammad Etoom, Jordon Gamma irradiation facility, Atomic Energy commission, Jordan
IT 29	Radiation beam technologies for tissue sterilization and advancements in artificial tissue engineering Division of Human Health, Department of Nuclear Sciences and Applications International Atomic Energy Agency, UNO Vienna International Centre, PO Box 100, 1400 Vienna, Austria
IT 30	Academics to Applications: Harnessing Nuclear Science for Societal Benefits Alpana Goel Amity Institute of Nuclear Science and Technology, Amity University Uttar Pradesh, Noida,201313
IT 31	Nuclear Analytical Techniques: Elemental Analysis for Quality – Safety of Medical Diseases and Food Resources Prof. A.D.P.Rao Department of Nuclear physics, Andhra University, Visakhapatnam-530003, India



IT 32	Nuclear Technology for Sustainable Agriculture and Environment Dr. Manoj Srivastava, Division of Environmental Sciences, Nuclear Research Laboratory, ICAR–Indian Agricultural Research Institute, New Delhi, India
IT 33	Radiation-Modified Chitosan: A Transformative Biopolymer for Sustainable Agriculture through Gamma and Electron Beam Applications Dr. S.G.Dalvi Vasanatdada Sugar Institute, Pune,- 412307
IT 34	Development and dosimetric characterization of BARC “ANUDOSE” dosimeter as a cost-effective import substitute for phytosanitary & low-dose applications of food irradiation Dr. Bhaskar Sanyal FTD, BARC, Mumbai
IT 35	The IAEA’s Contribution to Innovation to Radioisotope and Radiation Applications Celina Horak, Radiochemistry and Radiation Technology (RCRT) Section Division of Physical and Chemical Sciences International Atomic Energy Agency, Vienna, Austria
IT 36	Operation Experience at the Gamma Irradiation Facility in Azerbaijan Zaur Khalilov, Azerbaijan
SP1	Radiotracer-Based Analysis of Flow Anomalies in Continuous Pulp Digesters Prof. Avinash Chandra, Department of Chemical Engineering, Thapar Institute of Engineering and Technology, Patiala-147004, INDIA
SP2	Radiotracers as tools for studying synthetic polymer membranes and membrane-based processes Dr. Ashok Pandey Department of Nuclear and Radiochemistry, Kishinchand Chellaram College, HSNC University, Mumbai-400020, India
SP3	Radiotracer-Based Residence Time Distribution Studies in Industrial Reactor Systems Dr. Argya Datta, NIT Raipur National Institute of Technology Raipur, Chhattisgarh
SP4	Isotopic Separations at Heavy Water Board Heavy water Board, Mumbai Ajit.R.Dusane
IF1	BEYOND: Optimized, mature, and reliable X-ray and E-beam irradiation solutions Raphaël Van Roermund IBA Industrial, 3 Chemin du Cyclotron 1348 Louvain-La-Neuve, Belgium



IF2	High Throughput Integrated Irradiation Processing Facility for Agro and Food Products Anant Vas Symec Engineers India Pvt Ltd Navi Mumbai, Maharashtra India 400705
IF3	Shri Subhasis Bhattacharya Managing Director RadiTech Hydromatics Pvt. Ltd. 10/23A Siddhinath Chatterjee Road, Behala, Kolkata-700034
IF4	Liliya Bui Linev Systems, Belarus (Dosimetry) (oral) bui@linevsystems.com

*Keynote Address*

Safety Regulation of Radiation Applications: Challenges, Approaches and Way Forward

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Dear friends, though the topic is specific to safety regulation of Radiation Applications, it cannot be dealt in isolation. An understanding of the development of Indian Atomic Energy program and associated legal and regulatory framework is essential to set the context to help appreciate the insights provided in this keynote address.

Safety is not a destination but a journey. Continuous efforts are needed to sustain the level of safety achieved and more efforts are needed to upgrade the safety level. Therefore, no place for complacency. We must acknowledge the fact that safety is not merely a technical subject but largely depends on the priority given to it through the attitudes and behaviours of all involved. Technical measures provide multiple levels of Defence in Depth (DiD) for protection. However, safety cultural influences are sufficiently widespread and have potential to increase substantially the probability of lining up a penetrable series of defensive weaknesses in these levels, defeating DIDs. Therefore, safety culture and its intimate relation with safety performance assumes paramount significance in the safety regulation.

This fact was well recognized by Dr. Homi Bhabha, founder of India's Atomic Energy program. While execution of research reactor projects APSARA and later CIRUS at Atomic Energy Establishment Trombley (AEET), he had put safety as top priority. His demonstrated safety leadership deeply influenced the attitudes and behaviours of all involved with respect to priority for safety. The early setting up of training school for human resource development further helped in spreading and sustaining safety culture in all the units of department of Atomic Energy (DAE). Cultivated practice of self-regulation guided all the activities of the department in accordance with the legal framework of Atomic Energy act 1948 and later Atomic Energy act 1962 and rules made there under. Act encompasses all aspects of atomic energy including safety and empowers Central Government to delegate any power conferred or any duty imposed on it by the Act to officer or authority subordinate to Central or State Government. Head, DRP, BARC was also 'Competent Authority' for radiation protection rules 1971 in addition to DAE.

Even though the system of self-regulation was inherently effective, to ensure continued effectiveness with expanding programme, need for a separate dedicated body for safety regulation was felt. Accordingly, Atomic Energy Regulatory Board (AERB) was established in 1983 with a mandate to regulate certain safety and regulatory aspects of nuclear facilities and radiation applications in the country. Initially AERB was assisted by DAE, SRC till 1987 in safety regulation of DAE facilities and by Division of Radiological Protection (DRP- which later became RPAD), BARC in regulation of non-DAE radiation facilities till 2001. As per its constitution order, AERB used to issue stage wise consents and authorization for commissioning and operation of nuclear facilities and

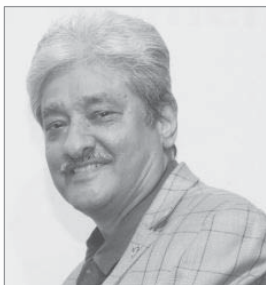


radiation applications. Since nuclear facilities were fully under government control (DAE) “Control” aspects of regulation as per AEA 1962 were getting fulfilled implicitly. When radiation protection rules 2004 were promulgated with Chairman, AERB as competent authority legal and regulatory framework scenario changed. The timeline of legal framework and concurrent development of regulatory framework (regulatory documents) with the technology for nuclear facilities has influenced the regulations and its way of enforcement. This is of special interest with respect to safety regulation of radiation applications as regulated entities here are as diverse as diverse and heterogeneous their applications in comparison to nuclear facilities which are fully under single entity (DAE) and are not as heterogeneous as radiation applications. The keynote address will delve on this aspect with focus on the issue of safety culture with respect to safety regulation of radiation applications. How clear understanding of distinction of two aspects of regulation “control” and “safety” with respect to enforcing authority, implicit in AEA-1962 and RPR-2004, evolved and led to identification of multiple agencies involved in “control” and “safety Regulation” and ultimately got reflected explicitly in SHANTI Act, 2025 will also be covered. The address will further delve on the fundamentals of safety regulation, their adoption in regulatory approaches, typicality of radiation applications and challenges posed by them to regulation, and way forward to meet the challenges.

Supporting technologies (IT and AI) can only help in execution of intended regulatory tasks efficiently and provide convenient interface with the applicant/licensee. But effective deployment of these support technologies requires appropriate System Requirement Specification (SRS) which depends on the clear understanding of “why”. “what”, “when” and “how” (www.h) of the intended tasks. This requires high level of technical & regulatory competence and maturity of the associated workforce.

To sum up, success of way forward lies in establishing seamless connection among “Promotion”, “control” and “Safety Regulation”. Seamless connection means filling and bridging all gaps without any folds (overlaps/conflicts). This requires full exploitation of (3 Cs)²: Cooperation, Coordination, Collaboration and Connect, Convey, Convince. DAE, AERB and Associations such as NAARRI have important roles in this endeavour.

Friends, what gave us success in the past may not get us more success in present situation. Introspection is a must to revalidate past ways and identify need for amendments/changes. This international conference on “Radiation Applications: Diverse, Mature and Sustainable” organized by NAARRI as part of its golden jubilee celebrations is quite appropriate and well timed. It provides a forum for retrospection and introspection of five decades of activities to learn from experiences, become more mature to anticipate future better and build on successes. I wish the conference a grand success.



Shri Dinesh Kumar Shukla is a former Chairman of Atomic Energy Regulatory Board (AERB) with over four decades of experience in operation and regulation of nuclear, radiation and industrial facilities. He had earlier served the Atomic Energy Regulatory Board (AERB) as Distinguished Scientist, Executive Director & Chairman of Safety Review Committee for Operating Plants (SARCOP) and as ex-officio Member of the Board. He was conferred the AERB Leadership Award-2017 in recognition of his exemplary contributions to the regulatory and safety programmes and in leading the activities of AERB in a goal-oriented manner.



Before joining AERB in 2015, Shri Shukla had served Bhabha Atomic Research Centre (BARC) for 33 years in various capacities, last being Head, Reactor Operations Division (ROD). He had been associated with several committees of AERB and BARC Safety Council (BSC) for the design and operational safety review of PHWRs, LWRs, reprocessing plants and radioactive waste management facilities. He had served as a member of the Management Committee for Board of Radiation & Isotope Technology (BRIT) and Radioisotopes, Radiation Technology and Application Committee (RTAC) of the Board of Research in Nuclear Sciences (BRNS).

Shri Shukla has been providing consultancy to IAEA on matters related to safety of research and power reactors, document preparation and for preparation of programs for various IAEA international conferences. He had served as member of the IAEA- Commission on Safety Standards (CSS) for three years. He had also served as member of the IAEA - INES Advisory Committee from 2017 to 2020. He was leader of Indian delegation to joint 8th and 9th review meeting of Convention on Nuclear Safety (CNS).

His work in the areas of Human and Organization Factors for safety, Safety Security Interface, Leadership and Management for Safety, Development of Integrated Management System for Regulatory Body, Development of guidance for application of Graded Approach in regulatory functions and processes, Strengthening Safety Culture have been well acknowledged nationally and internationally. In recognition of his work in these areas and his illustrious and scintillating scientific accomplishments during the four decades of work in operation and regulation of nuclear, radiation and industrial facilities, he was bestowed upon the Honorary Degree of Doctor of Science (Honoris Causa) by the GLA University, Mathura, UP in the year 2024. Utilizing his vast experience, in-depth knowledge of the above areas, he revamped the whole functioning of the AERB with emphasis on greater in-house work, enhanced engagement of employees in decision making and setting a climate of excellence and safety culture in the organization. This helped AERB to effectively influence the safety culture and organization culture of licensees through “leading by example” approach. He steered AERB through the covid pandemic period in an exemplary manner, balancing the safety of the staff and the safety of the licensed facilities and activities.



Radiation Technology: Driving Sustainable Industrial and Environmental Innovations

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Radiation technology is increasingly recognized as a versatile and sustainable tool for addressing industrial, medical, and environmental challenges. By enabling controlled modification of physical, chemical, and biological properties of materials, radiation processing has provided innovative solutions across manufacturing, agriculture, healthcare, and environmental protection.

Concerns regarding the logistics and safety of radioisotopes, along with evolving regulatory frameworks, have accelerated the adoption of accelerator-based alternatives such as electron beam and X-ray systems. These technologies deliver efficient, precise, and chemical-free processing, with established applications ranging from sterilization of medical products and pharmaceuticals to polymer cross-linking and advanced material engineering in sectors such as automotive, aerospace, and electronics.

From an environmental perspective, radiation technologies contribute significantly to sustainability through wastewater treatment, pollutant reduction, and the safe management of hazardous wastes. Despite challenges such as high initial investment, specialized expertise, and stringent safety requirements, the opportunities far outweigh the limitations.

Looking ahead, radiation technology is poised to play a pivotal role in advancing sustainable development worldwide. Through continuous research, expansion of applications, and global collaboration, it can enable cleaner environments, safer healthcare, and more efficient industrial processes for the future.



Mr. BumSoo Han served as a Radiation Chemist at the International Atomic Energy Agency (IAEA) from 2017 to 2025. Before joining the IAEA, he founded and served as CEO of EB TECH Co., Ltd., a pioneering company that successfully delivered over 60 electron accelerators to research institutions and industries.

Throughout his career, Mr. Han has been deeply involved in promoting accelerator-based technologies for applications in industry, agriculture, and environmental protection. One of his key interests lies in the use of radiation technologies for environmental remediation.

Currently, Mr. Han serves as an advisor to the Korean Association for Radiation Application (KARA) and as a member of the Committee of the U.S. National Academy of Sciences titled “Assessing Opportunities and Challenges for Expanded Use of Electron-Beam Technologies.”

Mr. Han holds a B.S. in Nuclear Engineering from Seoul National University (1982), an M.S. in Advanced Materials from KAIST (1984), and a Ph.D. in Metallurgical and Materials Engineering from the Colorado School of Mines (1991).



A Strategic Investment Opportunity- Private Multi-Purpose eBeam Technology Centers in India: A Suggested Framework for Technical, Financial, and Market Feasibility Analysis

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India is undergoing a powerful phase of economic expansion, driven simultaneously by advances in agriculture, manufacturing, and technology-intensive sectors. Government programs such as *Make in India*, *National Food Security Act* and *Swach Bharat Mission* offer tremendous opportunities for widescale investment into private multi-purpose ionizing technology centers all around India. Presently, cobalt-60 is still the primary source of ionizing technology for all ionizing technology applications all around India except for the wire and cable industries. The Indian wire and cable industry can be considered the pioneers in the adoption of eBeam technology in India. However, the switch over from chemical crosslinking did involve a significant amount of education and outreach. Similarly, today the switch over from cobalt-60 to eBeam and X-ray in the Indian context requires significant amount of education and outreach. It goes without saying that the adoption of eBeam and X-ray technologies in India will result in significant reduction in nuclear security risks associated with cobalt-60 sources. Despite the clear nuclear-security advantages of transitioning away from cobalt-60, widespread adoption of eBeam and X-ray technologies in India will not occur on security arguments alone. The reality is that substantial government subsidies for cobalt-60 procurement and facility development continue to distort the market, making legacy technologies artificially inexpensive. Overcoming this structural barrier requires compelling, investment-grade documentation that demonstrates the financial viability, technological readiness, and market competitiveness of multi-purpose panoramic eBeam and X-ray facilities. Only when entrepreneurs and investors have access to bankable analyses—grounded in real operating costs, revenue streams, and sector-specific opportunities—will the shift toward advanced accelerator-based technologies gain meaningful traction in India. The potential customers for these multipurpose facilities could potentially span a wide spectrum, including pre-harvest and post-harvest agriculture, single-use medical supplies and devices, food ingredients such as spices, traditional medicinal formulations, polymer modification, as well as biotechnology and pharmaceutical products—including vaccines and antibiotics, prepared meals as well as clients focused on export markets. Unlike many countries where ionizing technologies are adopted primarily to meet export-market requirements, India's vast domestic consumer base enables widespread adoption without relying solely on export-driven demand. Moreover, India's progressive regulations governing the use of these technologies for food and feed significantly expands the potential customer base for these facilities. The global supplier base for eBeam and X-ray systems has expanded significantly, with



vendors now offering a full range of commercially available technologies—including low-energy eBeam (LEEB) and X-ray (LEEX), medium-energy eBeam (MEEB) and X-ray (MEEEX), and high-energy eBeam (HEEB) and X-ray (HEEX). India's vast geography and widely distributed agricultural and industrial centers create significant opportunities for establishing eBeam facilities across multiple regions. However, feasibility assessments must carefully evaluate local conditions—including the availability/reliability of electrical power (or alternative energy sources), the strength of product supply chains, proximity to transportation hubs, and other logistical considerations essential for successful facility operation. Feasibility studies built on reliable historical data and prudent projections, combined with tailored equipment choices and achievable operational targets, can provide a strong foundation for success. With substantial investment capital now available in India, the outlook for advanced eBeam and X-ray facilities is highly promising. Moreover, investor interest can be broadened beyond traditional sectors to include hotels, hospitals, and resort chains—industries that consistently pursue efficiency, standardization, and cost reduction -making them strong candidates to invest in advanced, socially beneficial technologies of this kind. It is equally essential that a comprehensive and sustained outreach and education program follows these studies.



Professor Suresh Pillai is the Director of Texas A&M University's National Center for Electron Beam Research and Professor of Molecular Microbiology and Senior Faculty Fellow. He is the Associate Department Head for Graduate Programs in the Food Science & Technology Department at Texas A&M University. He is a Fellow of the Institute of Food Technologists, International Forum on Industrial Processes and is currently a Fulbright Specialist. He has served on several US federal agency committees/panels such as those associated with the FDA, NASA, USDA, Dept of Energy, Homeland Security as well as Texas Radiation Advisory Board. He has over two decades worth of experience with eBeam and X-ray technologies. His current research is focused on harnessing eBeam technology for a wide variety of commercial applications including vaccines, food processing, wastewater remediation, etc. He has published over 200 peer-reviewed research papers, edited/authored 6 reference books, 35 book chapters and has presented his work around the world.



Radiation-induced polymerization: towards industrial materials with higher performance using greener curing methods

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The radiation-induced crosslinking of multifunctional monomers has emerged as a highly effective approach for curing solvent-free liquid coatings, inks, and adhesives, as well as for producing high-performance composite materials. Compared with conventional thermal curing, this technique provides several important advantages. Over recent years, both free-radical and cationic polymerization mechanisms have been extensively examined. By tailoring the formulation of the precursor matrix and tuning key processing variables—such as total dose, dose rate, dose stepping, and initial temperature—it is possible to exert substantial control over the curing kinetics and the resulting material properties. These aspects will be illustrated using representative acrylate- and epoxy-based model systems [1–3].

Despite these advances, several issues remain that require further fundamental and technological investigation:

- (i) Rapid polymerization of multifunctional monomers leads to micro-heterogeneous network structures that must be characterized and quantified using microscopic, thermo-physical, and spectroscopic methods;
- (ii) The adhesion and surface characteristics of radiation-cured coatings exhibit pronounced sensitivity to processing conditions
- (iii) To qualify matrices derived from simple difunctional monomers for high-performance composites, substantial improvements in toughness are still needed.

Recent studies demonstrate that both the bulk and surface properties of radiation-cured materials can be enhanced by advanced precursor formulations combined with systematic variation of process parameters [3,4]. Results on the microstructure and surface behavior of model systems cured under different conditions will be presented. Notably, radiation-triggered polymerization-induced phase separation of thermoplastic modifiers in epoxy matrices appears more effective than thermal curing in producing toughened materials, yielding fracture resistance values (K_{IC}) of approximately $2 \text{ MPa}\cdot\text{m}^{1/2}$ or higher [5,6]. This improvement is attributed to the low initial temperature at the onset of polymerization and the extremely rapid curing, both of which restrict the growth of phase-separated thermoplastic domains and lead to morphologies favorable for toughening.



One recent step forward in reducing VOC emissions and energy consumption is the adoption of electron-beam (EB) curing for topcoats on steel coils used as building cladding [7]. The technology now appears as a reliable alternative to solvent-based coatings that are currently cured worldwide use gas-fired ovens. Strict requirements apply throughout production—from paint formulation and storage to application, curing, and final performance on the steel strip. Key criteria include storage stability, suitable rheology, high curing reactivity, processing robustness, adhesion, scratch and impact resistance, bendability, corrosion protection, gloss, and outdoor durability. Developing solvent-free EB-curable paints and optimizing their processing to satisfy these specifications demand precise control over numerous material and process parameters [8].

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Xavier Coqueret, received his PhD in organic chemistry from the University of Reims, France, in 1984. He joined the CNRS (National Center of Scientific Research) as a junior scientist to study the photochemistry of polymer-borne chromophores at the University of Lille. Being appointed as a full Professor of polymer chemistry at the Ecole Nationale Supérieure de Chimie de Lille (1991-2005), he extended the activities of his group to the modification of polymers by cross-linking or grafting using high energy radiation (electron beam and X-rays), and to radiation-initiated polymerization. In 2005, Xavier Coqueret joined the University of Reims to initiate a research activity on Polymer chemistry, with emphasis on radiation processing, high performance composites and bio-based materials. From 2008 to 2018, he has been heading the Reims Institute of Molecular Chemistry. He is the author of more than 160 research articles, 20 book chapters, and co-inventor of 22 priority patents (h-index 33 after Google scholar, May 2025).



Self-Reliance in Personnel Monitoring of External Radiation Exposure

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Personnel monitoring for occupational exposure to external radiation in India began in 1953 with photographic film badge dosimetry. Over the decades, this system has evolved into a robust and largely self-reliant national programme developed and coordinated by the RP&AD, BARC. This evolution reflects a thoughtful and sustained emphasis on indigenous capability and technological self-sufficiency.

A major milestone was the indigenous development of $\text{CaSO}_4:\text{Dy}$ thermoluminescent phosphor in the mid-1970s, followed by the introduction of $\text{CaSO}_4:\text{Dy}$ -based TLD badges for routine personnel monitoring from 1975 onwards [1]. The high sensitivity and stability of this phosphor enabled the gradual and complete replacement of film badge dosimetry in DAE institutions and, subsequently, in non-DAE radiation facilities.

Neutron dosimetry has followed a similar path towards self-reliance. Early methods based on nuclear track emulsion films have been progressively replaced by CR-39 solid-state nuclear track detectors [2]. These systems now incorporate automated image analysis, standardized badge designs, and barcode-based traceability, enabling efficient and consistent neutron dose assessment in mixed radiation fields.

The establishment of the National Occupational Dose Registry System (NODRS) in 2008 [3] marked a significant step in centralized dose record management. Subsequent network-based enhancements have enabled secure electronic submission, retrieval, and long-term preservation of individual dose records. At present, occupational dose monitoring services are provided through a nationwide network of approximately 18 accredited TLD laboratories, covering radiation workers across DAE and non-DAE sectors.

Recent developments include the application of machine-learning techniques for automated screening of thermoluminescence glow curves, identification of anomalous responses, and recovery of dosimetric information from compromised or anomalous glow curves [4]. Operational experience has also informed refinements in dose recording levels for reducing the incidence of false positive dose entries.

In view of evolving international recommendations, the existing three-element TLD badge system has been evaluated for its response characteristics and found to be compatible with the revised operational quantities defined in ICRU Report 95[5, 6].



Parallel research efforts on optically stimulated luminescence dosimetry, particularly using indigenously produced $\alpha\text{-Al}_2\text{O}_3\text{:C}$, have demonstrated promising characteristics such as higher sensitivity, improved reusability, and faster readout [7]. These developments position OSL dosimetry as a strong candidate for future integration into routine personnel monitoring programmes.

Overall, this sustained and multi-dimensional progress highlights India's achievement of near-complete self-reliance in external radiation dosimetry. Spanning phosphor development, detector fabrication, readout instrumentation, quality assurance, and dose data management, thereby strengthening occupational radiation protection in line with national regulatory requirements.

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Prof. B. K. Sapra is an Outstanding Scientist and Associate Director, Medical Group at Bhabha Atomic Research Centre. She also serves as Head of the Radiological Physics and Advisory Division and is a Sr. Professor at the Homi Bhabha National Institute, Mumbai. Her research focuses on radiation protection dosimetry, occupational radiation safety, biodosimetry, aerosol science, and radon/thoron measurements. She has made significant contributions to national programs in radiation monitoring, quality assurance in dosimetry and advancements in medical physics applications of radiation.

Prof. Sapra has to her credit about 180 peer-reviewed publications, one Indian patent and has guided several students for Ph.D. and M.Tech Programmes. She has served as a member in various national and international safety committees, regulatory committees and academic programme committees of the Department.



Preserving the Past, Powering the Future: Innovative Radiation Approaches for Cultural Heritage

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Croatia's cultural heritage (CH) has repeatedly been exposed to war, neglect, and natural disasters, creating an urgent need for robust, scalable preservation strategies. This contribution presents the long-term experience of the Ruder Boskovic Institute (RBI) in applying ionising radiation for the protection of CH. Over several decades, a wide variety of CH artefacts – including wooden sculptures, altarpieces, furniture, textiles, leather, paper and composite objects – have been stabilised by radiation-based disinsection, disinfection and, when needed, decontamination.

The Croatian War of Independence marked a turning point, when large-scale evacuation and rescue operations demanded rapid and reliable methods to secure endangered collections. On the recommendation of an international consortium of curators and preservation experts, gamma irradiation was introduced as a key step prior to storage, particularly for evacuated, mostly polychrome wooden sculptures, including examples recovered from church ruins. In the following years, collaboration with the Croatian Conservation Institute, museums, archives and university restoration departments expanded [1].

As the collaboration in the field developed, research activities have started to focus on how gamma irradiation affects sensitive materials and structures. Systematic studies on model paper and its mycobiota [2], leather treated with common preservatives [3], and nacre ornaments [4] have clarified the combined influence of irradiation conditions and biological activity on colour and mechanical stability. Investigations into protein-based binders in historical painting media have further refined understanding of the behaviour of complex paint layers under irradiation [5]. Building on this evidence, RBI and its partners have developed a general framework for the treatment of infested objects, for the stabilisation of collections stored in unfavourable microclimatic conditions, and for emergency interventions after disasters.

In parallel, radiation chemistry and molecular self-assembly have been harnessed to design protective organic nanocoatings on metals relevant for CH. Work on green nanocoatings prepared by crosslinking self-assembled fatty acids on metals, has demonstrated the potential of irradiation-assisted coatings for enhanced corrosion protection of bronze, copper and patinated surfaces [6].

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Sustainable disinfection of Cultural Heritage materials using gamma radiation

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The preservation of Cultural Heritage (CH) requires methods that ensure long-term protection of artifacts while minimizing risks to both materials and operators. Ionizing radiation has emerged internationally as an effective and environmentally sustainable tool for the disinfection and disinfestation of artworks made of organic substrates, including paper, parchment, wood, textiles, and synthetic materials. Despite its growing use in several countries, radiation processing in the CH conservation field remains underexploited in Italy, where concerns regarding potential physico-chemical alterations still limit wider adoption among conservators. Robust scientific evidence is therefore crucial to promote an informed and responsible integration of radiation-based treatments within standard conservation operational procedures.

Gamma irradiation represents a particularly attractive option compared to more traditional chemical-based disinfection techniques, as it avoids the use of toxic compounds, leaves no residues, and can be applied in a non-invasive, uniform, and scalable manner. It allows rapid treatment of large artifacts and enables the simultaneous processing of multiple objects. Recent research carried out at the Calliope gamma irradiation facility of the ENEA Casaccia Research Center [1] has focused on characterizing the molecular, structural, and chromatic effects induced in CH materials exposed to controlled doses of ⁶⁰Co gamma radiation [2–5]. Using complementary analytical techniques, including Fourier Transform Infrared (FTIR), Raman, and Electron Paramagnetic Resonance (EPR) spectroscopies, together with colorimetric measurements, this work evaluates the extent and nature of radiation-induced modifications in selected organic substrates commonly found in historical artifacts. Microbiological assessments were also conducted to quantify the biocidal effectiveness of the treatments against biodeteriogenic organisms.

The findings contribute to a deeper understanding of the secondary processes triggered by ionizing radiation and support the safe implementation of this technology in CH conservation. Case studies involving ancient and modern paper, parchment, synthetic leather, and textile fabrics illustrate how optimized irradiation protocols can ensure both effective disinfection and the preservation of material integrity. Additionally, preliminary studies on inks are presented to highlight the effects of radiation on these components. Overall, these results demonstrate the potential of gamma irradiation as a reliable, sustainable, and scientifically validated approach for the protection and long-term conservation of Cultural Heritage.



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Her research activity focuses on gamma radiation effects evaluation on different materials (crystals, glasses, polymers, optical devices, bio-based systems, CH artifacts, organic matrices), on dosimetric measurements and on gamma irradiation tests in different conditions. She is involved in national and international Project and Programme and in several collaborations (Eurofusion, F4E, IAEA, ESA, ASI, CERN). She is author of more than 115 publications in peer-reviewed scientific journals and communications at national and international Conferences.



Developing NORM database for addressing Public Concerns

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Naturally Occurring Radioactive Materials (NORMs) form an intrinsic part of the Earth's crust, with their distribution and activity levels governed by complex geological, geochemical, and climatic factors. Globally, the **spatial variability of NORMs** is well recognized regions such as **Ramsar in Iran, Guarapari in Brazil, Yangjiang in China, and Cornwall in the United Kingdom(1)** exhibit elevated natural background radiation levels due to the presence of uranium, thorium, and potassium bearing minerals in local soils and rocks. Conversely, large continental areas record much lower activity levels (1) underscoring the **strong regional dependence of natural radioactivity**. These variations play a key role in environmental radiological assessment, health studies, and the establishment of realistic regulatory standards. In the **Indian context**, such variability is particularly pronounced. The **monazite bearing coastal stretches of Kerala, Tamil Nadu, Odisha, and Andhra Pradesh [2-5]** are globally recognized for their elevated levels of natural background radiation, primarily attributed to thorium and uranium rich heavy mineral sands. However, most inland regions of India exhibit background radiation well within the global average [6]. Despite decades of localized studies, there is **no comprehensive, uniformly generated baseline (virgin) database** encompassing India's diverse geological, geomorphological, and ecological settings. Developing such a **national baseline database** has become imperative in the current scenario. It serves multiple objectives: a) establishing a **scientific reference** against which future changes natural or anthropogenic can be assessed, b) improving **radiological risk assessments** through accurate background characterization, c) supporting **environmental monitoring and land use planning** in mining, construction, and coastal development sectors; and d) most importantly, **mitigating unwarranted public fear** surrounding natural radioactivity by providing transparent, evidence based information.

This talk will highlight the **spatial patterns of NORMs** observed globally and within India, discuss the methodologies and technological advancements (including **GIS-based mapping, remote sensing, and machine learning tools**) for characterizing spatial variability, and emphasize the importance of **inter agency collaboration** (e.g., BARC, AERB and academic institutions) in establishing a **nationwide virgin database**. Such an initiative would significantly strengthen India's environmental radioactivity management framework and contribute to a more informed and balanced public perception of natural radiation. Summary of literature relevant to spatial distribution of radio nuclides in the Indian environment and some remarks on how it may help with the goal of developing a database are presented. Gaps remained in the studies are discussed. Some of the key observations are:



- India's **coastal belts** show **dose rates 10–70 times higher** than the global average, due to **monazite (Th-rich)** mineral deposits.[2,3]
- **Inland regions** (Deccan Plateau, Himalayas, Indo-Gangetic plains) mostly align with or fall below global averages.[1,6]
- **Spatial variability** within a single state can exceed **two orders of magnitude**, underscoring the need for a **national baseline (virgin) database**. [3]
- Despite elevated natural background radiation in some areas, **health impact studies** show **no statistically significant increase** in radiogenic effects at these levels emphasizing the need for **public education** based on evidence.[7-9]

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The evolution, status and future of global radiation processing

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The history of radiation processing dates back to the 1950's with the first commercial production of cobalt-60 and linear accelerators. Since these early steps, the science, technologies and applications of irradiation have grown enormously. Today, radiation processing is a global industry that helps to keep us safe and healthy, supports our economies and helps to protect the global environment.

The business of irradiation has evolved as radiation processing has moved from an age of pioneers to that of multinational businesses. Today, radiation processing is a complex, dynamic and competitive marketplace. Organisations and technologies are evolving, new science is being introduced, and current challenges are being addressed. Additionally, there is a greater focus on sustainable operating practices, and this is changing the way that organisations operate.

Radiation processing has a bright future as demand continues to grow and new applications are introduced. This presentation summarises the important issues of the irradiation market, highlights the ongoing technology developments, and looks at the prospects and focus for the future.



Mr. Martin Comben is the iia's representative in the EMEA region and takes a lead in managing initiatives with affiliates, the IAEA and other partner organisations. He is Chair of the IMRP Organising Committee and manages the iia's Gamma Working Group. Prior to joining the iia, Martin spent over 20 years working in various international business roles within the irradiation industry. He has extensive knowledge of the gamma irradiation industry as well as the operational, technical and regulatory environment surrounding the use and handling of cobalt-60 sources.



Innovation of Electron Accelerator and Industrial Applications

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The report is structured around four key sections: innovation background, sustainable development and innovation, irradiation technology solutions, and international cooperation. Currently, the application of irradiation is witnessing vigorous development. As a crucial piece of equipment for irradiation applications, electron accelerators will play an increasingly significant role, and the demand for innovation in this field will also grow stronger.

As China's largest supplier of accelerator equipment, CGN Dasheng provides electron accelerator devices covering high, medium, and low energy ranges. Its business scope includes accelerator R&D and manufacturing, electron beam radiation application development, non-destructive testing equipment, and intelligent manufacturing. The company is set to play a vital role in the innovation of electron accelerators. The sustainable development and innovation of electron accelerators encompass the following aspects:

- The electron linear accelerator's power has been increased from 20kW to 32kW, and its application has expanded from the food industry to the medical sterilization field, thereby enhancing processing efficiency;
- The accelerator structure has evolved from the original vertical design to horizontal semi-self-shielded and horizontal self-shielded structures;
- The power conversion efficiency of the accelerator has been improved, helping customers save more on operational costs.
- On the application side, electron accelerator technology continues to innovate application scenarios, addressing issues related to environmental governance and the irradiation modification of wires and cables.

Future innovation requires collaboration. CGN adheres to an open stance, has accumulated abundant good practices in international cooperation, and will continue to carry out international innovation cooperation in the years ahead.



Mr. ZHANG YANG is Project Manager with CGN Dasheng Electron Accelerator Technology Co.,Ltd. (CGND), China. CGN Dasheng is a leader in the design, manufacture and installation of electron accelerators. Mr. Zhang has been involved in sales, marketing and servicing of electron accelerators in India since 2017. He has successfully participated in various electron accelerator projects in India. His current activities are focused on the innovation of E-beam technology such as new power supply system and high-speed under-beam handling systems.



Harnessing Electron Beam Capabilities: Aerial's Vision for the Future of Radiation Processing

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Electron beam technology offers compelling advantages for radiation sterilization: it is safe, fast, scalable, tunable, and sustainable. Yet despite these attributes, the technology remains underutilized. Aerial believes the industry can unlock electron beam's full potential through process optimization, advanced simulation techniques, and new release paradigms.

The Challenge of Dose Uniformity

Unlike gamma or high energy x rays, which penetrate deeply and are able to irradiate pallets of products, electrons have mass and charge, giving them finite penetration depth and creating potentially significant dose gradients within products. Edge effects, scattering, shadowing, and voids all influence dose distribution, potentially creating unacceptable variations between minimum and maximum dose levels.

The Dose Uniformity Ratio (DUR), defined as maximum dose divided by minimum dose, is the critical parameter determining whether electron beam processing suits a given process definition. Reducing DUR through several approaches is possible: reconsidering process definition and material selection, adapting packaging and product orientation, adjusting beam energy up to 11 MeV or beyond, and using scattering plates to create multidirectional electron distribution. Their simulation work demonstrates that scattering plates alone can reduce DUR significantly. An example shows a DUR reduction from 1.99 to 1.39.

The Shift Toward Electronic Dosimetry

The most transformative element involves moving from physical dosimetry toward "e-dosimetry" based on Monte Carlo simulation. Taking inspiration from radiation therapy treatment planning, this approach uses CT scans to create detailed three-dimensional product models, which then serve as input for simulations tracking millions of virtual electrons through product materials.

Aerial's simulations of a sterility test device showed excellent agreement with physical measurements, with simulated DUR of 1.99 matching the experimental value of 1.93. This correlation suggests simulation can reliably predict dose distribution, enabling virtual experimentation with different configurations without consuming products or beam time.



Release Based on Irradiator Parameters

Industry may also envision Release Based on Irradiator Parameters (RBIP), where product release depends on real-time monitoring of machine parameters rather than physical dose measurements. If validated parameters are periodically verified and maintained, products can be released without monitoring dosimetry. This approach requires industry guidance, early adopters willing to generate regulatory data, and development of real-time monitoring tools.

The Path Forward

Aerial acknowledges that e-dosimetry and RBIP raise unresolved questions about CT resolution requirements, material segmentation, simulation accuracy, uncertainty quantification, and how to define minimum and maximum dose computationally. These questions must be answered consistently with fifty years of successful radiation sterilization practice, likely requiring updated standards and guidance documents. The electron beam technology is ready. Realizing its full potential requires collaboration among standards organizations, regulators, early adopters, equipment manufacturers, and research organizations to develop the frameworks and tools needed for this next chapter in radiation sterilization.

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Florent KUNTZ received his Physics Engineer Diploma in the field of nuclear science from University of Strasbourg-France. His involvement in Radiation Processing began during his Ph.D. in which he conducted research on new developments in electron beam dosimetry. (University of Strasbourg-France). Florent KUNTZ is working with Aerial, a Technological Resource Centre, as Strategic Development Manager in radiation processing and dosimetry. In the field of radiation processing, Florent KUNTZ performs trainings on industrial irradiation dosimetry, helps the industry in IQ/OQ/PQ, in dosimetry system selection and calibration. He has also developed the famous AerODE, AerEDE and DosASAP customized optical and EPR dosimetry equipment. Florent KUNTZ also promotes projects aimed at implementing new methods in this field, such as irradiator parameter-based release (RBIP) and the use of Monte Carlo simulation capabilities to move from physical dosimetry to virtual dosimetry. As dosimetry expert, he conducted several missions with the International Atomic Energy Agency and is member of the Irradiation Panel, ASTM and CEN/ISO committee.



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

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At present, there are more than 1,300 electronic accelerators across China. Among them, 39 low-energy electron accelerators were delivered in 2024, and El Pont accounted for more than half of these.^[1] El Pont's self-shielded low energy accelerators below 1MeV are mainly used in the following industries: 1. Sheet and foam materials; 2. Wires and cables, especially automotive wiring harnesses; 3. Battery diaphragm, mainly used in the energy storage battery industry; 4. Tire pre-vulcanization; 5. Film industry, including EVA film for photovoltaic panels, POF shrink-film and PVDC food packaging film; 6. Surface curing of decoration panels; 7. The surface curing of coil and extrusion coatings. Among them, two applications of surface curing have been the main R&D focus of El Pont in low-energy machine in recent years. El Pont has developed the world's first all-EB line for decorative panels. The coatings are from Sherwin-Williams. The speed of the production line reaches 30m/min (2.5 times the production efficiency of thermal curing approach), the production process has zero VOC emissions, and the decorative boards processed through full EB curing have excellent performance in resistant to yellowing (QUV Tested for 168 hours, $\Delta E \leq 1$), odourless (level 0.5), zero formaldehyde release, excellent silky touch properties as well as many other performance indicators; the production of decorative panel by using this technology is high in efficiency and low in unit cost, and environmental performance of E-beam cured coatings are far ahead of existing decorative panels on the market. This product is currently attracting a lot of interest in the market. By the end of 2024, two more EB decorative panels will be produced and put into production, and El Pont will have three commercial production lines for EB decorative panels. El Pont also signed a strategic cooperation agreement with AkzoNobel to jointly develop EB technology for coil coatings. So far, this collaboration has been experimented with several times and has made great progress. Although it is still some time before it is officially put into production, it has already aroused the interest of many giants in the steel industry. In summary, we believe that the development and promotion of low-energy curing using electron beam technology will make a great contribution to global carbon neutrality and bring huge economic benefits to society.

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Dr. Yuwei Zhang is a member of the International Advisory Committee for NICSTAR2026. She currently serves as Chairman, General Manager, Deputy General Manager, and Technical Director of Wuxi EL PONT Radiation Technology Co., Ltd., and concurrently holds the position of General Manager of the company's joint venture-Zhongtong EL PONT High-Tech Co., Ltd., focusing on the R&D and application of downstream products for radiation crosslinking or curing.

She holds a Ph.D. in Mechanical Engineering from the University of Bristol, UK, and a Bachelor's degree in Polymer Materials and Engineering from Tongji University, Shanghai. Having been deeply engaged in the fields of radiation technology and polymer materials for many years, she has gradually grown from a technical specialist responsible for new product development to a core manager across multiple positions. She currently still concurrently holds multiple key positions at Wuxi EL PONT Radiation Technology Co., Ltd., accumulating comprehensive experience in technological R&D and enterprise management.

Her main research areas include the determination of the glass transition temperature of polymers, the effects of curing cycles and thermal history on adhesive properties, and the development of downstream products for radiation crosslinking or curing. She has published multiple peer-reviewed research papers in international journals such as *The Journal of Adhesion* and *International Journal of Adhesion and Adhesives*, and has also published a paper in *Nuclear Technology* focusing on the pilot production and performance research of silicon plastic rapid diodes via electron irradiation technology.



High-energy industrial electron accelerators ILU type

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Budker Institute of Nuclear Physics is constantly developing new industrial accelerators. This report is describing to a series of accelerators of the ILU type. These accelerators are successfully operating in the market for sterilization of disposable medical devices. Entering the promising food processing market requires increasing the power of accelerators and their efficiency to operate in the bremsstrahlung mode. A line of 3 accelerators with energies up to 5 MeV, up to 7.5 MeV and up to 10 MeV with an electron beam power of up to 100 kW has been developed. Accelerator ILU-10 with beam energy 5 MeV and power 50 kW is recommended for countries that do not intend to use the 7.5 MeV limit for irradiation of food products using. For countries that currently have a maximum energy limit of 5 MeV, but are planning to increase it to 7.5 MeV, the ILU-12 accelerator is intended. ILU-12 has a beam energy range of 5-7.5 MeV and a power of up to 60 kW. For countries where it is permitted to irradiate food products with X-rays with a maximum energy of 7.5 MeV, the ILU-14 accelerator with a power of 100 kW is intended. This accelerator can also have an electron beam with an energy of 10 MeV.



Aleksandr Bryazgin is the Head of Laboratory of Budker Institute of Nuclear Physics. The main field of activity is industrial electron accelerators ILU and their applications. Almost many tens industrial accelerators ILU was delivered to plants and scientific organizations. They work for cross-linking polymers, medical devices sterilization and food irradiation. Aleksandr Bryazgin author of 132 scientific articles.

1989 was graduated from Novosibirsk State University and entered Budker Institute of Nuclear Physics as a junior scientific researcher.

2003 Defending a PHD thesis on the Radiation-technological installations based on ILU accelerators.



Applications of Ga-68 based radiopharmaceuticals: Clinical Update

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Abstract

Gallium-68 (Ga-68) based radiopharmaceuticals are pivotal in modern positron emission tomography (PET) imaging, offering high sensitivity for detecting various cancers and other conditions. These agents leverage Ga-68's favorable properties for precise diagnostics and theranostics.

Physical Properties

Ga-68 is a positron-emitting isotope with a 68-minute half-life, decaying 89% via positron emission (mean energy 0.89 MeV). This short half-life enables rapid imaging protocols and low radiation doses, while its production from a $^{68}\text{Ge}/^{68}\text{Ga}$ generator eliminates the need for an on-site cyclotron.

Key Radiopharmaceuticals

- *^{68}Ga -DOTATATE/DOTATOC/DOTANOC*: Target somatostatin receptors (SSTR) overexpressed in neuroendocrine tumors (NETs), meningiomas, and some lymphomas; superior for lesion detection over conventional imaging.
- *^{68}Ga -PSMA (e.g., PSMA-11)*: Binds prostate-specific membrane antigen in prostate cancer, enabling precise staging and restaging; widely approved for clinical use.
- *Others*: ^{68}Ga -FAPI for fibroblast activation protein in various cancers; ^{68}Ga -NOTA-exendin-4 for insulinomas. ^{68}Ga -alpha v beta 6 integrin target cancer integrin and useful in head and neck carcinoma and pancreatic carcinoma.

Clinical Applications

Dominant in oncology for NETs (^{68}Ga -DOTATATE as standard), prostate cancer (PSMA PET), and emerging uses in breast, lung, and renal cancers. Supports theranostics by pairing with ^{177}Lu analogs for imaging-guided therapy.

Advantages and Challenges

Advantages include inhouse generator-based pharmacy, fast pharmacokinetics, and high image resolution.

Challenges involve high positron energy (affecting resolution) and generator yield limits (cyclotron-based production could be a solution), though recent advances improve scalability

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Novel radionuclides for medical applications in theranostics: perspectives and challenges

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Radiopharmaceuticals are medicinal products that combine radioactive isotopes with carrier molecules, play a vital role in modern nuclear medicine. Nuclear research reactors are essential facilities in radioisotope production. Among them, the Maria research reactor at the National Centre for Nuclear Research (NCBJ) in Otwock, Poland, with a power of 30 MW, belonging to the medium neutron flux reactors (around $2.5 \times 10^{14} \text{ cm}^{-2}\text{s}^{-1}$), contributes to the global supply of Mo-99, I-131, and other important radionuclides for therapeutic use, such as Lu-177, Ho-166, etc.

The Maria research reactor and the GMP-certified facilities at the Radioisotope Centre POLATOM form the unique research infrastructure of the NCBJ. Extensive research on developing technologies for neutron-irradiated radionuclides and their therapeutic applications is conducted in collaboration with clinical partners supported by national and European funding. Recently, NCBJ/POLATOM has led the SECURE project (1), which focused on advancements in the design of irradiation targets and production routes for both existing and new isotopes used in nuclear therapy and diagnostics. They also contributed to the PRISMAP project (2) and IAEA coordinated research projects. As a result, technologies for producing Tb-161 (3) and Sc-47 (4) have been implemented.

To meet the high demand for radioisotopes for medical applications, particularly with a focus on their theranostic value, the new research facility, “Center of Design and Synthesis of Radiopharmaceuticals for Molecular Targeting, CERAD” was built. The 30 MeV cyclotron, which accelerates protons and alpha particles to 30 MeV and deuterons to 15 MeV, is a key device of CERAD (5). This three-particle accelerating cyclotron may be particularly useful in producing At-211, an alpha-emitter with promising properties for Targeted Alpha Therapy. Production of At-211 is currently being developed under accelerate.eu project (4). Further applications of the reactor and cyclotron-produced radioisotopes are in the pipeline.

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Prof. Renata Mikolajczak, with over 30 years of experience in radioisotope and radiopharmaceutical development, is coordinating the research activity of the Radioisotope Centre POLATOM, National Centre for Nuclear Research in Poland. She is a professor of medical sciences and holds a Ph.D. in physics and a DSc in medical biology. The coordinator of the CERAD project with its 30 MeV cyclotron. Since 2020, she has served as the chair of the expert group, PRP Working Party - Precursors for Radiopharmaceutical Preparations, of the European Pharmacopoeia of the EDQM. IAEA expert and lecturer in Radiopharmacy and member of the IAEA's Standing Advisory Group on Nuclear Applications (SAGNA). Publications (Scopus2025): 128, citations 2013; Hirsch-index: 29.



Novel ^{225}Ac -labeled Antibody for Targeted Alpha Therapy of Pancreatic Cancer

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Significant advances have been made in identifying vectors for targeted therapy applications. The aim being to treat the right patient with the right drug at the right time and at the right dose. As each patient's disease is unique and thus the treatment, accurate patient selection and response monitoring is essential to enhancing the need for theragnostics. As selective targeting vectors have advanced in their size, shape and complexity, so have the radionuclides. Having been developed with varying nuclear properties and chemistries that are used to radiolabel these vectors. The radionuclides are incorporated or attached to the drug molecule for diagnostic imaging and can be followed by a different radionuclide for targeted radiotherapy, particularly for metastatic cancer. These diagnostic tools aid not only in diagnosing disease, but in quantitating expression and assessing normal tissue uptake, enabling the calculation of the appropriate dose to minimize normal tissue toxicity and maximize efficacy. Advances have been made that are now making radionuclides more available as well as new chelators allowing for the development of improved agents which can allow choosing the right radionuclide with the appropriate nuclear properties to be attached to a given vector.

In recent years, radiopharmaceuticals have been of high interest due to their ability to diagnose and treat cancer non-invasively and with high efficacy. Radionuclides that decay via alpha emission have been of particular interest, due to their high linear-energy transfer. One such alpha emitter, Ac-225, is promising for targeted alpha therapy (TAT), which is a method for targeting and treating cancer and other related diseases.¹ Targeted alpha therapy consists of conjugating a chelator, or a binding site for the radionuclide, to a targeting vector and labeling it with an alpha-emitting radionuclide. The resulting complex provides a radioactive payload to a specific tumor site, causing double-strand DNA breaks in tumorous cells. The Isotope Research and Production Department (IP) at Brookhaven National Laboratory has been instrumental in the research and production of Ac-225^{2,3}. In the present work, a novel tumor specific antibody named TOBi-89, which selectively targets human pancreatic ductal adenocarcinoma (PDAC)⁴ was investigated for its ability to be conjugated to the dodecane tetraacetic acid (DOTA) chelator and macropa labeled with Ac-225; this complex is of interest for its potential to be used as an agent for TAT. Radiolabeling studies were conducted with the DOTA-TOBi-89 and Macropa-TOBi-89, and the radiochemical yield and purity were assessed using radio-instant thin layer chromatography (radio-iTLC). The stability of the complexes were assessed via radio-iTLC studies after incubating the complex in human serum over several days. Affinity of the complexes were evaluated, and a comparison and contrast of the results will be presented.



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Cathy S. Cutler is a strategic advisor for the US Department of Energy Office of Science Isotope Research & Production Department (IRP) and works as part of the Isotope Department at Brookhaven National Laboratory. Dr. Cutler has over 30 years of experience in the development and evaluation of radiopharmaceuticals, utilizing bioinorganic and radioanalytical chemistry to develop and evaluate radiopharmaceuticals for both diagnosis and therapy. Her research ranges from making use of inorganic chemistry to design new metal-based radioisotopes for use in radiopharmaceuticals and targeted nanoparticles to establishing techniques to evaluate their *vivo* behavior. Dr. Cutler works primarily on developing and evaluating radiopharmaceuticals for the diagnosis and treatment of cancer. The IP group focuses on developing methods for radioisotope production, novel separation methods to provide carrier-free isotopes, and implementing methods to provide large scale production of radioisotopes for commercial use, clinical trials, and medical applications. Dr. Cutler's current focus is on developing production and separation methods for high-specific activity radioisotopes to create a suite of diagnostic and therapeutic agents that can be tailored to the individual patient's needs. This is complex, cutting-edge science and engineering that requires developing the radiochemicals themselves as well as designing the facilities and techniques to produce them in quantities that can be scaled up for clinical trials and ultimately routine use. She is the immediate past president of the Society of Nuclear Medicine and Molecular Imaging an international organization that represents professionals the develop and implement nuclear medicine.



Medical Cyclotrons: A Viable Business Model

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PET-CT imaging plays a crucial role in the diagnosis, staging, evaluation of therapy response and regression of cancer. As per IAEA, there should be at least one PET-CT machine per million population. Considering this requirement, 1450 PET-CT scanners are needed in India. The current number is only about 500. The major impediment in setting up the PET-CT facilities is the non-availability of the radiopharmaceuticals. [^{18}F]Fluorodeoxy glucose (FDG) is the major radiopharmaceutical used in PET-CT imaging. Fluorine-18 is a cyclotron produced with a half-life of only 110 minutes and hence difficult to be transported to long distances.

In India, there are only ~25 working medical cyclotrons of which half of them are government owned and operated for in-house use only. Only eleven out of the 35 states and union territories have a medical cyclotron. The patients need to travel long distances to get PET-CT imaging making it a cumbersome and costly affair. A nationwide spread of PET-CT imaging is essential. It is ideal to have a cyclotron within a 200 km radius of the nuclear medicine center to ensure availability of radiopharmaceuticals. At least 50 more cyclotrons are needed in India. There are a large number of medium cities in India where medical cyclotrons can be installed and operated profitably.

High levels of technical competence are needed for setting up a cyclotron facility. Careful planning of the cyclotron operational and radiopharmaceuticals production area as well as support systems to ensure smooth work flow. Being injectable products, radiopharmaceuticals are prepared under Class A clean room conditions under GMP compliance. Radiation safety has to be ensured by having shielded hot cells and computer-controlled synthesis modules capable of handling high levels of activity. HVAC of the facility need to be designed to ensure safe operation of the machine as well radiation safety to the workers and the environment.

At present, permissions and licenses for setting up a cyclotron are needed from the Atomic Energy Regulatory Board (AERB) only. Currently, radiopharmaceuticals are listed in Schedule K of the Drugs and Cosmetics Rules, which exempts them from DCGI regulation. However, it is essential that the manufacturing facility is designed, built and operated anticipating DCGI regulation coming into force in future.

A new stand-alone medical cyclotron project could cost Rs. 50-60 Crores depending on the configuration of the cyclotron, hot cells, quality control and radiation safety equipment selected. As the medical cyclotrons can work for 20-30 years, it is essential that the project is planned keeping in mind future requirements. At the same time, over planning the facility need to be avoided to contain the project cost.



Availability of trained manpower for the operation and maintenance of the facility is a critical factor. Even though the routine production is done in automated modules with minimal human intervention, in the long run it is better to have well qualified staff who can mature in the organization and take leading roles in future installations.

Our experience suggest that the revenue will improve substantially once the facility functions for a few years. Kerala had just two PET-CT machines prior to the start of the Molecular Cyclotron, whereas 23 installations are operating now and another ten are under planning. Despite a good business prospect, there are not many business groups coming forward to set up cyclotron projects. This needs to change in order to ensure evidence-based treatment to cancer patients all across India. Existing cyclotron facilities can contribute towards this by sharing information as well as supporting groups willing to set up new facilities.

There are excellent technical documents published by the International Atomic Energy Agency detailing the entire cyclotron technology, project planning and radiopharmaceuticals manufacturing under GMP compliances which can be perused by those who are interested to set up new cyclotron projects [1-4].

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Dr. M.R.A Pillai, Ph.D., D.Sc., FICNM is a radiopharmaceutical scientist with about fifty years of academic and research experience. Held positions of responsibility at the Bhabha Atomic Research Centre; Board of Radiation and Isotope Technology; Homi Bhabha National Institute; University of Missouri-Columbia and the International Atomic Energy Agency. Dr. Pillai is currently working as Group Director, Molecular Group, Cochin and Hon. Professor of Practice at Mar Athanasios College, Kothamangalam. He is the Associate Editor of Cancer Biotherapy and Radiopharmaceuticals and Editorial Board Member of four other international journals. He published ~220 papers in international journals, 3 books, edited 14 IAEA publications and contributed several chapters in books. He is a recipient of several awards including Homi Bhabha Oration Award from SNMI; Lifetime Achievement Award from ANMPI; Dr. M.V. Ramaniah Lifetime Achievement Award from IANCAS; Atmanirbharata Award from ISAS, Shri R.G. Deshpande Award from NAARRI, Distinguished Service Award and five other awards from the IAEA. He travelled to ~55 countries.



Strategies to Promote the Adoption of Electron Beam Worldwide

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The Office of Radiological Security (ORS), within the U.S. Department of Energy's National Nuclear Security Administration, works with partners in the United States and globally to promote the safe and secure use of advanced radiation technologies which benefit society. Advancements in electron beam (eBeam) offer many benefits to the user, including increased throughput, removals of costly security and end-of-life management concerns, and easing of regulatory burden. Recognizing these benefits, ORS shares U.S. technical expertise and innovation. This is done through hosting informational workshops, presenting at international conferences and symposia, completing joint research projects on specific topics, and identifying gaps to drive future research and development. For example, in partnership with Texas A&M University, ORS has completed feasibility studies with five international partners on the adoption of eBeam technology. These studies provide partners with tailored, bankable documents outlining technical requirements and forecasted impacts of introducing eBeam in their countries. Domestically, ORS facilitates collaboration between U.S. national laboratories, industry, and academia to break down barriers and increase the availability and accessibility of eBeam technologies. ORS' eBeam efforts aim to increase awareness of the technology and its benefits, while also working with industry to make the technology more available to interested end-users, promoting the adoption of this advanced technology to make sterilization more widely available and expand its use into new and emerging industries.



Kristin Hirsch is the Director of the Office of Radiological Security (ORS) within U.S. Department of Energy's National Nuclear Security Administration's (DOE/NNSA) Office of Global Material Security, a position she has held since March 2019. ORS works domestically in the United States and internationally with more than 100 global partners on the safe and secure use of radiation technology to benefit society, enhancing security by stopping adversaries from acquiring radioactive material for malicious use. ORS works to eliminate risk by removing and when necessary, replacing radioactive material with advanced technologies that do not use a radioactive source and preventing adversaries from acquiring radioactive material by pioneering security technologies and capabilities while strengthening industry, law enforcement, and government partnerships. Ms. Hirsch previously spent 3 years as the Director of the U.S. DOE office in Astana, Kazakhstan; as a project manager for the Global Threat Reduction Initiative implementing nuclear and radiological security projects in Europe; and 3 years as an Attaché in the U.S. DOE Office in the U.S. Embassy in Moscow, Russia. She started her federal career in 1999 working for the Department of Defense. Ms. Hirsch holds a bachelor's degree in history and a master's degree in international Affairs.



Leveraging Regional Partnerships to Promote the Adoption and Expansion of Advanced Alternative Technologies

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While traditional gamma-based irradiation methods are the most common form of ionizing radiation treatment for single-use medical devices, chemical remediation, and agricultural applications, advanced alternative technologies, like electron beam (eBeam), are quickly becoming commonplace among countries conducting large-scale irradiation. Traditional gamma-based devices use high-activity radioactive materials like Cobalt-60 (Co-60) to treat products, eBeam generates ionizing radiation without the need of a radioactive source, eliminating the risk posed by high-activity radioactive materials. The U.S. Department of Energy's National Nuclear Security Administration's (DOE/NNSA) Office of Radiological Security (ORS) works with partners around the world to enhance U.S. and global security by preventing adversaries from acquiring dangerous, high-activity radioactive materials through a two-pronged approach: eliminate the risk posed by radioactive materials by promoting the advancement and adoption of non-radioisotopic alternative technologies and prevent adversaries from acquiring this material by pioneering technologies and capabilities while strengthening industry and government partnerships.

ORS leverages regional partnerships to promote the advancement, expansion, and adoption of advanced alternative technologies as part of the Office's global risk reduction efforts. ORS has partnered with the IAEA's Regional Office of the Regional Cooperative Agreement (RCARO) on a 5-year project (2024-2028) designed to promote the adoption and advancement of eBeam technology in Asia and the Pacific. This collaborative project has successfully built a network of experts and technology users in the region to advocate for the use and adoption of advanced alternative technologies – while linking industry and academic institutes with decision makers to drive the adoption of these technologies on a national scale. Each year, the project team conducts tailored expert missions with partners around Asia and the Pacific designed to build out a roadmap towards the adoption or expansion of eBeam technology in the selected country, while encouraging the transition away from traditional gamma-based devices. Experts from neighbouring countries that have adopted the technology are invited to provide insight and assistance on the transition to eBeam and other advanced technologies. Each completed expert mission helps to expand the regional network of advocates and experts in advanced alternative technologies, which leads to a safer, more secure world.

ORS continues to look for opportunities to expand the growing global network of experts and champions of advanced alternative technologies through strategic partnerships to advance the office's primary mission of a safe, more secure world through the expansion of these technologies.



Ms. Katie Larsen is a Project Manager supporting the Alternative Technologies portfolio within the U.S. Department of Energy's National Nuclear Security Administration's (DOE/NNSA) Office of Radiological Security (ORS). ORS works domestically in the United States and internationally with more than 100 global partners on the safe and secure use of radiation technology to benefit society, enhancing security by stopping adversaries from acquiring radioactive material for malicious use. ORS works to eliminate risk by removing and when necessary, replacing radioactive material with advanced technologies that do not use a radioactive source and preventing adversaries from acquiring radioactive material by pioneering security technologies and capabilities while strengthening industry, law enforcement, and government partnerships. Ms. Larsen has been supporting ORS since 2021 and has spent time working on various portfolios. She has worked with partners in and around the Middle East/North Africa to secure and replace high-activity radioactive materials and continues to support the ORS mission by advocating for the promotion and adoption of advance alternative technologies around the globe. Ms. Larsen holds a bachelor's degree in international studies and modern languages and a master's degree in international relations.



Equivalence Studies of Alternative Technologies: Electron Beam (eBeam) vs Cobalt-60

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The U.S. Department of Energy/National Nuclear Security Administration's Office of Radiological Security (ORS), through a two-pronged approach, works to *eliminate* the risks posed by high-activity radioactive materials that could be used maliciously and *prevent* adversaries from acquiring radioactive material by promoting the adoption of safer, more secure non-radioisotopic alternative technologies, including electron beam (eBeam). Because eBeams are machine-based, they do not contain radioactive sources, eliminating the dangers posed by radiation-based sources. This effort includes supporting research projects including, but is not limited to, studies comparing machine-based and gamma-based irradiation testing for medical, food, and commercial products at a variety of energy levels and doses. The research is focused on generating empirical data on the equivalence of eBeam technology to Cobalt-60 technology. This presentation will discuss a series of equivalence studies which evaluate eBeam technology against traditional radioactive sources. These analyses will focus on various operational and safety parameters relevant to each method. Aspects such as penetration depth, dose uniformity, throughput capabilities, security considerations, and infrastructure requirements associated with both electron beam and radioactive source technologies in each respective process will be explored.



Dr. Kurt Housh is the Program Manager for the Alternative Technologies - Prevent portfolio in the Office of Radiological Security (ORS) within U.S. Department of Energy's National Nuclear Security Administration's (DOE/NNSA) Office of Global Material Security, a position he has held since 2025. ORS works domestically in the United States and internationally with more than 100 global partners on the safe and secure use of radiation technology to benefit society, enhancing security by stopping adversaries from acquiring radioactive material for malicious use. ORS works to eliminate risk

by removing and when necessary, replacing radioactive material with advanced technologies that do not use a radioactive source and preventing adversaries from acquiring radioactive material by pioneering security technologies and capabilities while strengthening industry, law enforcement, and government partnerships. He started his federal career in 2023 working in DOE/NNSA. Dr. Housh holds a Ph.D. in chemistry.



When Modeling and Dosimetry Meet to Empower Accelerated Adoption of eBeam and X-ray Technology

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The use of machine-based sources, such as eBeam and X-ray, provide numerous advantages over gamma-based irradiation including: higher throughput, no source decay, the capability to tailor dose and energy delivered to the product, and no security requirements. The United States Department of Energy Office of Radiological Security (ORS) has been working closely with sites interested in including proper dosimetry in their transition from gamma -base irradiation protocols to machined based sources and have identified gaps in the knowledge base of new potential users. One overarching barrier users face when transitioning long legacy research and irradiation protocols to eBeam and X-ray processing from gamma irradiation is understanding how to manage packaging design, and dosimetry for irradiation. To address this challenge, ORS has developed a number of tools and capacity building endeavors to educate the user community on the value of modeling along with proper dosimetry protocols. One such tool developed by Pacific Northwest National Laboratory (PNNL) for ORS partners includes PUFFIn (PENELOPE User Friendly Fast Interface). PUFFIn, designed as a fast and simple Monte Carlo simulation tool for the transport of photons and electrons, can operate with very little compute power making it accessible to a larger audience of technicians, engineers, and scientists. The current status of the PUFFIn modeling tool includes the ability to draw product configurations directly in the platform, to upload full 3D configurations created from CAD input files or images from X-ray tomography scans. Traditional understanding of dose delivery requires prior knowledge of dose delivery and placement of a large number of dosimeters throughout the product packaging. These dosimetry techniques require numerous dosimeters to be placed through the conveyance, measurements to be validated before product release. The capabilities of the Monte Carlo modeling tool along with advanced dosimeters are emerging into a new exciting field of virtual dose mapping, where products can be released faster to the market after sterilization/irradiation. This capability will drive the user community to save more money and drive adoption of eBeam/X-ray as an enabling technology. Once more traditional dosimetry techniques are limited for low energy eBeam (LEEB). Modeling and virtual dosimetry has the opportunity to play a key role in overcoming these challenges.



Randolph Schwarz is a nuclear engineer working for Pacific Northwest National Laboratory. He is the developer of the PUFFIn simulation software. He has worked both in private industry and in the government developing Graphical User Interfaces for nuclear applications for the past 30 years. Randolph has an M.S. from the University of Washington in Nuclear Engineering and a second M.S in Computer Science from Washington State University.



Industrial Electron Beam Technology: Challenges and Opportunities

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Industrial electron beam (EB) technology has emerged as a versatile, high-throughput tool for radiation processing applications including polymer cross-linking, surface modification, medical devices sterilization, wastewater treatment, flue-gas treatment, sludge hygienization food irradiation and advanced materials processing. Compared to gamma sources, electron beams offer advantages of high dose rates, electrical switchability, improved process control, and elimination of radioactive isotopes.

Despite decades of successful deployment, the large-scale adoption of EB technology across diverse industries continues to face several technical, operational, and economic challenges. Key challenges include the development of robust, high-power accelerators with long operational lifetimes, stable beam parameters, and minimal downtime under harsh industrial environments along with long-term reliability. Limitations in beam penetration depth, dose non-uniformity for thick or complex geometries, and efficient energy utilization remain critical constraints, particularly for bulk materials and high-density products. From a technology perspective, electron gun lifetime, RF and high-voltage system robustness, thermal management, and radiation-hard diagnostics continue to define system performance and operating cost. Equally important are non-technical barriers, including high capital investment, regulatory compliance, and the shortage of trained personnel for operation and maintenance.

At the same time, significant opportunities are arising from advances in accelerator physics, power electronics, solid-state RF systems, compact and modular high-gradient structures, and digital control technologies. This talk will critically assess the current limitations of industrial electron beam technology, draw lessons from field deployment, and outline realistic pathways for expanding its role in sustainable radiation processing, with particular emphasis on scalability, reliability, and cost-effectiveness.

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Dr. Rajeshwar Singh Sandha is the Head of “Industrial Accelerators Division” at Raja Ramanna Centre for Advanced Technology. He is the Executive Management Authority of “Electron Beam Radiation Processing Facility” at ARPF, Indore, India. He has more than one decade of experience with eBeam technologies. His current work is focused on improving the accelerator’s design, developing indigenous industrial sources for manufacturing, supply and after sales service and establishing a High

Throughput Food irradiation Processing Facility. He has published several papers in accelerator conferences.



Security During Radioactive Source Reloading at Gamma Irradiation Facilities

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Potential vulnerabilities may exist at gamma irradiation facilities during the process of reloading or replacing radioactive source pencils, which could create opportunities for radiological source theft. Considerable variations in procedures and policies between licensees, service providers, and transportation carriers exist as related to radiological security during source reloading. During engagements with the gamma irradiation community, stakeholders have raised concerns regarding potential vulnerabilities during the process of reloading sources.

For the purposes of this presentation, the scope of the source reloading process includes the state between the times when a transportation vehicle with fresh sources arrives at the facility boundaries and ends when a transportation vehicle leaves the facility premises with the depleted sources. The scope also includes any associated pre-planning and coordination activities prior to actual source delivery. The scope does not include the transportation of sources outside the facility, e.g., from the source manufacturer within a country or along routes between countries.

A joint International Irradiation Association (iia) and World Institute on Nuclear Security (WINS) Workshop on the Security of Gamma Irradiation Facilities was held on the margins of the International Meeting on Radiation Processing (IMRP) Conference in Bangkok, Thailand, on November 12, 2022. During one of the sessions, approximately 55 participants (representing manufacturers, regulatory agencies, operators, security professionals, and service providers from a variety of countries) were asked to share their thoughts on risks during source reloading and on whether security arrangements during source reloading are adequate.

This presentation summarizes the findings of the iia-WINS workshop, identifies some *potential* vulnerabilities and variations within the process (without mentioning any *specific* companies or operators), and provides considerations that may address some of those *potential* vulnerabilities during the source reloading process.



Michal Kuca is a Distinguished Member of Technical Staff at Sandia National Laboratories (Albuquerque, New Mexico, United States of America). Michal has worked at Sandia for 22 years, and in the last 15 years he has supported the U.S. Department of Energy's (DOE) Office of Radiological Security (ORS) in various positions. He has been a Technical Program/Project Manager and Physical Security Subject Matter Expert in Radiological Security where he managed and designed the physical security systems at civilian sites throughout the U.S. and abroad. In this role he collaborated with radiological regulatory agencies, various law enforcement agencies, and other stakeholders in an effort to secure



radiological material at civilian sites. Within the last 9 years he has been supporting the ORS's In-Device Delay (IDD) program. IDD forms collaborative partnerships with manufacturers of devices that contain high activity radiological material in effort to assess device vulnerabilities and engineer, test, and implement delay and intrusion detection enhancements for those devices



Radiation processing for various purposeful applications

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All over the world, there has been a tremendous increase in the use of applications of radioactive materials over the years for various purposes. India has been no exception and, in fact, we are observing significant growth rate in the recent past and still have to catch up with the rest of the world where its usage is much more common. In the last four decades, Shriram Applied Radiation Centre (SARC) of Shriram Institute for Industrial research is providing radiation processing services to Health Care Industry for various purposeful applications including Sterilization of Medical Devices. In addition to this Shriram Institute has successfully undertaken various research projects on utilization of Gamma radiation (Co-60) for various purposes such as: Radiation Sterilization of Health care Products; Modification of materials for various industrial and strategic applications; Shelf-life extension of Fruits and Dehydrated Vegetables; Decontamination of pathogens in Meat and Meat products; Post Harvest Management; Environment protection.

SARC also undertake studies to establish, validate, and optimize irradiation parameters for radiation processing of various types of products such as Healthcare products including Medical Devices, Ayurvedic/Herbal/Spices & Pharma products, Packaging material, and Industrial products.

Some of these studies along with the capabilities of SARC with regard to utilization of Gamma source (Co-60) will be discussed.



Dr Sanjay Rajput is presently working as Head, Shriram Applied Radiation Centre (SARC) of Shriram Institute for Industrial Research, Delhi. He did his Ph.D in Chemistry and Working with the Shriram Institute for the last 37 years. He has vast experience of utilization of Gamma Radiation (Co-60) in various applications such as: Development and modification of polymers for various industrial applications including Health Care Products, Packaging Material for Food Products and Pharma Products, De-polymerization of Polymers; sterilization of Health Care Products and Pharma products. Shelf-life enhancement of Food & food products including fruits and dehydrated vegetables and spices, Agri-Produce, Aurvedic/Herbal Products, Animal /Pet feed etc.

He has been member of several prestigious national scientific committees including member of Scientific Panel for Food Additives, Flavorings, Processing Aids and Materials in Contact with Foods, constituted by FSSAI. He is also member of various section committees of BIS on Sterilization of Hospital items. He is providing supervision to the students of various universities for Master/PhD Thesis. He has more than 44 research papers/articles published/presented and 7 patents to his credit.



Sediment dynamics investigation using radiometric methods

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Introduction

The International Society for Tracers and Radiation Application (ISTRA) is a society of scientists, engineers and technologists from various countries involved in development and applications of radioisotopes and radiation techniques in industry. The society operates as a training center for application of radiometric methods in industry (www.istra-society.org). The main objectives of the society are, in brief, three-fold:

1. To act as the international technical and scientific society for tracer and radiation applications to bring together individuals, teams and institutes working in the relevant fields.
2. To be the international certification body for practitioners in these fields (including setting training syllabus, arrange hands-on experimental exercises (courses), perform examinations and issuing qualifications to individuals in the form of certificates.
3. To foster communication, cooperation and networking between individuals, teams, and organizations working in tracer and radiation applications through professional activities including the Tracer Conference series.

The society has recently signed a Practical Arrangement with IAEA and a Memorandum of Understanding with **China Isotope and Radiation Association**.

Radiometric methods for sediment dynamics investigation

Radiometric technologies such as radioactive tracers and nucleonic control systems have been widely used in various industries and environmental installations to optimize processes, improve product quality, save energy, reduce pollution release and quantitatively measure sediment transport. Sediment transport is of a key importance especially in the actual context of climate change. There is a continuous flow of sediments along the coastlines, in ports and access channels, in dams' reservoirs. This flow is increasing due to climate change impact. The basic concept for radioactive tracer methodology is injecting a radionuclide into a moving fluid and employing radiation detectors downstream to measure the transfer of the injected tracer inside the measured system. Radioactive tracers are the most competitive tracers employed for online (non-invasive) field investigations; radioactive tracers have high detection sensitivity for extremely small concentrations; they offer the possibility of direct in-situ measurements, from the outside of a pipe, vessel, or underwater.



Today, radioactive tracers are facing problems of availability, licensing, and public acceptance for investigation of sediment transport in coastal areas. Even if most of the radioisotopes employed as radioactive tracers for sediment transport investigation are still produced in some nuclear reactors, some works are in progress to develop the use of natural radioactivity.

Another aspect of sediment transport is the management of sediment (especially fine particles) in harbor basins, navigation fairways and dams reservoirs; There is a continuous inflow of sediments in ports and access channels and therefore maintenance dredging is necessary. To determine when and how much there needs to be dredged the underwater sediment and mud layers must be monitored and analysed. This paper presents an innovative vertical profiling technique measuring the depth, thickness and density of the underwater sediment layer. The instrument uses X-ray to measure the sediment density. The data is used for two important aspects.

First in the preparation of dredging works where the data is used to determine ton dry matter of the dredged material. In combination with acoustic methods like multibeam echo sounders it is used to visualize the sediment layers under a multibeam surface.

Another important aspect of soft sediment is the navigability. Ships can navigate through loose mud layers if the physical characteristics of the mud stay below a critical limit. Today the measured physical characteristic in many ports is density. The proposed measurement technique allows visualization of density and enables ports to evaluate nautical depth criteria.

Nucleonic Control systems are another key tool for the measurement of sediment concentration (or mixture sediment in water density and therefore maintenance dredging is necessary. To determine when and how much there needs to be dredged the underwater sediment and mud layers must be monitored and analysed. This paper presents an innovative vertical profiling technique measuring the depth, thickness and density of the underwater sediment layer. The instrument uses X-ray to measure the sediment density. The data is used for two important aspects.

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Dr. Patrick BRISSET, is the general secretary of ISTR. He was IAEA Technical Officer 2011-21 in charge of Non-Destructive Testing, Radiotracers, Nucleonic control systems and sealed sources industrial applications, - Nuclear Sciences and Applications Department- Nuclear Applications Physics and Chemistry Division. Before he was head of the Applied Radiation Laboratory in CEA-DRT Saclay- France. He is ISTR Level 3 in 5 methods/ techniques.

He has over four decades worth of experience with Radiation Technologies for Measurement. His current activity is focused on radiotracers and nucleonic control systems industrial and environmental applications.



The Evolution of Safety in Industrial Gamma Radiography

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Technical Overview

The technical evolution of industrial gamma radiography is a study in balancing radiological protection with mechanical reliability. This presentation provides a deep dive into the engineering transitions from "fishing pole" exposure methods to modern S-tube shield projector systems. We analyze the critical design constraints that dictate the performance of contemporary Gamma RT devices, specifically the non-linear relationship between shielding capacity and total equipment weight.

Technical Discussion Points

- **Shielding Material & Geometry:** Evaluation of the transition from fixed column systems to complex S-tube geometries, focusing on how shielding material changes impact the ANSI/ISO safety standards.
- **Engineering Trade-offs:** Quantitative analysis of the four-way optimization required for industrial source projectors:
 - **Shielding vs. Weight:** The impact of increased weight on transport costs and handling safety versus the benefit of lower dose rates.
 - **Complexity vs. Reliability:** How increasing mechanical complexity to meet safety standards can potentially degrade long-term durability.
- **Human Factors Engineering (HFE):** Implementing HFE to reduce cognitive load through intuitive user interfaces and ergonomic controls, thereby mitigating risks associated with technician fatigue.
- **System Resilience:** A focus on designing "Resilient Systems" that are engineered to respond, absorb, adapt, and recover from unexpected field disruptions and "near-miss" events.

Conclusion

As the NDT industry faces a demographic shift, with 60% of radiographers being over 45 years old, equipment design must prioritize both safety and ease of use. Future innovations in digital radiography solutions, enhanced safety packaging, and SCAR simplification will be essential to maintaining the sustainability of the Gamma RT market.



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Jake Bourn is the Vice President and General Manager at QSA Global, Inc., where he leads global operations, international sales, and manufacturing initiatives. With extensive experience in the industrial NDT sector, Jake has a proven track record of managing cross-functional teams and driving technical innovation within the field of non-destructive testing. His prior leadership as the Engineering and Director of Operations at QSA Global provided him with deep technical expertise in the production and safety management of radioactive sources. A frequent international traveler and industry speaker, he is dedicated to implementing continuous improvement and enhancing safety standards across the global radiography market.



Radioisotope based power sources

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Radioisotope based power sources (RPS) alternatively called as nuclear batteries convert energy of radioactive decay into electrical energy. The attraction for RPS is due their potentially long operational life, silent operation, less maintenance making them suitable for applications where recharging or solar energy are not feasible. In RPS the radioisotope decay energy can be harnessed to yield electricity using either thermal or non-thermal conversion [1, 2].

Radioisotope Thermoelectric Generators (RTG) is a thermal to electrical converter which uses a radioactive heat source and thermoelectric converter based on semiconductors. RTGs, like usual thermoelectric power generators have large numbers of p - n legs that are serially connected to add the voltage produced by each leg and placed thermally in parallel so that each leg face a uniform temperature gradient [1,3]. When a temperature difference is maintained between both the ends of a RTG, charge carriers in both p - and n - legs migrate from hot-end to the cold-end generates electrical power. The energy conversion efficiency of a RTG depends upon properties of constituent's p - and n -type materials as well as on the temperature difference and in best cases it can reach up to 8-10% for temperature difference of 300-400K [3]. Worldwide RTG are being used as "sustained long-lived high power sources (~ 100 We)" for various niche applications including deep space exploration, remote & terrestrial applications.

Betavoltaic batteries are relatively low power sources (1-100 μ We) which directly convert the radioactive decay energy of beta particles into electrical power (a non-thermal conversion) by creating electron-hole pairs in a charge separation structure such as semiconductor p - n junctions. At the p - n junction, the built-in electrical field in the depletion layer results in a driving force that separates radiation generated electron-hole pairs. The most likely fate of the charge carriers generated beyond the depletion region is that they will either recombine or become trapped by defects. Depending on the diffusion length of charge carriers that is determined by the crystalline quality of semiconductor, the charge carriers may drift into the depletion region and become part of the current driven by the junction's electric field. In such devices the matching of radiation transport length in semiconductor with thickness of depletion layer is very critical. So far the most widely used radioisotopes in commercial betavoltaic batteries are tritium (^3H) and nickel-63 (^{63}Ni) by virtue of low energy beta particles emitted by these sources cannot induce structural damage to semiconductor devices [4].

However recently high energy beta sources such as ^{90}Sr are also being used with the semiconductor devices for electricity production. The direct coupling of high energy beta source with semiconductor device results in severe displacement damage in semiconductor. Such damage in semiconductor device increases the dark current and lower down the output power with time. To overcome the radiation induced damage in semiconductor devices caused by high energy beta



sources, use of intermediate layer of scintillator material with high photo yield has been reported. Scintillator converts energy of beta particle into photon and subsequent conversion of photon to electric power using a semiconductor $p-n$ device is a promising approach for making radiation resistant beta photo-voltaic power sources. Therefore, conversion of high energy of beta particle into light using scintillator material followed by conversion of light into electric power present an elegant way to make an efficient beta battery with long life of operation, where the length scale matching of radiation transport and device thickness is not critical [2,4,5]. The present talk will describe the overview of RPS including radio-isotope thermoelectric generators (RTG), betavoltaics and beta-photovoltaic energy conversion devices.

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Radioactive Particle Tracking Technique and It's Application in Industrial Process Systems

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Multiphase flow reactors are the heart of many industries. However, even after decades of their use for many industrial processes, the design and scale-up of such reactors are still based on some heuristic's rules. This is mainly due to the poor understanding of their complex flow physics, which is mainly due to the lack of suitable measurement technique. Radioactive particle tracking (RPT) technique has emerged as a powerful and versatile technique for probing multiphase flow reactors. In the RPT technique, a single radioactive particle (which is a gamma-ray emitter) is used as the marker of the phase whose velocity field is to be mapped. In case of liquid phase tracking tracer particle is made neutrally buoyant and, in case of solid phase tracking size, shape and density of the tracer particle is kept same as of the solids present in the flow. The motion of the marker particle is tracked by using specially designed scintillation detectors and related electronics which are strategically placed around the bed to achieve maximum resolution and sensitivity. By using a suitable reconstruction algorithm Lagrangian track of the particle is achieved which can further provide the Lagrangian particle velocity. To get the sufficient statistics data are acquired for a long time with a relatively high frequency. Hence, a huge set of data is obtained through these experiments which are further processed to get time averaged information, like mean axial and radial velocities, RMS velocities, granular temperature etc. Further, various quantities like autocorrelation, Hurst exponent and mixing index, Kolmogorov entropy etc. that represent the prevailing flow regimes and flow characteristics can be extracted through the time series analysis of RPT data. In this presentation, details of RPT technique, hardware used, reconstruction algorithm and post-processing methods will be discussed briefly. Thereafter, case studies will be presented for RPT implementation on various multiphase flow reactors at different scale. The data for laboratory scale gas-liquid system, gas-solid cylindrical and conical fluidized bed, circulating fluidized bed and pilot plant scale gas-solid circulating fluidized bed will be presented to establish the accuracy of RPT at two different scales. Further, data for size wall nozzle injection fluidized bed and gas-solid binary fluidized bed will be presented to demonstrate the capabilities of RPT to investigate the complex flow physics.



Dr. Rajesh Kumar Upadhyay has obtained his PhD degree from IIT Delhi in 2010. He has worked for 9 years in IIT Guwahati as an Assistant Professor and Associate professor positions. Thereafter he has joined the IIT (BHU) Varanasi in year 2019 and working their till now as a Professor. He has published around 25 international journal publications, around 60 international conference publications and authored 4 book chapters. His group extensively work on radioisotope-based techniques mainly radioactive particle tracking (RPT) and gamma-ray densitometry to investigate the flow fields in laboratory and pilot plant scale setup. His major expertise are: Multiphase flow reactors, Fluidized Beds, Measurement Technique, CFD Simulations, Hydrogen production, and hydrogen energy.



Feasibility study of a Dual-Mode 7–10 MeV Electron Beam and X-ray Accelerator for Industrial Applications in Jordan

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The rapid expansion of Jordan's medical and food industries has positioned the country as a key regional hub for production and distribution. However, current irradiation capacity, limited to a Co-60 gamma facility operated by the Jordan Atomic Energy Commission (JAEC) is no longer sufficient to meet growing market demands. This study assesses the feasibility of establishing a dual-mode 7–10 MeV accelerator for industrial radiation processing, capable of delivering both electron beam (e-beam) and X-ray (bremsstrahlung) irradiation.

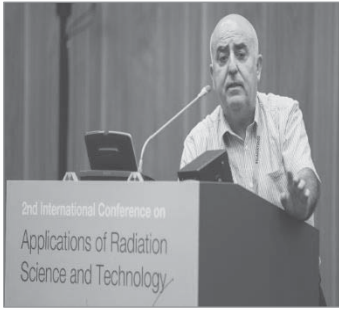
The proposed facility builds upon existing private-sector facility, including shielding, conveyor systems, control room and storage areas, and is designed to provide multi-purpose sterilization and decontamination services for medical devices, pharmaceuticals, cosmetic, veterinary, and food products. Technical analysis shows that such an accelerator can deliver doses between 0.5 and 30 kGy and, in X-ray mode can achieve more penetration depths making it suitable for bulk processing of products.

Economic evaluation indicates a projected payback period of about 20 years at 60% utilization, supported by a diverse range of product streams. The facility will comply with IAEA safety standards, ISO 11137 for radiation sterilization, and Codex Alimentarius guidelines for food irradiation. The environmental assessment highlights the benefits of a non-radioisotopic, energy-efficient, and environmentally safe process.

The study concludes that establishing a dual-mode 7–10 MeV e-beam/X-ray facility in Jordan is technically feasible, economically viable, environmentally sustainable, and strategically important for advancing industrial irradiation capabilities in the region.

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Moh'd Amer Etoom obtained B.Sc degree in Mechanical Engineering in 1987 from Jordan University. He has more than 38 years' experience in design, supervision, implementation and maintenance of mechanical systems in various areas such as civil engineering, buildings, Royal Jordanian Airlines and Jordan Electricity Authority. He has also served as Calibration Officer in Metrology Department of Jordan. In 1998, he joined Gamma Irradiation Facility of Jordan Atomic Energy Commission,

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Radiation beam technologies for tissue sterilization and advancements in artificial tissue engineering

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Radiation beam technologies employed for the sterilization of biological tissues in tissue banks, alongside advancements in the field of artificial tissue engineering, represent significant developments in biomedical science. IAEA is involved more than 30 years in the use of the ionizing radiation techniques for tissue banking [1].

Dr Jorge Morales Pedraza, former Radiation and Tissue Banking Programme Manager in the Technical Cooperation department of IAEA was in charge of this activity. The IAEA published A Code of Practice in 2007 “Radiation Sterilization of Tissue Allografts: Requirements for Validation and Routine Control” [2]. The current Code of Practice requires revision, and a critical analysis has recently been published outlining methodologies for its improvement [3].

The IAEA facilitates and coordinates research applied radiation biology to address specific challenges by fostering a critical mass of expertise in the fields of radiation technologies. Coordinated Research Projects (CRPs) serve as the primary mechanism for conducting international studies. The first tissue banking CRP was “Safety and Optimization of Radiation Sterilization in Tissue Banking: Studies on Functional Properties of Irradiated Tissue Grafts” (2010-2017), 16 participating institutions from 15 Member States, completed.

The aim was to find the optimal radiation dose and processing methods for tissue sterilisation without compromising structural function for clinical use. In parallel, IAEA was exploring the related area of Stem Cell Therapy in another CRP “Improving Outcomes in Radiotherapy Using Novel Biotechnologies: Modification of Tissue Reactions and the Use of Stem Cell Therapeutics” was conducted 2008-2012 and involved 13 institutions from 10 IAEA Member States (MSs). The major aim of the project was to provide the Member States with new and relevant knowledge on stem cell therapeutics (i.e. optimization of techniques) to prevent radiation-induced damage to normal organs/normal tissues. The next step was to integrate these approaches and move from tissue banking to tissue engineering.

The joint CRP “Instructive Surfaces and Scaffolds for Tissue Engineering Using Radiation Technology” (2014-2019), in cooperation the IAEA Division of Physical and Chemical Sciences brought together 15 participating institutions from 14 MSs. The main aim of the project was to engineer instructive scaffolds and surfaces using radiation technology to produce artificial tissues using autologous and allogeneic cells for clinical use. The next step was to move towards regenerative medicine integrating aforementioned approaches: tissue banking, stem cell therapy and tissue engineering.



Despite current treatments, patients continue to suffer from cutaneous radiation syndrome (CRS) necessitating exploration and implementation of new technologies. Regenerative medicine, by way of adult mesenchymal stem/stromal cell therapy (MSCT), provides novel solutions, which help to improve patients' quality of life. The main aim of the project is to disseminate and improve adult MSCT, tissue engineering and biobanking technology for treatment of CRS, including experimental research, pre- and clinical studies, in purview of regulatory guidance.

The new CRP E35011 on Mesenchymal stem cell based regenerative medicine technologies for treatment of radiation induced lesions will start soon, it is open for applications, see <https://www.iaea.org/newscenter/news/iaea-launches-stem-cell-project-to-treat-radiation-skin-injuries>. The main aim is to develop adult mesenchymal stem/stromal cell therapy (MSCT), optionally in combination with artificial tissue engineering, to treat cutaneous radiation syndrome (CRS), including experimental research, pre- and clinical studies, in purview of tissue banking and regulatory guidance.

In summary, the IAEA has progressively advanced from radiation sterilization of tissue grafts to integrated approaches combining tissue banking, stem cell therapy, and tissue engineering to support regenerative medicine. Through a series of Coordinated Research Projects, the Agency has optimized sterilization protocols, developed radiation-based scaffolds for artificial tissue, and promoted mesenchymal stem cell therapies to mitigate radiation-induced damage. These initiatives aim to provide Member States with validated technologies and regulatory frameworks for clinical application, culminating in the launch of a new CRP on MSCT for treating cutaneous radiation syndrome—marking a pivotal step toward combining biobanking and tissue engineering for improved patient outcomes.

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Dr. Oleg Belyakov is a Radiation Biologist and the Coordinator of the Biological Dosimetry Model Laboratory (BDML) at the International Atomic Energy Agency (IAEA) located in Vienna and Seibersdorf, Austria. He also holds the position of Adjunct Professor in Radiation Biology at the University of Eastern Finland. With over 30 years of extensive experience, Dr. Belyakov is recognized as a leading expert in the field of radiation biology. His areas of specialization encompass radiation biology, radiotherapy, biological dosimetry, and tissue banking. Dr. Belyakov has played a pivotal role in numerous high-level international projects and has established significant research initiatives. His contributions to radiation research are exemplified through collaborations with esteemed institutions such as Columbia University and NASA. His work has been acknowledged with several prestigious awards, and he continues to advance the discipline through his publications and leadership in global radiation science initiatives.



Academics to Applications: Harnessing Nuclear Science for Societal Benefits

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Amidst ongoing technical advancements and industrial revolution, the United Nations has adopted 17 sustainable development goals with objectives to achieve peace, prosperity, and environmental sustainability. In alignment, nuclear science is recognized as a transformative force for clean energy, healthcare, agriculture, and industry. To achieve these objectives skilled manpower equipped with knowledge in nuclear sciences is required to serve in various industries. Moreover, to meet global need spanning from nuclear physics, radioprotection to nuclear safety and security, Amity Institute of Nuclear Science and Technology (AINST) has established a state-of-the-art radiation detection facility [1] at its Noida campus.

A unique capability of remote accessibility making it first of its kind in India. The facility is available to users to access radiation detectors online, enabling remote education and training for institutions not having access to such laboratories. The laboratory is equipped with liquid nitrogen cooled High-Purity Germanium (HPGe), CeBr₃ & NaI(Tl) scintillation and alpha spectrometers along with neutron detectors, waterproof GM counters, and six radioisotope identifiers (RIIDs). To measure the low background activity and environmental samples four low-background setups of 10 cm thick lead passive shielding stations are available.

The study of radiation absorption in banana and radiation risk assessments in various food [2], and soil samples. In addition, the radiation measurements in different building materials have been performed. Radon estimation [3] has also been estimated using charcoal canister method. Further, smuggling of radioactive materials poses serious safety risks, while conventional X-ray scanning offers limited detection. AINST has introduced a low cost, non-destructive gamma ray-based method, using peak elongation ratios for identifying low activity nuclear materials. Utilizing the capabilities of ANN an optimization study for gamma ray attenuation has also been performed. This approach provides a fast, reliable, and generalized alternative to traditional techniques, advancing radiation shielding, nuclear safety, and medical imaging. The shielding assessment for neutrons has also taken up one of the research problems. The faculty members and students are involved in application-based experiments using the facility. The details of the work will be presented during the conference.

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Dr. Alpana Goel is the Director and Head of Institution at the Amity Institute of Nuclear Science and Technology (AINST), Amity University Uttar Pradesh, India. She is an internationally recognized expert in nuclear physics and nuclear security education, with extensive academic, research, and policy-level experience-

She earned her Ph.D. in Nuclear Physics from IIT Roorkee and has made significant contributions to nuclear structure physics, nuclear isomers, and nuclear security capacity building. Dr. Goel has directed major academic initiatives, including the DST–SERB School on “Role of Symmetries in Nuclear Physics” held at Amity University Uttar Pradesh. She is the co-author of the Springer Nature book “*Nuclear Isomers – A Primer*” (2021) and has published over 100 research papers in reputed national and international journals. Her research has been supported by funding from DST (India), DTRA (USA), and CRDF Global.

Dr. Goel has strong international exposure, having worked as a Nuclear Security Consultant at the International Atomic Energy Agency (IAEA), Vienna from December 2021 to April 2022. She has also served as the Chair of Working Group-II of the International Nuclear Security Education Network (INSEN), IAEA (2017–2019) and is a Past Chair of INSEN. Since 2022, she has been a Subject Expert for the Nuclear Security School under the ICTP–IAEA / Marie Skłodowska-Curie Fellowship Programme (MSCFP).

She currently serves as the Indian Ambassador for Women in Nuclear Security (WINS), Austria, and is a Board Member of Women in Nuclear–India. She is also associated with leading professional bodies including IANCAS, the Indian Nuclear Society, and is a Life Member of the Indian Association of Physics Teachers (IAPT). Additionally, she acts as Faculty Advisor to the AEE Amity Student Chapter.



Nuclear Analytical Techniques: Elemental Analysis for Quality – Safety of Medical Diseases and Food Resources

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Particle Induced X-ray Emission (PIXE) and Energy Dispersive X-ray Fluorescence (EDXRF) are two prominent methods among nuclear analytical techniques by which, study of inorganic elemental profile related to variety of fields/category of samples have been performed by our research group. Trace elements pertaining to normal, benign hypertrophic and cancerous tissue samples of prostate gland were analyzed by using PIXE and discussed the role of the observed elements relating to disease. Further hair samples of bipolar disorder patients were evaluated with the determined trace and macro elements due to PIXE spectra and observed their abnormal profile. Cu/Zn ratio was found to be higher relative to controls, imbalance of certain elements caused to generate more free radicals and some other elements imbalance led to reflect changes in dopamine (neurotransmitter) activity. Fe and Cu were found to be higher in hair samples of alcohol induced psychosis patients compared to normal. Higher levels of Mn, Cu, Pb, Fe and serum Mercury were found among Parkinson patients compared to age matched normal persons exhibiting corroboration with the earlier studies. Detailed variation and profile of obtained elements relating to patients and normal persons can be highlighted during presentation of the paper to understand role of elements connecting to concerned disease. Elemental analysis of spices reflected to show higher values of Cl and K in pepper while Cr higher values were observed in Anise, Dill, Cummin, and Coriander, hence these might be useful to control diabetes.

Later cereal grains, leafy and root vegetables of Ethiopia were analyzed for determination of concentration relating to observed elements reflecting contamination impact on them due to samples collected locations by using EDXRF. Further variety of coffee beans grown in Ethiopia were studied for nutritional elements variation evaluating changes in between roasted and non-roasted beans. Influence of environmental conditions on the nutritious elements of these coffee beans were also investigated. Medicinal plants, packed food items, plants having applications for perfume(s) manufacturing etc. were studied by using EDXRF and discussed about the role of different elements observed among them for understanding their quality and safety of these items.

Medicinal plants using by tribal people for different traditional diseases for curing them were studied by using EDXRF and interpreted the obtained results in terms of inorganic elements role relating to various ailments. Sea weeds and mangroves were also analyzed for their usage as a function of elements they contained. Rice, pulses and millets were studied and explained the obtained results in terms of nutritious quality for management of sustainable health; based on their macro and micro elements. These raw materials were cooked in aluminium and earth pot utensils to obtain their elemental modifications on cooking relative to raw materials. These facilitated to understand the role of container and cooking method for maintaining good health.



Fishes are highly nutritious food resource items. Marine fishes are large component among fish consumption by the consumers. But sea ports are polluted due to industrial effluents and anthropogenic garbage. There Different species of marine fishes collected during all the seasons belonging to southeastern part of India covering Visakhapatnam and Kakinada ports along with Bheemunipatnam and Pudimadaka to analyze impact of pollution on nutritional elements of marine fishes, which in turn their influence on health of these fishes' consumers.

Understanding these inorganic elements' role in the management of health facilitates to manage chronic diseases such as diabetes and hyper tension. These two ailments are usually affected by the most of the people from middle age and during these years are being appear even in the lower age. The age of fishes, season, tissue component etc. played important role in varying nutritional elements concentration. The results are inspired to develop different compositions for controlling diabetes and hyper tension by taking plants species besides spices that arise with negligible costs as those are available locally. The complete scenario of these investigations can be highlighted during the presentation of the work in the conference.



Prof. Angalakuduru Durga Prasada Rao was born in the village; Kuchinapudi that belongs to Nizampatnam Mandal of Bapatla district. He finished postgraduation in the nuclear physics department of Andhra University, Visakhapatnam in the year 1987. After finishing his M.Phil. and doctoral program joined in the same department as a faculty member in the year 1994. He obtained Master course in the field of education from the Annamalai university and in the field information technology from the Manipal University. He has been serving as a professor of nuclear physics department of Andhra University, Visakhapatnam starting his career as a member of the faculty at an early age in 1994. He is presently serving as board of chairman in the department and engaged in directing and inspiring students to find their place amongst the global competition. During 2009-16, he has served as the head of the department, during which a mega alumina meet was organized pulling around 100 eminent personalities around world. It facilitated to upgrade teaching class rooms and laboratories with their support. Project work was introduced in the 4th semester of M.Sc., course. Students were made to visit many DAE organizations namely BARC, IGCAR, VECC, RRCAT etc. During 2018-19 as Registrar of Vikrama Simhapuri University (VSU), Nellore, met the challenges of building this new University, thus worked hard to get approval from government for construction of new buildings and foundation laid for development of infrastructure. Long pending CAS was performed raising faculty satisfaction and resolved several pending service issues of non-teaching also. Proposals were submitted to the UGC for obtaining 12 (B) status. The university won NSS award at national level and received it in New Delhi. He has also been serving on the governing bodies, enquiry committees and board of studies related to reputed institutes and organizations besides government departments.

His areas of research interest include material science, applied radiation physics such as elemental analysis with nuclear techniques and medical physics. He has over 137 research publications in reputed international journals and conferences and supervised the 22 PhD and 7 M.Phil. scholars besides several M.Sc., project works. He was carried three major projects sanctioned by funding agencies, visited Japan, USA, Russia and UK for presentation of research work in the conferences. He has received BEST TEACHER award from the government of AP in the year 2025.



Nuclear Technology for Sustainable Agriculture and Environment

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Nuclear science and isotopic technologies have emerged as indispensable tools for transforming modern agriculture and addressing the interconnected challenges of food security, soil degradation, nutrient-use inefficiency, and environmental pollution. The precision offered by isotopes such as ^{15}N , ^{32}P , and ^{13}C allows researchers to track nutrient transformation, fertilizer recovery, and loss pathways with unparalleled accuracy (1). The ability to quantify nitrogen-use efficiency from chemical fertilizers, nano-fertilizers, and organic nutrient sources under real field conditions has greatly improved our understanding of nutrient dynamics. These insights help optimize fertilizer recommendations, reduce greenhouse gas emissions, and support national goals of climate-resilient and low-emission agriculture (2). Compared with traditional methods, isotope tracer approaches retain the integrity of soil–plant–atmosphere interactions, thereby providing more reliable data for sustainable nutrient management plans (3).

Mutation breeding using gamma irradiation has contributed significantly to global and national efforts in developing crop varieties resilient to drought, salinity, lodging, and diseases, while also enhancing yield potential (4). More than 3,000 officially released crop varieties worldwide have been developed through nuclear-induced mutations, highlighting the power of this technology in strengthening food and nutritional security. In India, several improved varieties of rice, pulses, oilseeds, and horticultural crops have been developed using radiation-induced mutagenesis, offering farmers robust options to cope with climate variability (5). These varieties not only enhance productivity but also reduce input requirements, thereby contributing to ecologically balanced farming systems.

Nuclear analytical techniques such as Neutron Activation Analysis (NAA), Proton-Induced X-ray Emission (PIXE), X-ray Fluorescence (XRF), and Isotope Ratio Mass Spectrometry (IRMS) provide sensitive and accurate measurement of trace elements, heavy metals, organic pollutants, and isotopic signatures in soil and water systems (6). Such measurements are essential for monitoring soil health deterioration, identifying contamination hotspots, assessing environmental risks, and designing remediation strategies. These tools also allow the quantification of soil organic carbon turnover and sequestration potential, which are particularly important for national carbon neutrality goals and sustainable land-use strategies.

Radiation technology plays an equally vital role in ensuring food safety, reducing post-harvest losses, and enabling safe trade in agricultural commodities. Gamma and electron-beam irradiation are increasingly used for disinfestation, microbial decontamination, and shelf-life enhancement of cereals, pulses, fruits, and vegetables (7). As these processes do not leave chemical



residues and maintain food quality, they are receiving global acceptance as environmentally friendly and consumer-safe alternatives. Radiation processing also supports phytosanitary compliance for export markets, strengthening India's agricultural trade potential.

In the context of environmental protection, nuclear techniques play an important role in assessing greenhouse gas fluxes, identifying nitrogen loss pathways, monitoring pesticide residues, and evaluating the long-term impact of fertilizers—including nano-fertilizers—on soil biology and ecological processes (8). These methods provide valuable scientific evidence for designing climate-smart, resource-efficient, and environmentally responsible agricultural practices.

Overall, nuclear technology offers an integrated and highly precise scientific foundation for sustainable agriculture, environmental stewardship, and climate-resilient development. Its multidisciplinary applications—from soil fertility enhancement and crop improvement to pollution monitoring and food safety—position it as a transformative driver in shaping the future of eco-friendly agriculture.

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Radiation-Modified Chitosan: A Transformative Biopolymer for Sustainable Agriculture through Gamma and Electron Beam Applications

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The transition toward sustainable and climate-smart agriculture demands eco-innovations that minimize chemical dependency, enhance crop resilience. Such innovations aim to reduce reliance on synthetic agrochemicals while improving productivity and environmental sustainability. Chitosan, a biodegradable and versatile biopolymer derived from chitin-rich seafood industry waste, has emerged as a promising biostimulant and plant defense elicitor. However, its limited solubility and high molecular weight often restrict its biological activity. Radiation technology—particularly gamma irradiation and electron beam (e-beam) processing—offers a clean, residue-free, and precisely controllable approach to modify the physicochemical and biological properties of chitosan. These processes tailor its molecular structure to produce low-molecular-weight, highly bioactive derivatives with superior solubility and biostimulant potential for climate-resilient agricultural applications.

Vasantdada Sugar Institute (VSI), Pune, Electron Beam Center (EBC), Kharghar, and Bhabha Atomic Research Centre (BARC), Mumbai, jointly developed this technology under the name “**Anuchaitanya**.” Controlled irradiation at optimized doses produces chitosan oligomers with potent elicitation capabilities.

This technology has been commercialized by VSI under the product name “**Vasant Urja**,” which is supplied to farmers across Maharashtra and adjoining states as part of sustainable agriculture initiatives. These radiation-processed derivatives exhibit strong elicitation potential by activating antioxidant enzymes, osmolyte accumulation, and defense-related gene expression in plants. Field and greenhouse evaluations across diverse crops—plantation crops such as sugarcane, turmeric, and ginger; cereals including rice, wheat, bajra, and jowar; oilseed crops such as soybean and groundnut; vegetables like potato, onion, and cabbage; fruit orchards including grape, papaya, mango and pomegranate, fodder crops & medicinal plants—demonstrate improved stress tolerance, photosynthetic efficiency, and nutrient uptake, secondary metabolite accumulation and enhanced crop productivity. Gamma irradiation provides deep and uniform penetration, suitable for large-scale modification, whereas e-beam treatment enables rapid, energy-efficient surface modification with minimal secondary waste generation. The synergistic use of both techniques allows precise tailoring of molecular size distribution and functional properties of chitosan for specific agricultural applications—ranging from foliar sprays and hydrogel formulations to nano-conjugated delivery systems.



The integration of radiation-driven valorization of seafood waste into multifunctional sustainable agricultural frameworks represents a paradigm shift toward **circular bioeconomy principles**—transforming seafood waste into high-value biostimulants through radiation science. This innovative approach not only enhances crop resilience under climate-induced stresses but also aligns with global goals for sustainable food security, environmental protection, and resource recycling.

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Dr. Sunil G. Dalvi is the Scientist at Agri. Sci. & Tech. Dept. VSI, Pune India. He leads a cutting-edge collaborative project with the **EBC, Kharghar, and BARC, Mumbai**, advancing the **radiations and nanobiotechnology** for sustainable agriculture. He has three decades worth of experience with agriculture biotechnology. He has pioneered the **development of gamma-irradiated chitosan-based nanobiostimulants**, driving innovations in **abiotic and biotic stress management, bio-circular economy, and wastewater remediation**. In recognition of his scientific excellence, he has received the **Outstanding Scientist Award** from **VSI, Pune**, and the **Best Research Marshal Award** for his ground breaking work on **chitosan applications in sustainable agriculture**. He has also earned **around 15 Best Poster Awards** at various **international conferences**, and **two of his research papers** were recognized by **Wiley Publishers** as the **most downloaded articles**, reflecting his global research impact. With **over 35 peer-reviewed publications, four book chapters**, and numerous international presentations, Dr. Dalvi continues to be a driving force in the field of **irradiation-enabled nanobiostimulant technology** for sustainable agricultural transformation.

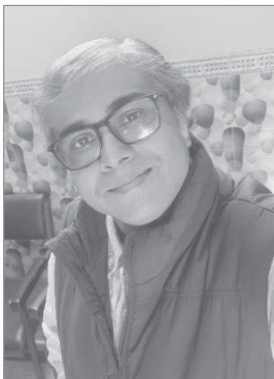


Radiation Technology in Food Preservation – Present Status and Future Roadmap

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Food is perhaps the most precious commodity on the earth as it is important for the sustainability of life. Mankind can ill afford to these losses. However, a significant proportion of the agricultural produce undergoes post-harvest spoilage involving biological and physical damages owing to various factors including insect pest infestation, contamination with microbes and other associated physiological processes. Preventing these losses is crucial not only for ensuring food security but also for narrowing the widening gap between food production and demand. This, in turn, helps maintain a balance between supply and demand, contributing to market price stabilization of agricultural commodities. Diverse chemical fumigants such as ethylene dibromide (EDB), methyl bromide (MB) and ethylene oxide (ETO), are routinely used for food preservation. But in recent times, these are getting gradually deregistered and being phased out due to their harmful impacts on the human health and the environment. This is likely to adversely affect the economics of many developing countries through undesirable effects on their exports of food commodities, unless alternate environment-friendly technologies are made available. In this context, food processing by ionizing radiation could serve as a highly effective and worthy alternative. Radiation processing stands out as a physical, non-thermal method that offers unique advantages. It effectively preserves the natural appeal, nutritional value, and functional qualities of food. In this process, food and agricultural products are exposed to a controlled dose of radiation from approved sources to achieve specific beneficial effects. Extensive efforts have been made by scientists at the Bhabha Atomic Research Centre (BARC) to harness nuclear energy for the benefit of the nation and humanity at large. This talk elaborates the technological details about food irradiation and highlights the success story of India's national food preservation program, which employs radiation technology as an effective and eco-friendly alternative to conventional chemical preservatives and fumigants.



Dr. Bhaskar Sanyal joined Food Technology Division, BARC after M. Sc in Physics and post M. Sc Diploma in Radiological Physics in 2002. His research interest lies in radiation measurements and detection of irradiated food. He was awarded Ph. D from HBNI, Mumbai in 2012 followed by post-doctoral fellowship in Kyungpook National University, South Korea. Presently he is Head, Food Engineering Section, FTD, BARC and Associate Professor, HBNI. He has published 60 papers in peer reviewed journals, and a large number of presentations in national and international conferences. He is recipient of AERB merit award, 2002; DAE Group Achievement award, 2007 and DAE Science & Technology award, 2020.



Advancing Global Benefits: The IAEA's Impact on Radioisotope and Radiation Technology Applications

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Radioisotopes and radiation technologies play a critical role in advancing health care, industrial efficiency, environmental protection, and cultural heritage preservation. The International Atomic Energy Agency (IAEA) supports Member States in maximizing the benefits of these technologies by fostering innovation, strengthening safety and quality frameworks, and enabling the translation of scientific advances into practical, real-world applications.

In health, the IAEA advances radioisotope production and radiopharmaceutical development by promoting novel and optimized production routes that enhance supply security and system resilience. Through the establishment of a Technical Working Group on Radiopharmaceuticals and close collaboration with the World Health Organization, the Agency contributes to internationally harmonized quality standards, supporting regulatory convergence and the safe clinical use of radiopharmaceuticals. These efforts facilitate the transition of advanced preclinical research into routine clinical practice.

Across industry and the environment, radiotracer and radiation techniques provide non-intrusive, high-precision tools to optimize industrial processes, support environmental remediation, and enhance quality control. The IAEA also strengthens national capacities in non-destructive testing, enabling reliable assessment of critical infrastructure and supporting rapid, safe decision-making in post-disaster and emergency situations.

Additional applications include healthcare sterilization, cultural heritage preservation, radiation-based environmental treatment, and polymer modification, including plastic waste upcycling under the NUTEC Plastics initiative.

A recent milestone is the IAEA Transportable Electron Beam System, which expands access to advanced radiation technologies through a modular, deployable platform for research, training, and demonstration. By lowering barriers to access while enhancing safety and security, the system exemplifies the IAEA's commitment to responsible technology deployment.

Overall, the IAEA integrates scientific excellence, technology transfer, and international collaboration to translate innovation into tangible, long-term benefits for its Member States.



Ms Celina Horak is Section Head of the Radiochemistry and Radiation Technology (RCRT) Section at the International Atomic Energy Agency (IAEA), where she leads international programmes advancing the practical deployment of radiation and nuclear technologies across the medical, industrial, and environmental sectors.

Drawing on 27 years of senior leadership at the Argentina National Atomic Energy Commission, she has worked extensively with industry and regulators to translate radiation science into safe, scalable applications. Her contributions include shaping sterilization technologies, supporting updates to the national Codex Alimentarius, and advancing GMP and radiation standards for medical devices and biological tissues, with impact on both national and international regulatory frameworks.



Operational Experience at the Gamma Irradiation Facility in Azerbaijan

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The Gamma Irradiation Facility of the Innovation and Digital Development Agency operates a panoramic Co-60 irradiator that provides radiation-based sterilization, decontamination, material processing and preservation services across medical, food, cultural and industrial sectors in Azerbaijan. This presentation provides an overview of the facility's operational framework, including process management, workflow coordination and key procedures that ensure consistent and reliable radiation processing. The presentation also reviews ongoing enhancement efforts designed to optimize operational efficiency and increase processing throughput. The insights shared reflect the growing role of radiation processing technologies in meeting industrial and scientific needs in the country.



Mr. Zaur Khalilov is the Head of the Gamma Irradiation Division at the Nuclear Research Department of the Innovation and Digital Development Agency, Azerbaijan. He manages the operation and development of the gamma irradiation facility and supports the expansion of radiation processing technologies for industrial, medical and scientific applications. He has significant expertise in irradiation operations, dosimetry and facility management, and has been involved in national and international development projects, including IAEA Technical Cooperation initiatives.



Radiotracer-Based Analysis of Flow Anomalies in Continuous Pulp Digesters

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Flow irregularities in industrial-scale pulp digesters were examined using radiotracer-based Residence Time Distribution (RTD) measurements. The RTD measurement technique plays a vital role in troubleshooting, understanding flow behavior, and optimizing operating parameters in both industrial and laboratory-scale systems. Owing to its many advantages such as high sensitivity, real-time flow tracking, minimal process interference, and reliable measurements under demanding industrial conditions, the radiotracer method offers a superior alternative to conventional tracers for large-scale RTD studies. As a result, it enables more accurate assessment and optimization of flow parameters, eventually improving process efficiency and plant performance. A series of RTD experiments were conducted on pulp digesters at two pulp and paper industries in Punjab, India. Bromine-82 (^{82}Br), Gold-198 (^{198}Au), and Technetium-99m ($^{99\text{m}}\text{Tc}$) were used as radiotracers to evaluate the RTD of continuous pulp digesters under various operating conditions. Initially, ^{82}Br (as ammonium bromide) and ^{198}Au (as chloroauric acid) were applied to a three-tube continuous pulp digester, followed by the use of $^{99\text{m}}\text{Tc}$ (as sodium pertechnetate) for two-tube digesters. In each measurement, an impulse of radiotracer was injected at the inlet of the first tube, and its concentration in the liquid phase was monitored at various locations along the digester. These studies enabled detailed observation of fluid-phase behavior and facilitated optimization of operating conditions. Additionally, two identical digesters consisting of two-tube were evaluated and compared using RTD measurements. The effective volumes of the digesters were estimated and compared with theoretical design specifications. A numerical convolution approach was employed to correct for the non-ideal pulse input of the radiotracer at the inlets of the second and third tubes of the digesters. To interpret the RTD data, established models such as the axial dispersion model with a plug-flow component and the tanks-in-series model with back-mixing were applied. Analysis of the measured RTD curves helped to identify flow characteristics, the degree of dispersion, and various flow abnormalities within the digester systems. The insights gained from this work provided practical recommendations that contributed to enhancing the overall operational efficiency of the plants.

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Dr. Avinash Chandra is a Professor and Head of the Department of Chemical Engineering at Thapar Institute of Engineering & Technology, Patiala, India, with nearly two decades of teaching and research experience. He earned his Ph.D. in Chemical Engineering from IIT Kanpur and holds an M.Tech. from HBTI Kanpur and a B.Tech. from IET Lucknow. He has also completed a PG Diploma in Operations Management, a Certificate Course in Radiation Safety from BARC, Mumbai, and a Certificate Program in Responsible Artificial Intelligence, reflecting his engagement with ethical and data-driven engineering practices. His research interests include fluid dynamics, heat and mass transfer, transport in porous media, non-Newtonian fluids, computational fluid dynamics (CFD), industrial-scale residence time distribution (RTD) analysis using radiotracers, polymer coatings, biofuels, and the application of data science in chemical engineering. Dr. Chandra has led and contributed to several sponsored projects funded by DAE-BRNS, UGC, DRDO, and industry partners. He has published extensively in reputed international journals, holds a granted international patent, and has served as Guest Editor for leading journals. A recipient of multiple awards and travel grants, he actively collaborates with national and international research organizations and convened SDCEE-2024.



Radiotracers as tools for studying synthetic polymer membranes and membrane-based processes

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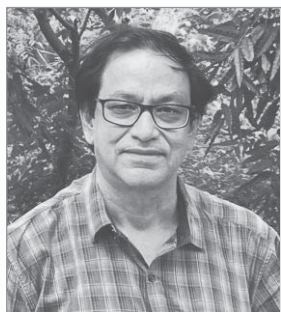
Radiotracers derive their significance from the use of extremely small quantities of radioisotopes (10^{-16} – 10^{-6} g), employed either directly or in the presence of a large excess of their stable isotopes. They function both as qualitative markers for tracing process pathways and as quantitative probes for determining the behaviour, distribution, and kinetics of non-radioactive species. Their exceptionally high detection sensitivity, often up to five orders of magnitude greater than conventional analytical techniques, enables precise measurements at ultra trace levels. Because isotopes of a given element exhibit identical chemical behaviour, radiotracers remain chemically invariant during physical, chemical, and biological transformations, ensuring reliable and interference-free monitoring. A wide range of radiotracers can be employed depending on the system under investigation. These include β -emitters such as tritiated water ($^3\text{H}_2\text{O}$) for studying water transport and hydration phenomena, several radiolabelled ions for ion-exchange and diffusion studies, and γ -emitting isotopes generated in situ by neutron activation of membrane materials or permeating species [1-6]. Among these, tritiated water is particularly important, as it enables direct probing of molecular water mobility within polymer matrices. Radiotracer techniques provide real-time, non-invasive, and highly specific information on molecular transport, reaction pathways, mixing behaviour, and flow dynamics [1]. Notably, radiotracers offer the only direct experimental method for measuring self-diffusion coefficients, which are otherwise inaccessible through conventional macroscopic diffusion or permeability measurements. In synthetic polymer membranes, radiotracer studies yield unambiguous insights into diffusional properties, selectivity, membrane homogeneity, micro environmental effects, dynamic interactions between ions, solvents, and the polymer matrix, as well as tortuosity of diffusion pathways. These capabilities make radiotracers indispensable tools for the rational design and optimization of membrane materials for technologically and commercially important membrane-based processes. Radiotracers have been used for studying membrane-based processes such as direct observation of vanadium ion permeation behavior through Nafion 117 using ^{48}V radiotracer for all-vanadium redox flow battery, membrane fouling, diffusion dialysis, membrane installations investigation, examination of hydrodynamic conditions in membrane separation modules, etc [7-9]. The radiotracers have also been used for understanding the formation and growth of noble metal nanoparticles in ion-exchange membranes, along with other complementary techniques. Similar radiotracer-assisted approaches have been successfully applied to environmentally relevant separation materials, such as chitosan-based composite beads for heavy metal removal from aqueous solutions, demonstrating their versatility beyond conventional membrane systems [10]. The evolution of the growth of silver nanoparticles in the ion-exchange films has been studied using a combination of $^{110\text{m}}\text{Ag}$ radiotracer, small-angle X-ray scattering (SAXS) experiments, and transmission electron microscopy (TEM) [11]. The radiotracers



offer unique possibilities for understanding synthetic polymer membranes, which helps in designing membranes for desirable applications with technological and commercial importance. The information about the diffusional properties, selectivity, homogeneity, microenvironment, dynamic interactions of the ions/solvent/species with membrane matrix and tortuosity in the diffusion path, etc., can be obtained unambiguously with appropriate experimental designs using radiotracers.

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Radiotracer-Based Residence Time Distribution Studies in Industrial Reactor Systems

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Residence time distribution (RTD) analysis is a widely used diagnostic tool in chemical reaction engineering, as it provides quantitative information on the flow behavior of process equipment under actual operating conditions. Although reactors are typically designed to approximate ideal plug flow or perfectly mixed flow, real industrial systems almost invariably deviate from these ideal conditions due to flow abnormalities such as bypassing, stagnant or dead zones, and channeling, which can adversely affect conversion, selectivity, and overall process efficiency [1,2]. RTD measurements based on stimulus–response experiments are therefore extensively used to identify and quantify such non-idealities and to support reactor diagnosis, optimization, and scale-up [1,2].

Conventional tracer techniques employing dyes, salts, or chemical tracers are generally limited to laboratory-scale systems and are unsuitable for large-scale industrial equipment due to poor sensitivity, difficulty in online detection, and incompatibility with harsh process environments [3-5]. Radiotracer techniques overcome these limitations and offer distinct advantages such as high detection sensitivity, in-situ and online measurement capability, physico-chemical compatibility with process fluids, and applicability to complex flow systems with recycle and recirculation [6]. As a result, radiotracer-based RTD studies have been successfully applied to a wide range of industrial reactors and process equipment; however, experimental investigations on large-scale systems with high recycle ratios remain relatively limited [7-10].

This talk presents radiotracer-based RTD investigations carried out on industrial ethyl acetate reactor systems consisting of two reactors connected in series and operating with large recycle ratios and external mixing through recirculation. In these systems, mechanical agitation was absent, and mixing was achieved solely by high recirculation flow rates. Bromine-82, injected as ammonium bromide, was used as the radiotracer, and the tracer response was monitored using external scintillation detectors placed at appropriate locations along the process lines.

The first set of industrial RTD experiments showed that recirculation rate had a significant influence on flow mixing behavior and mean residence time (MRT) of the reactor system. Analysis of the experimental RTD curves revealed appreciable bypassing of process fluid in the first reactor, along with the presence of a large stagnant volume exchanging material with the active volume, while the second reactor behaved close to an ideal CSTR over the operating range studied. Variations in recirculation flow were also found to directly affect the MRT of the overall reactor system.



Following modifications in reactor configuration to accommodate future capacity expansion, a second set of radiotracer RTD measurements was performed on the revamped system. These studies demonstrated altered hydrodynamic behavior, including changes in bypass and stagnant volume fractions, highlighting the strong influence of reactor geometry and orientation on macromixing characteristics.

To complement the industrial investigations, RTD experiments were conducted on a laboratory-scale recycle reactor with controlled recycle and recirculation rates. These experiments enabled systematic evaluation of the effects of recycle on MRT, bypassing, and stagnant volume. A phenomenological RTD model was developed and solved numerically using a fourth-order Runge–Kutta method, and the model predictions showed good agreement with experimental data. The qualitative consistency between laboratory-scale and industrial-scale results further reinforces the robustness of radiotracer-based RTD analysis for complex recycle reactor systems.

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Dr. Arghya Datta is currently serving as an Assistant Professor in the Department of Chemical Engineering at the National Institute of Technology Raipur, Chhattisgarh. He received his PhD from Thapar Institute of Engineering and Technology, where he carried out extensive radiotracer-based residence time distribution (RTD) investigations on industrial-scale recycle reactor systems in close collaboration with scientists from Bhabha Atomic Research Centre (BARC) under a BRNS-sponsored project. His work involved the design and execution of on-plant radiotracer experiments, RTD modeling, and quantitative diagnosis of flow abnormalities such as bypassing and stagnant zones without plant shutdown. He has completed his post-doctoral work from SSS National Institute of Bioenergy (An autonomous research institute of Ministry of New and Renewable Energy) where he worked on three projects of National Importance under SAMARTH Mission of Government of India. He has authored 12+ journal papers and six book chapters, and is currently guiding three PhD scholars and one master's student. His research interests include radiotracer applications, reactor hydrodynamics, biomass thermochemical conversion, and process optimization for energy systems.



Isotopic Separations at Heavy Water Board

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Heavy Water Board (HWB) primarily mandated for production of Deuterium oxide, commonly known as Heavy Water, produced by separation of Deuterium from Hydrogen and its enrichment to nuclear grade, suitable for its use as coolant and moderator in Pressurised Heavy Water Reactors (PHWR).

Isotope separation methods commonly consist of Diffusion, Distillation, Centrifugation, Thermal Diffusion, Exchange reactions, and Electrolysis, which are employed on case-to-case basis to achieve sizable degree of separation and further enrichment. HWB is engaged in separation of isotopes of Hydrogen, Boron and Oxygen and employed processes like Chemical exchange, Distillation and Electrolysis on industrial scale, as the other viable processes were not found economical for a larger scale industrial facility. HWB also employed multiple isotopic separation techniques to achieve extraction and enrichment of given isotope based on optimized Separation duty. Accordingly, cascade theory is adopted for designing and operation of isotopic separation facilities. HWB has successfully implemented H_2S-H_2O and NH_3-H_2 based chemical exchange process facilities for production of Heavy Water on industrial scale.

Hydrogen is having three isotopes, i.e. Hydrogen, Deuterium, and Tritium, where Hydrogen and Deuterium are stable isotopes and Tritium is radioactive. Natural abundance of Deuterium is around 150 ppm $D/(D+H)$ a/a Isotopic purity (IP), in Hydrogen and its naturally occurring compounds. The Deuterium is enriched through a chemical exchange process upto a sizable IP and then exposed to Vacuum Distillation for final enrichment upto Nuclear grade Heavy Water.

Boron is having two stable isotopes i.e. B-10 and B-11, where B-10 natural abundance is around 20 % a/a IP. Since many of the Boron compounds are in solid form in ambient conditions, it is necessary to select certain specialty compound for achieving isotopic separation of B-10 and B-11 through conventionally available Isotope separation methods. Accordingly, Boron trifluoride-diethyl ether complex, commonly known as BF_3 -complex is employed for isotopic separation and further enrichment. HWB is equipped with facilities for converting the BF_3 complex into useful B-10 enriched compounds required for Fast Breeder Reactor program.

While, B-10 enriched compounds finds application in Nuclear field, B-11 which, is getting simultaneously enriched during B-10 enrichment, finds applications in the field of Semi-conductor industry. HWB is exploring potential to support Indian Semi-conductor industry by sourcing the B-11 compounds for production of B-11 enriched BF_3 gas required for doping of semi-conductor chips and other such applications. Isotopic separation technique utilized is Exchange Distillation of BF_3 complex. HWB is equipped with facilities for converting the BF_3 complex into useful B-11 enriched compounds required in Semi-conductor industries.



Oxygen is having three stable isotopes i.e. O-16, O-17 and O-18 with their natural abundance as 99.763%, 0.037%, and 0.200% respectively. O-17 has application in biomedical research where determination of cerebral metabolic rate of oxygen utilization is monitored by assessing the changes of metabolically generated H_2^{17}O in brain tissue from inhaled ^{17}O -labeled oxygen gas. O-18 enriched water finds application in the field of nuclear medicine and biomedical research. 10 % O-18 enriched water finds applications in human metabolism studies and > 97 % O-18 enriched water is used as precursor of F-18, used in detection and staging of cancer / malignancies using Positron Emission Tomography (PET) scanning. Vacuum distillation of water is adopted for achieving desired concentration of O-18 isotope. The product O-18 water at end of distillation cascade usually gets simultaneously enriched with Deuterium. The desired product for F-18 synthesis is H_2^{18}O . Hence, the Deuterium is replaced with Hydrogen using combination of electrolytic splitting & catalytic recombination.

HWB has taken-up augmentation of O-18 water production to support imaging / PET scanning in the country and aims to make such facilities affordable to a common man and benefit society at large. There will be possible export avenues, which would support FOREX generation. Such efforts would aim to achieve self-reliance and Atmanirbharta in medical imaging field.



Shri Ajit R. Dusane is B. Tech, Chemical Engineer, joined Heavy Water Board, in 1998. He worked at HWP-Manuguru for first year from his joining and later worked extensively on Energy conservation and Plant operating performance monitoring activities at HWP-Tuticorin. He is having vast experience in both $\text{H}_2\text{S}-\text{H}_2\text{O}$ and NH_3-H_2 chemical exchange process and vacuum distillation of off-grade water for production of Heavy Water. He has been instrumental in process development for Oxygen-18 enriched water technology and was actively involved in design and development of India's first H_2^{18}O plant at HWP-Manuguru. He has steered several ambitious projects of HWB. Presently, he is holding post of Additional Chief Engineer (Project) and looking after mega projects of HWB. As Unit Project Coordinator, he is also coordinating all the capital projects of HWB. He is actively involved in Restart-up activities at HWP-Tuticorin, Production of Deuterium labelled compounds at HWBF-Vadodara, Developmental activities for production of nuclear grade Sodium, Setting-up of augmented O-18 water production facility at HWP-Manuguru and Heavy Water Augmentation projects to meet Amritkal vision - 2047.



BEYOND: Optimized, mature, and reliable X-ray and E-beam irradiation solutions

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More than 60 Rhodotron® systems are currently in operation worldwide, with over 20 additional units under construction or planned. The technology has reached full industrial maturity, with stable performance across a wide power range and proven suitability for both E-beam and X-ray applications.

Beyond® solutions were developed to maximize the Rhodotron® performance by optimizing the entire irradiation chain. Product geometry, packaging configuration and material density are evaluated together with transport, loading and conveying parameters to ensure efficient dosimetry and high throughput. Analytical models and advanced Monte Carlo simulations are used to determine optimum beam parameters and processing layouts, with a focus on dose uniformity ratio, electrical efficiency and overall cost effectiveness.

Recent industrial deployments have demonstrated consistent agreement between simulations and on-site measurements for both E-beam and X-ray lines. Sensitivity studies of X-ray processes have identified critical parameters influencing dose distribution and throughput, and dedicated hardware improvements have been implemented to ensure stable and optimal processing conditions.

With a large installed base and an extensive support ecosystem worldwide, Beyond® solutions now provide a mature, validated and fully engineered platform for high-performance industrial irradiation.

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Dr Raphaël Van Roermund is the Head of Product Management at IBA Industrial Solutions. He is responsible for defining product solutions for medical devices sterilization, food irradiation and phytosanitary irradiation. Before joining IBA Industrial in 2025, he has worked for 14 years in Proton Therapy, helping deliver solutions for cancer treatment. He holds a Ph.D. in physics and two master's in engineering and physics.



High Throughput Integrated Irradiation Processing Facility for Agro and Food Products

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Gamma Irradiation in India has a seemingly permanent untapped potential, especially when it comes to food and agricultural products. India is a temperate country with a very significant agricultural sector that suffers from heavy losses, spoilage and export rejection of its produce. Gamma Irradiation in India is a fully indigenized technology with globally competitive setup and operational costs, and can play a major role in reducing losses, spoilage and rejection of Indias food products.

However, despite the existing technological capability and the definitive market need for this technology, Gamma irradiation has not been used to treat food and agro products in any significant manner in India so far. This is primarily because of ingrained issues in the supply chain and financial model, including the high logistics and handling costs, requirement of high-volume processing of more than 30 tons/hr and lack of proactive government policy in this area.

This presentation aims to provide a solution to two of the main problems – Handling and Scale. The presentation provides a versatile design solution for a gamma irradiation facility for high volume irradiation of food and agro products in all their different forms. The design aims to treat products in loose bulk form, Packed HDPE bags, Plastic Crates, Pallets, FIBC bags etc and aims to minimize handling and transfer costs while providing large volume throughputs so as to bring the processing costs down to economical levels.

For this concept to be successful however, it is vital that the irradiation facility be integrated with necessary pre- irradiation processing infrastructure and post irradiation processing storage infrastructure and thus it is necessary to build a fully integrated solution that can handle a wide range of products in a single facility.



Ananth Vas is one of the directors of Symec Engineers (India) Pvt Ltd. Symec is a supplier of gamma irradiation and electron beam irradiation machinery in India. He has a Master Degree in Mechanical Engineering from Drexel University, USA and an MBA in Finance and Marketing from the Indian School of Business, Hyderabad. He has been the director of Symec Engineers since 2008 and has over 20 years of experience in the irradiation industry in India and has been involved in more than 15 gamma irradiation and one electron beam irradiation projects apart from numerous other projects involving radioactive materials handling and process equipment.



RadiTech Hydromatics Pvt. Ltd.: Integrated Solutions in Radiation Technology, Process Automation, and IPH Infrastructure

Subhasis Bhattacharya, Managing Director

RadiTech Hydromatics Pvt. Ltd.
10/23A Siddhinath Chatterjee Road, Behala, Kolkata-700034

RadiTech Hydromatics Pvt. Ltd, founded by Mr. Subhasis Bhattacharya (Managing Director), is a trusted and well-established organization in the field of Radiation Technology, Process Automation, and Integrated Material Handling Systems. The company builds upon more than two decades of technical expertise, innovation, and industry experience cultivated through Mr. Bhattacharya's leadership and his earlier role as Founder Director of Danver Hydromatics Pvt. Ltd.

The seamless integration of Danver's experienced technical team into RadiTech ensures continuity in engineering excellence, service quality, and long-standing client relationships. This strategic transition has further strengthened RadiTech's capability to deliver reliable, high-performance, and customized turnkey solutions.

RadiTech offers end-to-end solutions for Radiation Processing Plants, including multipurpose and research irradiators, hot cells, customized radiation equipment, radiography cameras, and transport and storage containers with lead pouring. The company also specializes in conveyor systems integrated with PLC- and SCADA-based process automation, tailored to meet the stringent operational and safety requirements of radiation facilities and industrial processing plants.

Main Products & Services

- *Irradiators (Multipurpose & Research)*
- *Fabrication of Radiography Cameras*
- *Fabrication of Transport & Storage Containers with Lead Pouring*
- *Hot Cells*
- *Customized Radiation Equipment*
- *Conveyor Systems with Process Automation (PLC & SCADA)*
- *Integrated Pack Houses for Fruits & Vegetables*

With complete in-house capabilities, RadiTech undertakes the design, manufacturing, installation, and commissioning of customized roller and overhead conveyor systems. Its scope of work includes control panel engineering, instrumentation, cabling, system integration, testing, commissioning, and performance validation, ensuring seamless automation, enhanced safety, and reliable plant operation.



The application of Radiation Technology in the Food Processing and Agro Industry in India is steadily increasing; however, its full potential especially when integrated with an efficient cold chain remains underutilized. RadiTech addresses this gap by providing comprehensive design consultancy and project facilitation services for multipurpose cold storage facilities and integrated pack houses for fruits and vegetables. The company's services cover concept planning, system design, technology selection, supply coordination, installation, and commissioning, enabling effective integration of radiation processing with cold chain logistics.



Shri Subhasis Bhattacharya is a Mechanical Engineer with specialized expertise in Radiation Processing Technology, special-purpose machinery, material handling and conveying systems, industrial hydraulics, pneumatics, and process automation. He entered the field of Radiation Technology in 2002 and was instrumental in commissioning India's first private radiation processing plant in Kolkata in 2004. Since then, he has actively contributed to the promotion and propagation of radiation technology in India and abroad through technical papers, presentations, and participation in national and international forums. In recognition of his contributions, Mr. Bhattacharya received the NAARI Appreciation Award in 2010 and is a Life Member of the National Association for Applications of Radioisotopes and Radiation in Industry (NAARRI).



EPR Spectrometer SPINSCAN X: An Open Research and QC Platform for EPR Dosimetry Applications

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The growing demand for versatile and reliable instruments in radiation dosimetry has driven the development of optimized measurement protocols for the SPINSCAN X EPR spectrometer, enabling accurate and reproducible dose assessment over a broad absorbed dose range from 1 Gy to 100 kGy (1). This bench-top system, developed by Linev Systems, supports a wide range of applications, from industrial radiation sterilization and routine QC to dosimetric control in radiotherapy (2), as well as advanced research focused on the identification and investigation of novel radiation-sensitive paramagnetic materials for EPR dosimetry (3).

Flexibility and a strong focus on research applications are integral to the spectrometer's architecture. The integrated software environment allows extensive customization, including adjustment of EPR signal processing parameters and implementation of custom data analysis algorithms via a scripting framework. In addition, a comprehensive database enables secure storage, auditing, and analysis of experimental data, facilitating reproducibility and long-term traceability. This infrastructure supports adaptation to specific laboratory protocols and compliance with relevant ISO standards and regulatory frameworks such as FDA guidelines.

The experimental evaluation of SPINSCAN X in low-dose measurements using alanine EPR dosimeters addressed key performance metrics, including sensitivity limits, dose measurement accuracy, and repeatability and reproducibility (1, 2). Special attention was given to signal quality under low signal-to-noise ratio conditions, requiring careful optimization of spectrometer settings and signal processing procedures, including methods to compensate for signal fluctuations caused by temperature and humidity. Particular emphasis was placed on the long-term stability of the system, critical for reliable dosimetric control in radiotherapy (3).

Overall, the bench-top SPINSCAN X EPR spectrometer has been shown to be a unique instrument, serving as a routine QC tool and an open research platform for the investigation of alternative paramagnetic materials with potential applications in the low-dose range (4). Its open architecture, adaptability, and integrated database make it well suited for the development and validation of new methods, comparative studies, and the solution of applied problems, including those related to regulatory requirements in radiation safety (2,3).

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Contributory Abstracts



Contributory Abstracts

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P2	Dose Uniformity and Shielding Assessment of Proposed Indigenous Multi-purpose Co Gamma Irradiator <i>Sridhar Sahoo, T. Palani Selvam, Dhiren Sahoo, B.K. Sapra</i>
P3	Degradation of Chloramphenicol using gamma irradiation <i>Ashika Debbarma, Prashant K. Mishra, Aarti S. Kakatkar, Raj Kamal Gautam, Vivekanand Kumar, Suchandra Chatterjee</i>
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P6	Aerial, an irradiation platform for R&D, education and dissemination of the benefits of electron accelerators. Case study of the dose rate effects in the framework of the radiation sterilization <i>N. Ludwig, F. Kuntz, A. Nasreddine, and A. Strasser</i>
P7	Space Applications at the ENEA Calliope Gamma Irradiation Facility <i>A.Cemmi, R. Carcione, B. D Orsi, I. Di Sarcina, J. Scifo</i>
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P13	Use of hurdle technology with radiation processing for shelf-life extension of minimally-processed tilapia (<i>Oreochromis spp.</i>) <i>Raj Kamal Gautam, Aarti S. Kakatkar, Ashika Debbarma Prashant Kumar Mishra, Vivekanand Kumar, Shashidhar, R. & Suchandra Chatterjee</i>
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P16	Dose mapping studies in category IV commercial food irradiation facility for phytosanitary treatment of fruits using BARC-ANUDOSE dosimeter <i>V. Prakasan, Bhaskar Sanyal and S Gautam</i>
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P38	¹⁸F-FDG Radiosynthesis using three Sep-Pak® Plus ALOX-N and One C 18 Plus Sep-Pak®: Radiosynthesis, Quality Control & Bio-Evaluation <i>Saikat Nandy, Junaid Bashir, Sutapa Rakshit, Yogita Shete & Nawab Singh Baghel</i>
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P41	Optimizing the capacity of the delay tank to safely dispose of the excreta of I-131 patients in a two-bed radioiodine therapy ward. <i>S.V. Ramanamurthy, K.B. Sricharan¹, K.J.U. Sekhar, K. Raja kumar¹, Sanjaykumar, G.J. Nagaraju</i>
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P44	Optimization of Radiolabeling & assessment of In-Vitro stability of [¹⁷⁷Lu] Lu-DOTA-Girentuximab targeting CA-IX in Renal cell Carcinoma <i>Sudeep Kumar Sahu, Swapna J Nabar, Sangita Lad, Aanchal Chawla, Sandip Basu</i>
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P99	Regulatory Inspection of Radiation Facilities in India <i>J.V.K. Sunil Kumar, Naushad N.</i>
P100	Characterization of Radiation Absorption Behaviour of Banana Leaves and Stems for Green Shielding Solutions <i>Astha Jain, Arpita Datta, Alpana Goel</i>



Design and Optimization of a Miniature Electron Gun for Compact X-ray Source Applications

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Miniature X-ray sources are gaining importance in medical diagnostics and cancer radiotherapy due to their safety and portability. A key advantage of this technology is the absence of radiation when inactive, eliminating radioactive waste and transportation concerns. The primary scientific challenge lies in designing an electron gun with a small beam spot and short focal length, enabling close placement of the object under test. While extensive research has focused on cathode development globally, limited efforts have been directed toward compact X-ray device design [1]. In this work, a miniature electron gun has been systematically designed and optimized using 3D simulation software [2]. Electrons emitted from the cathode are focused electrostatically by a focusing electrode held at cathode potential. The beam is then accelerated by a 10 kV electric field and directed onto a high atomic number anode target, generating X-rays that are transmitted to the object with a controlled dose rate. The geometry of the focusing electrode critically influences the final beam spot size at the anode. Through iterative simulation, the beam diameter was reduced from 1.97 mm to 0.13 mm. To ensure device reliability, electric stress analysis was conducted to prevent high-voltage breakdown. The final device configuration is a cylindrical structure measuring 9.5 mm in diameter and 75 mm in length, with a conical section directing the beam onto a 1 mm diameter tungsten disk. This compact design marks a significant step toward deployable, low-risk X-ray sources for healthcare applications.

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Dose Uniformity and Shielding Assessment of Proposed Indigenous Multi-purpose ^{60}Co Gamma Irradiator

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Board of Radiation and Isotope Technology (BRIT) has proposed a low-cost affordable multi-purpose gamma irradiator for medium dose application. The plant is designed to irradiate multiple products such as spices and allied products, marine products, fruits and vegetables etc. The irradiation cell will be surrounded by cylindrical concrete structure of thickness 170 cm. The source cage consists of two frames each containing 12 number of pencils amounting to 250 kCi. The product boxes will move around the source frame (see **Figure 1**) in a circular orientation.

Monte Carlo methods were applied to calculate: (a) dose distribution in the product boxes of densities 0.6, 0.8 and 1.0 g/cm³ (these densities represent different products), and (b) radiation levels around the concrete shielding. Product boxes of dimensions (50 x 50 x 70 cm) and (40 x 50 x 70 cm) were simulated. **Table 1** presents the maximum, minimum dose rate values and Dose Uniformity Ratio (DUR) for the investigated product densities of the product boxes. The statistical uncertainties on the calculated dose rates are in the range of 0.5 - 3%. Smaller box size results in marginal improvement in DUR. The leakage radiation levels around the concrete shield are within the permissible level of 1 $\mu\text{Sv/h}$.

Table 1. Maximum (D_{max}), minimum (D_{min}) dose rate values and dose uniformity ratio for different product densities and in product boxes of (50 x 50 x 70 cm) and (40 x 50 x 70 cm).

Sr. No.	Density (g/cm ³)	50 x 50 x 70 cm			40 x 50 x 70 cm		
		D_{max} (kGy/h)	D_{min} (kGy/h)	DUR	D_{max} (kGy/h)	D_{min} (kGy/h)	DUR
1	0.6	3.06	1.63	1.88	3.72	2.01	1.85
2	0.8	2.98	1.38	2.16	3.63	1.74	2.09
3	1.0	2.80	1.13	2.48	3.52	1.52	2.32

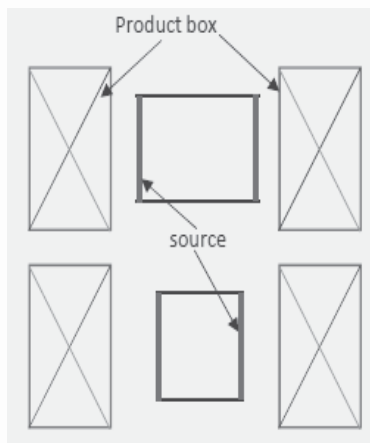


Figure 1. Schematic diagram of source and product box arrangement in the plant.

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Degradation of Chloramphenicol using gamma irradiation

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Globally antibiotics consumption has increased by 46% in the past 20 years in terms of defined daily doses (DDD) per 1000 inhabitants per day. Recent studies have shown that water, soil and foods such as fish are contaminated by different antibiotic residues. Fish samples were also found to be contaminated by Chloramphenicol (CAP) which is banned in food items raising major health concern for consumers [1]. CAP is a broad-spectrum antibiotic with known potential fatal side effects, including suspected carcinogenicity and toxicity in sensitive individuals [2]. Hence, present study focused on the effect of different processing methods on CAP. Heat treatment, Autoclaving and gamma irradiation was used for degradation of CAP. Heat treatment of 100 °C for 15 min and autoclaving showed no significant degradation, while 4 kGy absorbed dose resulted in 90% degradation of CAP (50µg/ml). The major degraded compounds were m/z 169 (R_t 1.98 min), m/z 155 (R_t 5.6 min), m/z 183 (R_t 6.5 min), m/z 354 (R_t 6.8 min) and m/z 336 (R_t 8.3 min) identified using LC-MSMS. The degraded compounds showed no antimicrobial activity when tested against different food borne pathogens. Loss of mutagenic activity was also observed in degraded compounds. The degraded compounds did not show any toxicity when tested against human cell line TK6 using MTT assay. Further, gamma radiation of 4 kGy showed 73.85 ± 0.03 % degradation of CAP residues (5µg/g) in spiked fish. All the results suggest that gamma irradiation can be a sustainable preservation method for fish which can degrade the antibiotic residues present in it.

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Effect of Pre and Post Fabrication Gamma Irradiation on NaOH-APTES Treated Hemp and Grewia optiva Fiber Reinforced PLA Composites

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Gamma irradiation is a sustainable method for modifying natural fibers to improve the effectiveness of biodegradable materials. This research investigates the effect of dual stage gamma irradiation on chemically treated PLA-Hemp-Grewia Optiva based hybrid biocomposite to improve interfacial bonding. Fibers were first treated with alkaline (NaOH) at concentrations of 5%, 10% and 15%, then further modified with silane by 3-aminopropyltriethoxysilane (APTES) at 3%, 4% and 5%. After chemical treatment, fibers were gamma irradiated before fabrication at three dose levels of 5, 15 and 30 kGy to activate the fiber surface, which enhances the silane grafting onto the fibers [1, 2]. After the fabrication of composites, the PLA hybrid composites were again gamma-irradiated at very low doses of 3, 5 and 7 kGy to improve surface quality and mechanical performance further [2, 3] with no matrix degradation. Mechanical characterization, along with SEM and FTIR analyses, indicated that synergistic dual gamma treatment greatly enhanced the adhesion between the fiber and matrix, the surface morphology and improved the strength of the composite material. Gamma pre-irradiation before the composite fabrication effectively enhanced the interfacial bonding, while gamma low dose post- irradiation contributed to the refinement of the surface properties and modest mechanical performance. These gamma treated PLA hybrid composites are potential materials for eco-friendly agricultural implements such as biodegradable sickle handles and light duty components as well as for biodegradable packaging and sustainable construction materials. This research indicates how radiation processing can be safely incorporated into the evolution of high performance, biodegradable engineering materials, supporting India's initiatives toward safe radiation applications and sustainable manufacturing.

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Innovative Gamma Irradiator for Medium Dose Application - A step towards Food Security and Sustainable Development

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Majority of the conventional land-based gamma irradiators (category IV) are typically designed for source activities in the range of 1–2 MCi of Co-60, incorporating a 2 × 2 pass concrete labyrinth for shielding and access [1,2]. These systems are primarily intended for high-throughput industrial applications, and their commissioning involves a capital investment of approximately ₹20-25 Crore. It has been observed that despite their capacity, many such facilities generally operate at a low occupancy factor, indicating suboptimal utilization. In order to promote wider dissemination of radiation processing technology and to facilitate participation by small and medium-scale entrepreneurs, BRIT has conceptualized a medium-range gamma irradiator that offers a cost-effective alternative to large-scale facilities. This system aims to deliver a satisfactory processing throughput at nearly half the investment cost of conventional irradiators, thereby extending the benefits of gamma irradiation technology to a broader industrial base.

The irradiator can process medium-dose products such as spices, fruits and vegetables, marine commodities, and ayurvedic products. The plant can house radiation source of 250 kCi of Co-60 arranged in a circular configuration with dual source racks to ensure uniform dose distribution. The product boxes of dimensions of sizes 40 × 60 × 70 cm or 50 × 50 × 70 cm are conveyed around the source. A mechanical provision to change the side of the product boxes has been incorporated to achieve an improved Dose Uniformity Ratio (DUR). The shielding structure adopts a circular concrete configuration, which effectively reduces size of labyrinth and cost while maintaining compliance with prescribed radiation safety standards. The plant with this source and product configuration can achieve a DUR of 1.8–2.0 with an estimated throughput of approximately 15 metric tons per day, depending on product density and dose requirements. This medium-range irradiator is expected to significantly enhance the techno-economic feasibility of radiation processing in India by offering an optimized balance between capital cost, operational efficiency, and product throughput.

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Aerial: An irradiation platform for R&D, education and dissemination of the benefits of electron accelerators. Case study of the dose rate effects in the framework of the radiation sterilization

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Electron beam or X-ray irradiation is a cold, residue-free physical treatment that has been applied in numerous fields for several decades. Among the desired effects on irradiated products are microbiological decontamination or sterilization, modification of the physico-chemical properties of materials (both at the surface and within the bulk), radical degradation of targeted molecules, and radiochemical synthesis of new compounds.

Aerial operates a platform of irradiation facilities based on electron accelerators producing low-, medium-, and high-energy electron and X-ray beams. These facilities are used for both research and applied studies on current industrial applications as well as for the development of innovative approaches in irradiation process control and dosimetry. The irradiation platforms will be presented together with the associated dosimetry laboratory and complementary facilities, including physico-chemistry, NMR, microbiology, sensory analysis, and freeze-drying laboratories.

As a case study, Aerial has taken part in the international collaboration Team Nablo (PNNL/IBA/Sartorius/BD/Aerial), which aims to reduce barriers to the broader adoption of X-rays and electron beams for sterilization. Several studies have been initiated in this context to assess the influence of dose rate on polymers [1]. It has been shown that dose rate cannot be considered independently, as the absorbed dose remains the primary determining factor. Furthermore, the temperature increase observed under irradiation—especially at high doses and dose rates—demonstrates that dose rate and temperature are intrinsically coupled.

Thanks to Aerial unique R&D tools, a dedicated experimental design was established using LDPE, PP, POE, CIIR, and PVC samples, covering dose levels from 15 to 85 kGy, dose rates from 0.003 to 12 kGy/s, irradiation temperatures from -5°C to 60°C , and oxygen concentrations ranging from 0 to 100%. This approach enables multifactorial analysis of the various irradiation parameters.

Physico-chemical, mechanical, and thermal properties were evaluated after treatment, and results show that the dose rate alone generally exhibits only a limited effect on post-irradiation modifications.

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Space Applications at the ENEA Calliope Gamma Irradiation Facility

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The Calliope gamma irradiation facility at the ENEA Casaccia Research Center (Rome, Italy) [1] allows a wide range of research and qualification activities for Space applications, providing controlled ^{60}Co irradiation environments for the assessment of radiation effects on materials and components intended for use in orbit. The facility participates in the Italian Space Agency ASIF program (<https://www.asif.asi.it/>), a national initiative that coordinates Italian irradiation facilities to support radiation testing for Space electronics. The laboratory routinely performs Total Ionizing Dose (TID) tests on electronic devices in compliance with ESA standards, including ECSS-Q-ST-60-22900 (Issue 5), which defines dose-rate intervals, irradiation conditions and post-irradiation annealing requirements [2]. Accurate dosimetry at Calliope is ensured through multiple dosimetric systems, including Fricke dosimetry, alanine-EPR, and thermoluminescent dosimeters (TLDs), all validated within the facility dosimetry laboratory. The facility also supports irradiation under bias. Thanks to dose rates that can be reduced to near-zero conditions inside the irradiation bunker, electronic boards and dedicated biasing setups can be safely operated during gamma exposure. Complementary post-irradiation stages are carried out in the thermal and climatic laboratory, where ovens and environmental chambers allow controlled-temperature annealing of components, which can also be maintained under bias for the duration of the prescribed ESA procedures.

At the Calliope facility, irradiation studies on optical and polymeric materials relevant to space missions, such as glasses, filters, adhesives, and coatings, are also conducted. These materials can be characterized at the facility characterization laboratory, which is equipped with FTIR, UV-Vis spectrophotometry, fluorescence spectroscopy, Raman spectroscopy, and Electron Paramagnetic Resonance (EPR), enabling comprehensive evaluation of radiation-induced degradation mechanisms. The Calliope facility is also involved in national and international Space research projects focused on Astrobiology (CRYPTOMARS Project), Bioregenerative Life Support Systems (BIOMIRATE Project), ISRU shielding materials (Space It Up! Project, funded from the ASI and the MUR – Contract n. 2024-5-E.0 - CUP n. I53D24000060005), satellites-controlled demise (<https://www.thread-eic.eu/>).

Through this contribution, examples of electronic, optical, and polymeric materials irradiated and characterized at the Calliope facility will be presented, demonstrating the laboratory capabilities in supporting Space qualification and technology development.

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Persulfate Assisted Radiolytic Degradation of Hydrochlorothiazide

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This study investigates the synergistic effect of gamma radiation in combination with persulphate (PS) as a combined advanced oxidation technique to degrade hydrochlorothiazide (HCTZ), a commonly used diuretic and environmentally persistent pharmaceutical in aqueous solution [1,2]. Gamma irradiation alone achieved a significant degradation of HCTZ with approximately 99% and 84.5% with an absorbed dose of 5 kGy for 20 and 50 ppm of HCTZ respectively. However, the addition of PS significantly decreased the dose required to degrade HCTZ, as shown in figure 1; the addition of 1 mM PS at an absorbed dose of 1.5 kGy degraded HCTZ to ~ 97%. The degradation efficiency was found to be dependent on concentration of PS, the rate of removal increased with increase in the concentration of PS from 0-5 mM. The increase in the degradation efficiency is attributed to in situ generation of sulphate radicals ($\text{SO}_4^{\bullet-}$) which oxidises HCTZ synergistically with primary radicals produced during water radiolysis ($\bullet\text{OH}$, e_{aq}^- , $\text{H}\bullet$). The degradation kinetics followed pseudo-first-order behaviour under all experimental conditions. The results suggest that the persulfate-assisted radiolysis is a highly efficient, scalable and sustainable technique to treat pharmaceutical effluents.

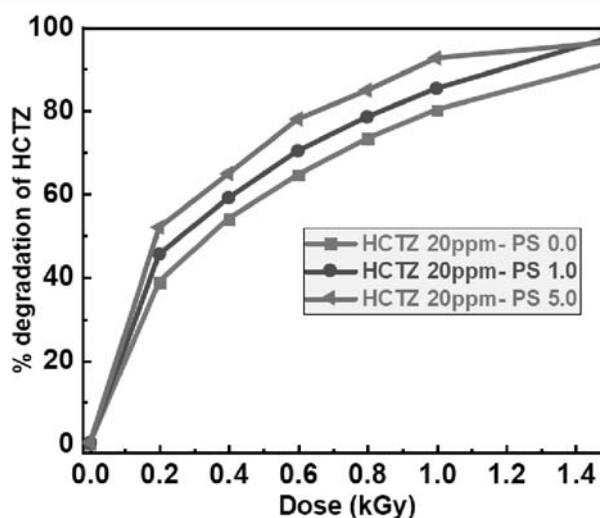


Figure 1: Effect of persulphate on HCTZ with Absorbed Dose.

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Dose Uniformity and Shielding Analysis of 100 kCi ^{60}Co -based Mobile Irradiator

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Board of Radiation & Isotope Technology is indigenously developing a mobile 100 kCi ^{60}Co -based irradiator that can be installed on a vehicle trailer providing mobility and portability. The on-site radiation processing will reduce spoilage of food products by delayed ripening and reduced microbial load. The total activity of 100 kCi is distributed uniformly among the 24 ^{60}Co sources arranged in two layers in a rectangular source frame. The irradiation cell is provided with lead shielding and the product boxes can be moved in and out of the irradiation cell through an interlock doors. The irradiation of food products in two product boxes (dimensions: 42 cm x 42 cm x 75 cm) will be carried out in a batch mode. The product boxes will be rotated 90 degrees on its axis for equal time resulting in irradiation of four sides. After completion of one batch of irradiation, the source rack will be lowered and stored in its Type B(U) transport cask. Simulation geometry showing source rack, product box, storage cask and shielding is presented in Figure 1.

Monte Carlo method is used for estimation of dose distributions in product boxes having bulk densities of 0.4 g/cm³, 0.6 g/cm³ and 0.8 g/cm³ representing different products. The calculated cumulative dose rate data (after irradiation on four sides) of the product box was analysed for Dose Uniformity Ratio (DUR) estimation. The cumulative dose rate (Gy/min) distribution in XY plane at Z=0 cm for product density 0.6 g/cm³ is shown in Figure 2. The calculated values of DUR are 1.8, 2.0 and 2.3 for product densities 0.4 g/cm³, 0.6 g/cm³ and 0.8 g/cm³, respectively. The statistical uncertainties on the calculated dose rates are in the range of 1- 4 %. The leakage radiation levels around the plant are calculated using point kernel method for both ON and OFF irradiation conditions. The calculated radiation levels are within permissible limit of 1 $\mu\text{Sv/h}$ as prescribed by the Atomic Energy Regulatory Board¹.

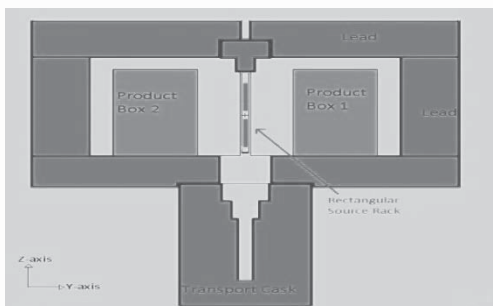


Figure 1. Simulation geometry of 100 kCi ^{60}Co -based mobile irradiator.

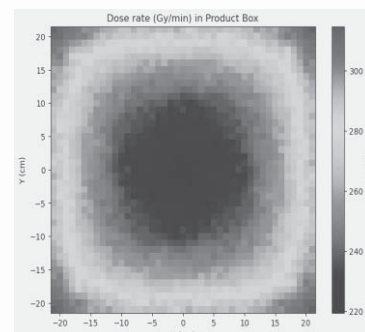


Figure 2. Cumulative dose rate (Gy/min) distribution in the product box ($\rho=0.6$ g/cm³) in XY plane at Z=0 cm.

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Design and Performance of a Field Emission-Based Electron Gun for X-Ray Generation with Gated Diode Architecture

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This paper presents the design and performance of a field emission-based electron gun optimized for compact, high-resolution X-ray generation. Field emission guns (FEGs) offer distinct advantages over traditional thermionic guns, including the ability to generate high-brightness electron beams at room temperature. This capability leads to enhanced spatial resolution, faster response times, and lower power consumption. However, FEGs utilizing nano-structured cathodes, such as carbon nanotubes (CNTs), face challenges in matching the performance of thermionic guns due to limitations such as poor time stability and reduced current density, mainly attributed to the screening effect. In this work, we introduce a novel electron gun that incorporates a gated diode geometry, where the gate electrode precisely controls the emission of the electron beam. The compound cathode architecture is employed to achieve high current density, primarily due to the Schottky effect and the anode proximity effect inherent in the compound cathode [1]. The cathode material used in this design is a CNT film developed via the floating catalyst chemical vapor deposition (FCCVD) method [2]. The FEG device has been tested and shown to produce a stable beam emission current of 2 mA at 2.4 kV DC, achieving a current density of up to 175 mA/cm² and a beam transmission efficiency of 38%. Stability tests conducted over 24 hours reveal fluctuations within $\pm 3.6\%$, indicating consistent and reliable performance. This work marks an important step forward in advancing the capabilities of field emission-based electron guns for medical, industrial, and scientific X-ray applications.

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Evaluation of Ceric-Cerous based chemical dosimeter for high dose irradiation applications

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Radiation processing is an expanding technology with numerous applications, such as health care products sterilization, treating sewage and hospital waste, polymer modification, and food processing. Quality assurance is vital for the success of radiation processing technology. Quality assurance is achieved with a reliable dosimetric system traceable to international standards. The dosimetry system is used to quantify the energy deposited or absorbed in a material from radiation sources. There are several chemical dosimeters like, ferrous sulfate solution, polymethylmethacrylate, ceric-cerous sulfate, dichromate solution, Alanine are extensively used for estimation of absorbed dose. The Ceric-Cerous dosimeter system is a reference standard dosimetry system and is used for quantification of absorbed doses in the range of 5×10^2 - 5×10^4 Gy [1]. In this study a Ceric-Cerous based chemical dosimeter was evaluated for dose response for high dose irradiation applications.

The Ceric-Cerous dosimeter was prepared with 15 mmol dm^{-3} ceric sulfate [$\text{Ce}(\text{SO}_4)_2 \cdot 4\text{H}_2\text{O}$] and 15 mmol dm^{-3} cerous sulfate [$\text{Ce}_2(\text{SO}_4)_3 \cdot 8\text{H}_2\text{O}$]. The recommended absorbed dose level with above indicated concentrations of Ceric-Cerous dosimeter is 5-50 kGy [2]. The use of the Ceric-Cerous dosimeter is based on the process of reduction of ceric ions to cerous ions. Gamma Chamber (GC-5000) equipped with a ^{60}Co source with a dose rate of 0.53 KGy/h was used in the study for irradiation of samples. The Ceric-Cerous dosimeter is irradiated at different absorbed dose levels (8-50 kGy). The response of the dosimeter was based on the difference in ceric ion concentration before and after irradiation. Electrochemical potentiometry was used for measurement of the redox potential difference between the unirradiated and irradiated solutions due to change in ceric ion concentration. Irradiation of ceric-cerous dosimeters was carried out in triplicates. The calibration curve between the absorbed dose and potential difference values after irradiation is found to be linear, with a correlation coefficient value of 0.96 in the dose of 8 to 50 kGy.

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Polyvinyl alcohol based chemical dosimeter for high dose irradiation applications

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The polymeric films with a dye are used as dose labels and indicators in radiation processing units for routine monitoring of absorbed dose [1]. The polymeric films with dyes exhibit either a permanent change in color or color bleaching upon irradiation, which is used to measure the absorbed dose levels. Polymeric materials like polyvinyl alcohol (PVA), polycarbonate, Polyvinyl chloride (PVC), and polyvinyl butyral (PVB) are studied extensively. The PVA based polymer materials are highly recommended because of their chemical and mechanical properties, such as a high degree of flexibility, water-solubility, non-toxic, and elastic nature [2]. The indicating materials are dyes such as methylene blue and methylene red, thymolphthalein (TP), ethyl violet and blue bromophenol, cresol red (CR), tetrazolium violet, and methyl viologen. In this study, dosimetric evaluation of PVA with Congo red (CR) and 2,6-Dichloro Phenol-indophenol (DCP) for high-dose irradiation applications are studied, and the results are presented in this paper.

The thin films with PVA with CR and DCP dyes were prepared using a simple technique, such as casting the aqueous solution [3]. The prepared PVA films with dyes are irradiated in the 0-80 kGy dose range. The Gamma chamber equipped with ^{60}Co source with a dose rate 0.54kGy/h and 8.5kGy/h were used for irradiation of films in this study. The change absorbance values are measured using the UV-visible spectrometer. The absorbance measurements for DCP and CR dyes are determined to be around 640 nm and 538 nm, respectively. The change in the absorbance values is found to be saturated after 20 kGy of absorbed dose. It is observed that the films changed their color from violet to red with an absorbed dose of 20 kGy and above. The color change was due to the bleaching of DCP with acid, produced from PVA after irradiation. The films synthesized are useful as labelled or indicator dosimeters in the case of medical product sterilization as a part of a quality assurance program in the radiation processing facilities for the absorbed dose range of 20 kGy and above.

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Use of hurdle technology with radiation processing for shelf-life extension of minimally-processed tilapia (*Oreochromis spp.*)

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Fish is one amongst healthiest food abundant source of essential nutrients. However, it is highly perishable and needs quick processing and cold-chain management to preserve it for longer uses. Radiation processing is approved globally for decontamination and improvement of microbiological quality and safety of several food commodities, including fish [1]. The initial microbial content of MPT was found to be 5.65 log CFU/g which was reduced to 4 log cycles immediately after irradiation. The untreated MPT was spoiled on 6th day of storage at 1 °C with mesophilic and psychrophilic count of 7.62 and 7.92 log CFU/g respectively. The radiation processed (4 kGy) MPT had a shelf-life of 38 days and spoiled on 45th day with the psychrophilic count of 7.25 log CFU/g. An acceptable level of psychrophiles in chilled fish is generally considered to be less than 6 log CFU/g [2]. All the MPT samples were devoid of mould and yeast growth during entire storage. The initial Total Volatile Base Nitrogen (TVBN) of control and irradiated sample was 16.96 ± 0.52 and 18.31 ± 0.52 mg N/100g respectively, which increased to 17.80 ± 0.95 and 17.22 ± 0.29 mg N/100g on 6th and 38th day of storage respectively. The initial Thiobarbituric Acid (TBA) content of control and irradiated MPT was 0.013 ± 0.004 and 0.31 ± 0.007 µg MDA/g respectively, which further increased to 0.05 ± 0.007 and 0.96 ± 0.01 µg MDA/g on 6th and 38th respectively. The initial organoleptic evaluation of both the samples was similar (7.4 to 7.5) on 9-point hedonic scale. However, on the 6th day of storage, the overall acceptability of control MPT reduced to 6.33 ± 0.71, whereas, the same was relatively higher (6.93 ± 0.96) in the irradiated samples on 38th day of storage. The nutritional composition of both the samples showed moisture content (74.86%), crude protein (19.44%), crude fat (1.9%) and ash content (0.93%). Therefore, the hurdle technology involving radiation processing and chilled storage have been effective in extending the shelf-life of chilled MPT.

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An EDXRF study of the impact of varying cooking methods on elemental profile of pulses

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Energy-Dispersive X-ray Fluorescence (EDXRF) is an established and widely used technique in food analysis for elucidating elemental composition, safety and authenticity screening of uncooked and cooked food. Pulses (decorticated or dehulled seeds of legumes) are rich source of proteins, certain minerals and vitamins and play an important role in human nutrition [1, 2]. In the Indian region, typical pulses consumed are Tur dhal, Masoor dhal, Mung dhal, Urd dhal, green gram, black gram and Bengal gram. In the present study, the technique of EDXRF has been employed to investigate which method of cooking is suitable to retain nutritional values by determining the elemental concentrations present among raw pulses and comparing them with the elemental concentrations present in pulses cooked in two different vessels namely aluminum utensil and earthen pot. The elements such as Ca, K, S, P, Zn, Cu, Ni, Fe, Mn, Cr, and Pb were detected in all the pulses of the present study. Four major elements K, S, P and Ca are obtained in cooked pulses. Higher values of S, P and Ca were present in pulses cooked in aluminum utensil and K concentrations were found to be higher in the pulses cooked with earthen pot cook ware. The presence of seven minor and trace elements namely Fe, Zn, Mn, Cu, Ni, Cr and Pb were also recorded in the cooked pulses. The variation of elemental concentrations among the selected pulses (raw, cooked in aluminum utensil and earthen pot) have been analyzed and highlighted during presentation of the paper.

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Beam Profile Measurement in DC Accelerator

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1 MeV DC accelerator designed for 100 kW beam power is commissioned at EBC Kharghar, for waste water treatment [1]. It consists of a thermionic electron gun, accelerating column and high voltage column housed inside 6 kg/cm² pressurized vessel. The column is followed by 3 m long beam line and 1.2 m long scan horn. Beam optics elements namely steering, focusing and scanning magnet are incorporated in the beam line for the transportation of the high current beam. To handle the high-power CW beam at 'Ti window', a 2-D scanning system is used. For the effective scanning of the beam and to avoid the thermal failure of Titanium foil it is desirable to have a beam size of ~10 mm at the foil. To optimize the beam size, it is necessary to know the transverse beam profile and size along the beam transport line. A partial invasive method is used to capture beam profile and size after the focusing magnet. An in-house developed Cross-Wire beam profile monitor, consisting of two tungsten wires of diameter 500 micron is used. The wires are fitted orthogonal to each other to get the size and profile information in two orthogonal directions in single scan. The device is designed to measure maximum beam size of 50 mm at beam current of 5 mA and beam energy of 1 MeV. Beam size and profile measurements are performed at different magnetic field values corresponding to magnet coil current of 3.5 A to 6 A; the measured beam size varied from 46.3 mm to 18.8 mm in X-direction and 47.8 mm to 18.8 mm in Y-direction. The minimum spot size at the titanium foil window is achieved for the focusing current of 3.85 A, the corresponding beam size at the cross wire is 44 mm along X-direction and 45.5 mm along Y-direction.

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Standardization of process control parameters for quarantine treatment of Pomegranate in a commercial food irradiation facility using imported and indigenous dosimeter

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Food irradiation is an effective technique with prime objective to address the food losses during postharvest storage. In present time it is also being increasingly used to meet sanitary and phytosanitary requirements of international trade and gaining market access for agricultural and horticultural produce. India is exporting fruits such as Mango, Pomegranate etc to various countries including USA overcoming quarantine trade barrier using radiation technology. Radiation absorbed dose is the key quantity that governs the process. For food destined for international trade, it is of the utmost importance that the process control is accurate and as per the accepted procedures. The important process parameters are dose distribution profile, source to product box alignment, and conveyor speed. Presently, the commercial food irradiation facilities in India are using imported Optichromic dosimeters to optimise the plant running parameters for quarantine application. The important process parameter namely dose mapping for quarantine treatment of Pomegranate was carried out using imported and recently developed BARC-ANUDOSE dosimeters at Irradiation Facility Centre, Maharashtra State Agriculture and Marketing Board, Vashi, Navi Mumbai. The dose distribution profile inside the product box was measured using imported radiochromic dosimeter and recently developed BARC-ANUDOSE dosimeters. Dosimeters of 78 numbers were placed in three planes (front, middle and rear) of the product box filled with Pomegranate. The Dose Uniformity Ratio (DUR) was measured as 1.58 with $Dose_{max}$ and $Dose_{min}$ as 998 and 632 Gy, respectively by the indigenous dosimeter. However, the imported dosimeters overestimated the doses by 14 to 20 %. The positions, of the $Dose_{max}$, $Dose_{min}$ and DUR were identical as identified by both the systems. The accuracy of the ANUDOSE dosimeter was assessed in National Standard Laboratory (RSSD, BARC) with acceptable traceability. The process control parameters such as optimized conveyor speed, positions of the $Dose_{max}$, $Dose_{min}$ and reference point were established for commercial radiation processing of pomegranate for quarantine treatment.

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Industrial level sterilization of medical devices by indigenously developed electron beam accelerator: A way forward for industrial deployment of e-beam technology in India

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Sterilization of medical devices is a critical step in ensuring patient safety and product reliability. The advantages of e-beam processing are ON or OFF technology, no chemical or radioactivity hazard, quickest processing time, scalable & sustainable technology compared to other sterilization technology. RRCAT has operationalized the AERB licensed e-beam based irradiation facility housing indigenously developed 10 MeV, 6 kW Linac. The critical quality management aspects as per Schedule-V of Medical Device Rules (MDR) 2017 have been established and implemented in the electron beam based irradiation facility. The facility has been accredited with ISO 9001:2015 & ISO 13485:2016 certifications and license has been granted by State Licensing Authority FDA for radiation sterilization of Risk Class-A & B medical devices.

Control on irradiation process is required to ensure consistent sterilization, delivering doses within specified limit of D_{min} . (Regulatory requirement to achieve required sterility assurance level) and D_{max} . (to ascertain that integrity of irradiated product) as per IS/ISO 11137. Control on critical process parameters (beam energy, beam current, pulse repetition rate, scanning current & time, and conveyor speed) has been implemented to ensure the dose delivery within specified limits. The critical process parameter's limits were characterized by dosimetry measurements during process establishment. A correlation between the critical process parameters and the actual dose delivered to the product has been established to confirm the integrity of the irradiation process. Alanine dosimeters are placed at reference locations on the product boxes to determine the minimum and maximum dose delivered to the product. More than 18 million medical devices are sterilized complying all the regulatory requirements and the rejection rate is less than 0.05%.

This paper presents the successful industrial level sterilization of medical devices using the indigenously developed electron beam accelerator [1,2]. The QMS establishment & implementation; process development & validation and sterilization of medical devices conforming to regulatory standards are also presented in this paper. This large-scale industrial irradiation of medical devices provides quantitative evidence of the accelerator's robustness and positions electron beam irradiation as a technology for sterilization of medical devices, paving the way for widespread industrial adoption of e-beam technology within India's medical device and radiation-processing sectors.

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Development of a Centralized Data Management System for Operational and Experimental Information in an Electron Irradiation Facility

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This paper presents the development of a centralized data management and monitoring system designed for an industrial electron accelerator facility. The system enables storage, and retrieval of various types of information, including machine parameters, operational logs, employee role data, experimental records, sample information, and maintenance activities [1]. All data are stored in a centralized database implemented using Microsoft SQL Server Express Edition, ensuring reliable and structured access.

The software is developed using VB.NET as a Windows Forms application and allows individual employees to log in with unique credentials from remote PCs connected over a local Ethernet network. The system provides a user-friendly interface for viewing operational and experimental information in various format, facilitating quick visualization of activities and machine utilization. Additionally, users can download or export experimental and operational data in Microsoft Excel or Word formats for daily, weekly, or monthly reporting. The developed system enhances operational transparency, traceability and data accessibility across the facility, supporting improved analysis and documentation of accelerator operations

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Inhouse development of a working model of category-IV food irradiation facility for wider public awareness of radiation technology

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Treatment of food with gamma radiation for shelf-life extension and microbial decontamination is a widely accepted technology worldwide [1]. Our country struggles to expanding the use radiation technology in food preservation because of widespread public misconception and misinformation. Several public awareness programmes are being conducted by Department of Atomic Energy, Government of India to dispel fears from the minds of people regarding radiation and irradiation technology [2]. Despite consumer concern, food irradiation is gradually gaining consumer acceptance due to increased awareness and the perceived safety and quality of foods [3]. A working, portable and self-explanatory model of a category (IV) irradiator is of much help in spreading promising technology. FTD, BARC has developed such a model in a cost-effective manner. The size of this working model is 850 mm X 850 mm X 810 mm. The irradiation room, a key component of the Irradiation Facility model, was fabricated using 5 mm thick polycarbonate sheets. These sheets were selected for their excellent transparency, impact resistance, and ability to present a controlled environment for demonstration purposes. The structure was assembled using 12mm sq. x 25mm long polycarbonate bar and M4 countersunk screws to ensure stability and light-tight. To illustrate the concept of biological shielding, a 35 mm thick shielding wall was constructed inside the irradiation room, using the same 5 mm thick polycarbonate sheets. This shielding represents the protective barrier typically used in real irradiation facilities to minimize radiation exposure to surrounding areas. The main frame of the conveyor profile is fabricated from a 3 mm thick aluminium sheet. Aluminium is selected for its lightweight, corrosion resistance, mechanical strength. The fabricated aluminium sheet is formed into the required profile through precision cutting. The structure is supported using 12 mm diameter, 82 mm long aluminium bars to maintain rigidity and structural alignment. A total of 11 idler sprockets, each incorporating a bearing and circlip, are used to guide and support the roller chain. A roller chain with a 12.7 mm pitch is used as the transmission medium to drive the conveyor. The roller chain engages with all idler sprockets to facilitate synchronized movement. The conveyor is driven by a drive sprocket attached to a 12V DC motor DC geared motors are used for source movement and product box movement through conveyor. The product box is fabricated using 35 mm square aluminium steel tubing with a 1.5 mm wall thickness, ensuring a balance between strength, weight, and ease of fabrication. The main structure of the source rack is fabricated from 5 mm thick polycarbonate sheets. Within the rack, 6 Nos. of hollow transparent Perspex (acrylic) tubes are vertically mounted to represent the radioactive source pencils typically



used in a full-scale gamma irradiator. The model is low cost, portable, rugged and needs minimum maintenance. This model is self-explanatory with source movement mechanism, product box feeding system, source storage water pool and mimics Cherenkov radiation during source storage. The electrical panel box is the control unit for powering and operating various components of the model. The panel houses the following components - 12V DC adapter (main power supply), 0.5A glass fuse (for overcurrent protection), 12V DC power regulator (for voltage control and stability), Push button with built-in indicator lamp (for switching and visual feedback), etc. The design and components used are fully indigenous.

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Electron Beam Assisted Delamination of Printed Circuit Boards for Rapid and Sustainable Metal Recovery

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Printed Circuit Boards (PCBs) represent a significant fraction of electronic waste and consist of both metallic and non-metallic constituents. The metallic fraction consists of metals such as Cu, Pb, Sn, Ag, and Au, while the non-metallic fraction includes fibreglass and a polymeric resin matrix [1, 2]. Therefore, it is imperative to recycle PCBs in order to recover metals and to protect the environment from their detrimental impacts. This work integrates electron beam (EB) irradiation as a pre-treatment step, followed by solvent-assisted thermal dissolution, to enable efficient metal recovery process from discarded PCBs. PCBs were irradiated using a 10MeV e-beam with doses ranging from 10 to 100 kGy, which facilitated the breakdown of their complex structure. PCBs were further treated with polar aprotic solvents i.e. dimethyl sulfoxide (DMSO) and dimethylacetamide (DMAc). The separation time of metal from PCBs decreased drastically as the EB dose was increased.

At the lowest dose of 10 kGy, complete separation of metal from the irradiated PCBs was observed in 70-80 minutes in DMSO and 100-120 minutes in DMAc at 130°C. While at 100 kGy dose, effective metal recovery was achieved within 25-30 minutes and 45-50 minutes in DMSO and DMAc, respectively. The recovered metal exhibited high purity that was evaluated using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) [3]. In order to enhance the sustainability of the process, solvents were regenerated and subsequently characterized using gas chromatography (GC), which showed that their chemical composition remained intact, with purity levels between 96 and 98%. The EB assisted recycling methodology proposed in the study significantly improves the overall efficiency of the process. While, simultaneously provides a more effective pathway for handling PCB waste, leading to a reduction in the overall environmental footprint.

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Electron Beam Induced Physicochemical Changes and Time-Dependent Microplastic Release from Polyethylene Orthopaedic Implants

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Keywords: E-beam irradiation; Polyethylene orthopaedic implants; Dynamic mechanical analysis; FTIR spectroscopy; Radiation-induced degradation

Electron beam (E-beam) irradiation is widely employed for sterilization of polymeric orthopaedic implants; however, exposure to ionizing radiation can induce physicochemical changes that influence long-term material stability. In this study, polyethylene orthopaedic implant specimens were irradiated at 0, 5, 25, and 40 kGy using an E-beam facility at Kharghar, India, to investigate dose-dependent radiation effects. Radiation-induced chemical modifications were examined using Fourier Transform Infrared (FTIR) spectroscopy of both the implant material and its corresponding monomer to identify structural alterations and oxidative changes. Viscoelastic behaviour was evaluated using dynamic mechanical analysis (DMA) to assess radiation-induced variations in stiffness and damping characteristics. Microplastic release into water was investigated using total organic carbon (TOC) analysis as a proxy for polymeric fragment leaching. TOC measurements were carried out after 0, 5, and 15 days of aqueous exposure to examine the evolution of leaching behaviour with time. The results indicate that lower irradiation doses (5–25 kGy) are dominated by crosslinking effects, resulting in relatively stable TOC levels over time, whereas higher dose exposure (40 kGy) promotes chain scission and oxidative degradation, leading to a progressive increase in TOC with prolonged immersion. The combined FTIR, DMA, and TOC results demonstrate a clear dose- and time-dependent relationship between irradiation-induced structural changes and microplastic release. This study emphasizes the need to optimize E-beam sterilization doses to ensure both microbial safety and long-term physicochemical stability of polyethylene orthopaedic implants.

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Enhancement in the Structural, Morphological, and Optical Characteristics of 30 KeV Kr⁺ Ion Implanted Porous Germanium Films

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Enhancing light absorption remains a major challenge for optoelectronic devices. Germanium (Ge) has recently attracted significant attention for applications in solar cells, photodetectors, and sensors. However, its high refractive index results in strong Fresnel reflections, reducing absorbance and device efficiency. To address this issue, efforts have focused on minimizing surface reflectance using antireflective coatings or by developing nanostructured Ge surfaces for improved optical performance [1,2]. This study investigates the surface nanostructures using the 30 keV Kr⁺ ion implantation on the morphological, and optical properties of RF sputtered polycrystalline germanium (Ge) films deposited on Si (100) substrates. The films subjected to Kr⁺ ion implantation at oblique angles of 65°, with fluences ranging from 1×10^{16} to 1×10^{17} ions/cm². Structural analysis using Glancing X-ray Diffraction (GXR) analysis confirmed the polycrystalline structure of the Ge films. Atomic force microscopy (AFM) revealed virgin film surface exhibiting island like morphology. While, ion implantation caused significant morphological alterations, resulting in nanoporous structures at lower fluences and ripple formations at higher fluences. Optical characterization showed that in the lower wavelength region, virgin film exhibited reflectance above 35%, whereas implanted films demonstrated a marked reduction, with reflectance dropping below 13%. The substantial decrease indicates enhanced antireflective behavior. The optical energy gap displayed fluence dependent variations, attributed to ion-induced defect formation and recrystallization processes. These results highlight the ion-implanted Ge films as strong candidates for next-generation optoelectronic devices.

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N₂⁺ Ion-Induced Structural and Functional Alterations in RF Sputtered Mo Films: Role of Ion Implantation Energy

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Keywords: Molybdenum films; RF sputtering; Ion implantation; Structural tuning;

Molybdenum (Mo) films are widely used as back-contact layers in photovoltaic technologies, such as CZTS and CdTe solar cells, due to their exceptional thermal stability, high melting point, chemical inertness, and low electrical resistivity. In the present work, Mo thin films with a thickness of 200 nm were deposited onto Si (100) substrates using RF sputtering under an argon atmosphere at room temperature. The films were subsequently subjected to nitrogen ion implantation at a fluence of 1×10^{17} N₂⁺ cm⁻² with implantation energies of 30, 80, 130, and 180 keV to investigate energy-dependent material modifications.

X-ray diffraction analysis demonstrated that nitrogen implantation induces significant structural evolution. At lower ion energies, increased lattice strain and defect concentration resulted in reduced peak intensities, greater FWHM values, and smaller crystallite sizes, indicating partial amorphization [1]. In contrast, higher implantation energies (130–180 keV) promoted dynamic annealing, which partially restored crystallinity, leading to larger crystallite sizes and reduced peak broadening. Atomic force microscopy further confirmed that implantation energy plays a crucial role in modifying surface morphology: RMS roughness increased and grain size decreased at lower energies, whereas higher energies facilitated grain coalescence and produced smoother surfaces [2].

Optical analysis via spectroscopic ellipsometry revealed that films implanted at lower energies exhibited higher absorbance, refractive index, and reflectance due to increased defect density and enhanced light-matter interaction. Conversely, higher implantation energies reduced these optical parameters as dynamic annealing decreased defect states and improved structural order [3]. These findings highlight the potential of ion-beam engineering for optimizing Mo-based materials for advanced optoelectronic and energy device applications.

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Krypton-Beam-Driven Surface Patterning and Structural Modification in Silicon Nitride Films

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Keywords: Ion-irradiation, Atomic Force Microscopy, Raman Spectroscopy, Silicon nitride Films.

Ion beam irradiation provides an effective pathway for tailoring nanoscale morphology and modifying the internal structure of films [1]. In this study, authors examine the influence of oblique-angle implantation of 130 keV Kr⁺ ions at a fluence of 4×10^{17} Kr⁺/cm² on the surface morphology, bonding configuration, and optical responses of silicon nitride films. Particular emphasis is placed on the interplay between ion-induced mass redistribution, sputtering-driven material removal, and structural relaxation within the irradiated layer. Atomic Force Microscopy (AFM) measurements reveal a clear evolution from a relatively smooth surface to ripple-like patterns that appear only within a specific angular window (45°- 65°) [2]. Structural analysis using Raman spectroscopy shows progressive degradation of Si-N vibrational mode accompanied by the emergence of Si-rich features [3], suggesting localized bond breaking and reorganization under heavy-ion impact in all Kr⁺ implanted surfaces. TRIM simulations support these observations, showing enhanced lateral energy spread and preferential nitrogen displacement increases with an increase in oblique incidence. Optical studies show reduced interference fringes and bandgap variations for all Kr⁺ implanted films, correlating with surface and sub-surface transformations. Together, the morphological, structural and optical changes point to a strongly angle-dependent instability mechanism that couples surface kinetics with sub-surface chemical alteration. These findings advance the understanding of ion-beam-induced patterning in silicon nitride and provide insight into controlled nanostructure formation opening pathways for optical and photonic applications.

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Tailoring the properties of ZnTe Thin Films through Oblique Argon Ion Irradiation

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Keywords: RF sputtering, ZnTe, Ion irradiation

Zinc telluride (ZnTe) is a group II-VI compound semiconductor that exhibits numerous applications in optoelectronic devices, such as LEDs and solar cells, owing to its direct band gap and high absorption coefficient in the visible region. ZnTe thin films of thickness 140 nm were deposited on Si (100) substrate using RF sputtering technique. The present study explored the impact of oblique Ar⁺ ion irradiation at angles of incidence 0°, 30°, 45°, 55° and 65° with a fixed energy of 95keV and fluence 3×10^{17} Ar⁺ cm⁻² on the structure, morphology, optical and electrical properties of deposited ZnTe thin films. Oblique argon-ion irradiation up to 55° induces crystallization in the ZnTe films, followed by deterioration in crystallinity at an oblique incidence angle of 65°, as revealed by Grazing Incidence X-ray Diffraction (GIXRD) studies. The Atomic Force Microscopy (AFM) investigation reveals columnar-like growth at low oblique angle of irradiation (up to 45°), which evolves into ripple-like morphology with increasing angle of irradiation up to 65°. The RMS roughness of the films has been found to decrease with increasing angle of irradiation. The optical band gap of the irradiated films is found to be significantly increased from 0.75 ± 0.01 eV at normal incidence to 2.64 ± 0.08 eV at oblique incidence angle of 65°. A significant rise in the conductivity of the films is observed with increasing angle of oblique irradiation.

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The digital basis for the system of hygienic rationing, control of radiation processing and irradiated foodstuffs traceability

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The global trend of reducing the use of chemical toxicants necessitates the application of new technologies, among which the use of ionizing radiation is one of the most promising areas. Numerous studies have confirmed the high efficiency of radiation treatment of food and agricultural products in order to meet the established requirements for phytosanitary and microbiological safety [1-4]. The use of ionizing radiation reduces the risk of food poisoning caused by Salmonella, Listeria, E. coli, and other dangerous bacteria. Based on the analysis of regulatory sources and our own research, we have substantiated and formed three elements of an effective regulatory system in the field of radiation biotechnology: mechanisms for hygienic regulation and operational validation of processing methods (including the establishment of optimal modes, taking into account the packaging and the level of initial contamination at a specific radiation processing facility); mechanisms for remote monitoring of processing and real-time decision-making; mechanisms for traceability and objective confirmation of the quality/safety of processed products (certification and control of QR-code labels). The Radurization PAK [5] is a scalable, adaptive system of services for industry participants: hygienic regulation service (planning and conducting studies to establish hygienic regulations), service for developing regulatory legal documentation and SMART standards (placing approved regulations and methods in a machine-readable format), and coordination service (access of certified centers to the "knowledge library" and coordination of downloads/orders based on territoriality, equipment, and downloads). The Radurization PAK and the Good Practices SC are creating a digital regulatory model that covers everything from the operational validation of technological processes to the confirmation of batch quality through a registry and QR codes. Such automated systems for remote control and compliance assessment by authorized bodies should be used in the Russian Federation and the EAEU to create a transparent market for the processing of products with ionizing radiation and to legitimize the circulation of processed products. After the Unified Control and Traceability System based on the Radurization Package is launched, a Register of approved foreign radiation treatment centers that process exported products will be formed. Foreign manufacturers, suppliers, and processing centers should apply standards containing Russian-approved requirements for minimum and maximum radiation doses, as well as for dosimetric monitoring.

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Certification Scheme (SC «The good practices») for irradiated foodstuffs based on the results of remote control using special software and hardware complexes (PAC «Radurization»)

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Radiation processing of food and agricultural products, which is used in more than 60 countries around the world, is recognized by global experts as safe only when differentiated absorbed radiation doses are regulated for specific product categories and consumers, when the processing method is pre-validated, and when strict control is exercised over the adherence to established technological parameters during routine processing [1-3]. Traditional monitoring methods based on selective audits based on checklists and a set of complex rules and procedures are quite time-consuming, time-consuming, not protected from human error, and ineffective in controlling complex processes where it is necessary to constantly monitor the dynamics of changes and/or to record deviations from the set parameters. Automated control and traceability systems allow to eliminate these limitations, the use of such systems allows to ensure compliance with safety requirements in real time, to increase the accuracy of detection of deviations and to reduce the risks of non-compliance. In international practice, the issues of control of processing by ionizing radiation and assessment of the safety of irradiated products are also solved through certification and traceability systems based on digital platforms and automated data management. The purpose of this work was to create a certification system based on remote monitoring of technological parameters, digital recording, and analysis of data from the process of product processing with ionizing radiation using artificial intelligence technology. As a result, the certification scheme Good Practices has been proposed [4], which includes six stages that ensure continuity, reliability, and traceability: audit of the processing center, including assessment of the process, infrastructure, and personnel competence; connection of the center to the PAC «Radurization»; verification of modes and approval of a detailed processing methodology for a specific product type (acceptable dose range, packaging/storing, parameters, dosimetric control, dose unevenness coefficient, HACCP elements, etc.); remote monitoring of the irradiation process for each batch, with data storage throughout the entire cycle; selective testing of irradiated foods in testing laboratories, with the results uploaded to the system and compared with remote monitoring data; issuance of a certificate of conformity for each batch and creation of a digital "passport" for the batch with a marking code and entry in the traceability registry. The development of a certification system based on a single digital eco-platform that combines tools for independent remote control, automated data capture, and processing using machine learning technologies is a significant step towards improving the efficiency of regulation in the field of



radiation biotechnology and modernizing sanitary and hygienic supervision. After the Unified Control and Traceability System based on the Radurization PAC and certification scheme Good Practices is launched, a Register of approved foreign radiation treatment centers that process exported products will be formed. Foreign manufacturers, suppliers, and processing centers should apply standards containing Russian-approved requirements for minimum and maximum radiation doses, as well as for dosimetric monitoring.

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Controlled Gamma Treatment of Heritage Textiles and Manuscripts: Biocidal Thresholds and Dose–Response Framework

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Gamma irradiation offers a practical method for addressing biodeterioration in archival materials, but its wider adoption is limited by the absence of dose standards and material-response benchmarks suitable for conservation settings. This study outlines a structured framework for establishing irradiation guidelines that balance microbial reduction with preservation of optical and chemical features critical to cultural heritage. Mock textile and manuscript materials will be prepared using cotton, linen and silk substrates with historically representative pigments, including indigo, madder, carbon black and red ochre. Fungal strains commonly encountered in stored collections—*Aspergillus niger*, *Penicillium chrysogenum* and *Cladosporium* spp.—will be introduced under controlled environmental conditions to reproduce typical biodeterioration. Irradiations will be performed using a calibrated Co-60 facility across incremental doses from 1 to 10 kGy. Microbial inactivation will be measured through viable counts and surface culture assays. Material response will be evaluated through colorimetry to track visible changes, FTIR and micro-Raman spectroscopy to assess chemical stability, and tensile testing to examine fiber strength, supported by microscopic imaging of surface morphology.

These datasets will be integrated to construct a dose–response map that identifies thresholds at which effective biocidal action can be achieved without compromising pigment fidelity or substrate integrity. The study aims to translate these findings into a practical assessment protocol that conservators can employ before and after irradiation, including characterization steps, acceptance criteria and decision points for treatment suitability. The present study provides a pathway for incorporating gamma radiation into heritage preservation workflows in a controlled, sustainable, non-destructive, and technically defensible methods. The study explores the possibility of ancient manuscripts using irradiation experiments.



XRF studies for Geographical origin determination

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Forty ruby samples were, weight ranging from 0.24 to 7.46 gm. collected from Keeranur, Parmethivelur, Manavadi and Srirangam Patti districts of Tamilnadu, along with host mineral rocks and soil. Morphology and inclusions of the samples were examined using gemmological microscope to evaluate the. The samples were further characterized by using instrumental methods like FTIR, UV-VIS and Raman spectrometers. Chemical composition of all the samples was determined by high resolution EDXRF measurements. High concentrations of chromophores Cr and Fe were found in most of the samples.

The price of the rubies depends on geographic origin and their colour. Due to different prevailing geochemical environments in the mines, the gemmological features of various coloured gemstones are influenced. The origin of the rubies is evaluated from gemmological features and chemical composition [1].

Energy dispersive x-ray Fluorescence (EDXRF) is a simultaneous multielement nondestructive analysis technique. XRF spectral Peak areas of individual elements like Si, Ca, Ti, V, Cr, Fe, Zr and Ga were converted to the corresponding concentrations by considering them as oxides, with respect to Alumina (Al_2O_3) using built in programme. Concentration of Al_2O_3 values is varying from 72% to 98%. In the case of reduced values, content of Si was found to be more. The main chromophore Cr present is in all the samples. It is well known that presence of Fe_2O_3 influences the colour of the ruby. Comparison of elemental concentration ratio is taken as a clue to evaluate the origin of colour stones. A scatter plot on the concentration variation of the Cr_2O_3 and Fe_2O_3 is used to evaluate the origin. We have included the documented data on rubies from Burma, Madagascar, Mozambique, and Tanzania region to evaluate the possible origin. It appears that our studied rubies are close to African region.

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Defect Depth Profile studies of radiation treated diamonds for colour enhancement: A method to identify type and energy of the radiation used

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It is well known that lab grown diamonds (LGDs) and low-grade natural diamonds are often exposed to ionising radiation to create colours green to blue [1]. This colour enhancement treatment involves exposing the diamonds to the high-energy ionising radiations like electrons/neutrons/alphas/heavy ions, which creates vacancies in the diamond's crystal lattice. These vacancies might interact with impurities leading to the formation of colour centers that give desired colours to diamonds. Radiation exposed diamonds might be annealed to achieve uniform colour. It is a challenge to identify whether a colour diamond is radiation treated or not. One of the methods to identify the type of the radiation used to determine the Defect Depth Distribution (DDD) of GR1 (741 nm) as a function of the depth in the coloured diamonds [2]. A methodology has been developed in GII to obtain DDS for 15 diamonds using confocal Raman microscope in Photoluminescence mode.

The coloured diamonds were counted for radioactivity using a GM counter and the absence of radioactivity suggested that neutrons were not used for treatment [3]. All the diamonds were segregated using our in-house developed D Vision pro as well as Diamond view utilising the observed fluorescence or phosphorescence, and growth patterns. They were characterised through IR absorption spectra. We measured DDDs for all the diamonds by tagging GR1 up to a depth of 200 microns in air at room temperature, using 633 nm laser probe of our confocal Raman Spectrometer. Peak areas corresponding to GR1 were normalized with respect to corresponding diamond line peak area to account for geometrical efficiency and variation in diamonds' weight. A clear distinction was seen in DDDs of the diamonds if they are exposed natural radiation or artificial radiation like electron beam. Details of experimental work and results & discussion will be presented in the manuscript.

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Preservation of juices by irradiation: Current status and challenges

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Abstract:

Nature is a rich source of bio-active compounds essential for catering nutritional requirements of human kind. Since ages variety of products are prepared by processing the natural raw materials. For instance, juices obtained from vegetables and fruits are rich in nutrients. While lot of development is made in processing of juices, it is essential to pay attention to their preservation as well. Juices are prone to spoilage due to growth of fungi, bacteria, parasites and microbes. Therefore there is a need to explore a novel technique to prevent decontamination. Conventional methods including thermal treatment are well adapted by industries for preservation of juice. However there are losses related to nutritional constituents and water soluble vitamins. This makes it essential to explore other techniques such as irradiation applied for the preservation of juice. Also the effect of the irradiation on degradation rate of juice and properties of juice need to be studied. The review emphasizes on the application of irradiation to preserve juice. Further the effect of irradiation on the shelf life of juice is also presented. In this paper, attempt has been made to present an overview of irradiation techniques applied to preservation of juice. We plan to explore the technique of juice preservation using irradiation.

Keywords: Irradiation, Juice preservation, Non-thermal preservation technique, Nutritional losses in juice, Spoilage of juice

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Role of irradiation techniques in conservation of archaeological subjects

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Abstract:

Archaeological materials such as artifacts, textiles, ceramics, metal objects, paper, leather, and excavated organic remains are highly susceptible to deterioration caused by physical, chemical, and biological factors. Traditional conservation practices—such as chemical treatments, surface coatings, and mechanical cleaning—have long been employed for their preservation; however, these methods are often time-consuming, labor-intensive, and may alter the physical or chemical integrity of the objects. In this context, irradiation techniques have emerged as effective, non-destructive, and environmentally safe alternatives for the conservation of cultural heritage materials.

Irradiation-based methods, including gamma irradiation, X-rays, and neutron-based techniques, are primarily applied for disinfection, sterilization, and preventive conservation without the use of harmful chemicals. These techniques are highly effective in eliminating biological agents such as insects, fungi, and bacteria from both organic and inorganic archaeological materials. In addition to pest control, irradiation-assisted analytical techniques—such as X-ray radiography, X-ray fluorescence (XRF), and neutron activation analysis (NAA)—play a significant role in material characterization, provenance studies, and assessment of internal structural conditions of artifacts.

When applied under controlled doses, irradiation ensures effective preservation while maintaining the physical integrity, authenticity, and historical value of archaeological objects. Although certain limitations exist, particularly regarding dose sensitivity and infrastructure requirements, irradiation techniques represent a scientifically advanced and promising approach for the long-term conservation of archaeological and historic materials.

Keywords: Irradiation, archaeological material conservation, non-destructive techniques, cultural heritage, historic materials



Beam Profile Measurement in DC Accelerator

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1 MeV DC accelerator designed for 100 kW beam power is commissioned at EBC Kharghar, for waste water treatment [1]. It consists of a thermionic electron gun, accelerating column and high voltage column housed inside 6 kg/cm² pressurized vessel. The column is followed by 3 m long beam line and 1.2 m long scan horn. Beam optics elements namely steering, focusing and scanning magnet are incorporated in the beam line for the transportation of the high current beam. To handle the high power CW beam at 'Ti window', a 2-D scanning system is used. For the effective scanning of the beam and to avoid the thermal failure of Titanium foil it is desirable to have a beam size of ~10 mm at the foil. To optimize the beam size, it is necessary to know the transverse beam profile and size along the beam transport line. A partial invasive method is used to capture beam profile and size after the focusing magnet. An in-house developed Cross-Wire beam profile monitor, consisting of two tungsten wires of diameter 500 micron is used. The wires are fitted orthogonal to each other to get the size and profile information in two orthogonal directions in single scan. The device is designed to measure maximum beam size of 50 mm at beam current of 5 mA and beam energy of 1 MeV. Beam size and profile measurements are performed at different magnetic field values corresponding to magnet coil current of 3.5 A to 6 A; the measured beam size varied from 46.3 mm to 18.8 mm in X-direction and 47.8 mm to 18.8 mm in Y-direction. The minimum spot size at the titanium foil window is achieved for the focusing current of 3.85 A, the corresponding beam size at the cross wire is 44 mm along X-direction and 45.5 mm along Y-direction.

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Development and dosimetric characterization of BARC “ANUDOSE” dosimeter as a cost-effective import substitute for phytosanitary & low-dose applications of food irradiation

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A significant portion of agricultural produce is lost postharvest due to insect infestation, physiological changes, and microbial contamination across the globe. Among the available food preservation technologies, radiation processing stands out as a physical, non-thermal method that offers unique advantages. It is also increasingly gaining market access to deliver a radiation dose in the range of 20 – 1000 Gy for agricultural and horticultural produce to meet sanitary and phytosanitary requirements of international trade. In order to achieve the desired objectives an accurate dose delivery and measurements are essential. Majority of the available dosimetry systems for food irradiation applications are not covering the entire low dose range (20 – 1000 Gy). In addition, the dosimeters are being imported resulting high cost burden to the irradiation facilities. The radiation response behaviour of the dyes and radiochromic dyes have always been an area of research interest in the field of radiation dosimetry. The dye-based dosimetry system is a reliable and cost-effective option to measure low dose from photons (Gamma / X- rays). A class of dyes is characterized by the presence of one or more azo groups (-N=N-) in their chemical structure and under the influence of photons, chemical reactions take place in the dye solution. A dye-based dosimeter named as BARC-ANUDOSE has now been indigenously developed. One of the major processes of the colour change in ANUDOSE dosimeter is radiation-induced degradation mediated by the primary active species generated from radiolysis of water (e^{-aq} and OH \cdot). A detailed dosimetric characterization proved ANUDOSE as a reproducible, stable, temperature, energy and dose rate independent field dosimeter. The accuracy of the dosimeter was validated by National Standard Laboratory with a variation of $\pm 1.15\%$ w r t reference standard. Successive field trials established ANUDOSE as an authentic, traceable, user-friendly and cost-effective dosimeter as an import substitute for food irradiation applications.



Development of high power industrial Linac for radiation processing at RRCAT

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RRCAT has developed prototype 9.5 MeV, 15 kW electron Linac for industrial irradiation applications. The increase in beam power from previous version was achieved by development of constant gradient type accelerating structure and high-power pulse modulator. High power beam testing was demonstrated at full parameters and Linac was qualified for food irradiation by performing dosimetry on coriander powder.

RRCAT is now developing high power industrial grade Linac targeting beam power greater than 20 kW. New developments being pursued include higher efficiency accelerating structure, Solid state modulator, twin RF feed, RF power dividers, Direction coupler, RF load and elimination of RF Circulator. The high power Linacs will cater to a variety of applications starting from low dose, high throughput food irradiation to sterilization of medical devices. RRCAT is also intensely working to develop industrial strength for manufacturing, supply and after sales service for Linacs.

RRCAT is operating Electron Beam Radiation Processing Facility (EBRPF) at Indore since 2022. This facility is now operating on regular basis and has processed more than 18 million medical devices till Oct 2025, using indigenous Linac with rejection rate less than 0.05%. RRCAT has deployed one 10 MeV, 10 kW Linac in an Indian industry for long duration trials in industrial environment. The Linac is being operated independently by the industry manpower and is being presently used for processing non regulated products. RRCAT is setting up a High Throughput Food Irradiation Facility (HTFIF) based on twin 9.5 MeV, 15 kW Linacs in opposing configuration. This paper describes 9.5 MeV, 15 kW Linac, the detailed plan for development of high-power industrial grade Linacs and their deployment for radiation processing [1,2,3].



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Development of 30 MeV Electron linac for medical radioisotopes generation and other applications

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SAMEER is developing high energy and high average beam power electron Linac for medical radio isotope generation and other applications [1]. An electron Linac with 30 MeV energy and ~10 kW beam power is in advanced stage of integration at SAMEER, Kharghar location. The serial acceleration of electrons in two accelerating structures each with >15 MeV energy capability is planned. The two Linacs are tested individually for beam energy and beam current. As designed, electron energy >18 MeV is measured using absorption method in Aluminum and peak beam current of ~80 mA is measured on a faraday cup. The series connection of two Linacs is in progress and system outgassing and preliminary beam experiment is planned shortly. The system is capable of running at 0.004 duty ensuring high average beam power. Natural Moly and Zinc material targets are prepared for irradiation with electron beam and photons respectively. Study shows that direct irradiation of natural Moly target with electron beam produces more activity compared to (γ, n) photon irradiation [2]. Due to high average power electron beam ~10 kW, cooling of targets becomes crucial. Indirect cooling is provided to the targets with water cooled copper heat sink. A high flux of photons and neutrons are generated during irradiation and it is shielded locally by lead, HDPE, Borated HDPE and Borated rubber [3]. A high flux of neutrons generated in the target with 30 MeV electron beam finds a lot of applications in imaging [4]. This paper will discuss the 30 MeV beam experimental results and applications planned.

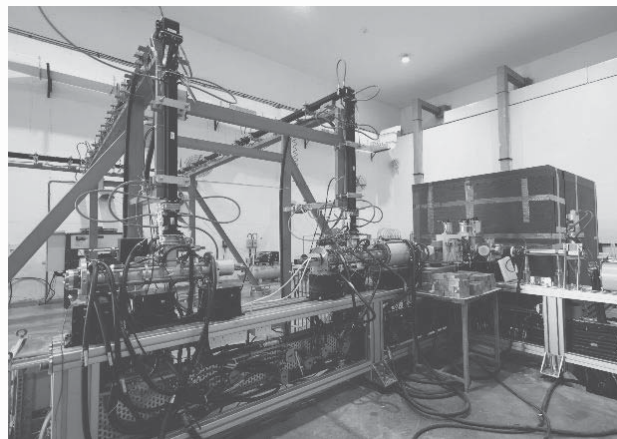


Fig. 1. Integrated beamline

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Development and Validation of MRL 30 Type-A Package for transport of Radiopharmaceuticals

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Safe transport of radioactive materials is critical in nuclear industry. India currently lacks indigenous suppliers for AERB approved reusable Type A packages, forcing private manufacturers to import at high cost. To promote self-reliance, Molecular Group developed the MRL-30 Type A package, in compliance with IAEA and AERB guidelines. The present study presents a comprehensive structural safety assessment of the MRL-30 package that can help for design optimisation and theoretical prediction of the tests stipulated by AERB. The MRL-30 package comprises three primary subassemblies: an outer stainless steel 304 drum, a shock absorbing expanded polyethylene (EPE) foam cushion, and an inner shielded (30 mm lead)/ sealed containment for the radioactive liquid. The total package weight is approximately 15 kg. A detailed finite element (FE) analysis by using ANSYS software was performed to evaluate mechanical performance under normal conditions of transport and special tests for transporting liquid. This include a 9 m free drop test, a 1.7 m bar penetration test and a stacking test with pressure equivalent of ≥ 13 kPa. The analysis examined the stress distribution, elastic strain, and deformation patterns with factors of safety (FOS) computed relative to material yield and failure limits. During the drop and penetration tests, the deformations were confined to the outer drum and connecting interfaces. The inner containment is maintained structural integrity. Water spray tests were showed no damage due to the SS 304 construction and the stacking tests indicated compressive stresses below yield limits without buckling. Experimental validation at ARAI Pune confirmed the FE predictions. The inner containment remained intact with the liquid filled vial intact. Overall, the MRL-30 Type A package satisfies all structural safety criteria, maintaining containment under normal transport conditions and during the special tests necessary for transportation of liquid radioactive material. The present investigation emphasizes the importance of FEM based structural analysis for design optimisation of radioactive packages and predictive advantages resulting to reduce cost of the unit.

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^{18}F -FDG Radiosynthesis using three Sep-Pak[®] Plus ALOX-N and One C18 Plus Sep-Pak[®]: Radiosynthesis, Quality Control & Bio-Evaluation

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^{18}F -FDG is synthesized by radiofluorination of mannose triflate, triflate is attached at the axial position (C2) whereas all the hydroxyl groups are deactivated by $-\text{COCH}_3$. The radiofluorination yield of mannose triflate is nearly 95%. Next, the $-\text{COCH}_3$ groups are acid hydrolysed with 1N HCl. The hydrolysis is 100%. The acidic solution, after acid hydrolysis is loaded on the purification cartridges and preferentially ^{18}F -FDG is eluted out with water. It is a known fact that neutral alumina in acidic condition forms a strong bond with F. Because of very low free ^{18}F -fluoride content, neutral alumina cartridge is sufficient to hold free ^{18}F -F⁻. One C18 Plus Sep-Pak[®] cartridge is required to hold unhydrolyzed/ partially hydrolysed ^{18}F -Mannose Triflate. A high yield, fully automated radiosynthesis of ^{18}F -FDG with ALOX-N PLUS Sep-Pak[®] and C 18 Plus Sep-Pak[®] is developed. Quality control and PET/CT imaging study in normal rabbit is reported. ^{18}F -FDG synthesis were carried out in a fully automated radiosynthesis module. All chemicals are of AR grade and procured locally. Radio TLC was analysed in MINIGITA DUAL form Elysia, Raytest. ^{18}F -FDG synthesis is similar to GE Tracerlab FX-FDG. pH was checked by pH paper from Merck®, RCP was checked by radio TLC in 95/5 MeCN/H₂O. Tetrabutyl ammonium (TBA) concentration is checked by Iodine chamber method. Sterility Test by standard 14 days challenge, BET by Gel clot method were carried out. PET/CT imaging study was carried out with an optimized protocol using Phillips Gemini TF 16 slices PET/CT. The radiosynthesis is fully automated with a duration of 55±5 min with an avg. yield of nearly 50% (n=4). The synthesized ^{18}F -FDG is of pharmacopeia grade. PET/CT imaging study showed normal distribution pattern. Pharmacopeia grade ^{18}F -FDG can easily be synthesized in large scale using Sep-Pak[®] Plus ALOX-N and C 18 Plus purification.



^{18}F -Sodium Tetra Fluoro Borate for diagnosis of Thyroid Disorders & Cancer: A Single Sep-Pak[®] Plus ALOX-N purification based radiosynthesis

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^{18}F -labelled Sodium Tetra Fluoro Borate (^{18}F]TFB), a substrate of human sodium/Iodide symporter (hNIS) is currently being evaluated worldwide as the first PET imaging agent for thyroid disorders and different types of thyroid cancer. In 2010, first radiosynthesis of ^{18}F]TFB was reported by isotope exchange method in 1.5 N HCl medium with 1.5 mg of NaBF_4 and purification with silver ion loaded cation exchange cartridge. However, problems with automation, low yield due to clogging of cartridge owing to AgCl formation led to the need of development of improved methods. In this study, a single Sep-Pak[®] PLUS ALOX-N purification based radiosynthesis is developed optimizing the different parameters for clinical grade ^{18}F - NaBF_4 . All radiochemistry experiments were carried out in a software controlled fully automated radiosynthesis module. All reagents and Sep-Pak cartridges were procured locally. TLC was analysed in MINIGITA DUAL form Elysia, Raytest. In brief, ^{18}F produced in GE PET Trace 800 by ^{18}O (p, n) ^{18}F reaction was trapped in QMA Sep-Pak cartridge. ^{18}F is eluted with different concentration of HCl. NaBF_4 in varying quantities dissolved in water is added and the isotopic exchange reaction was carried out at different temperatures and durations. For evaluation of reaction output, the reaction mixture is collected and isotope exchange % is checked by radio TLC in Methanol as well as 95:5 MeCN:H₂O solvent. The no. of Sep-Pak[®] PLUS ALOX-N cartridges and elution volume were also optimized. Optimization experiments leads to a single ALOX-N Sep-PAK[®] PLUS purification based radiosynthesis procedure with ~ 20% (without decay correction) yield. The synthesized ^{18}F - NaBF_4 is clear, colourless, free of any suspended particle, pH-5.5-6.0 with >95% radiochemical purity and suitable for IV injection. Clinical grade ^{18}F - NaBF_4 can be produced by optimizing the reaction parameters using single ALOX-N PLUS Sep-Pak[®] purification.



A modified Bhabhasphere delivery system designed for reliable delivery of ^{90}Y -glass microspheres into Hepatic artery

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Introduction: [^{90}Y] Yttrium-glass microsphere (Bhabhasphere, particle size: 20-40 μm ; activity: 1.48-5.55 GBq) is now a well-established therapeutic agent for transarterial radioembolization (TARE) for the treatment of hepatocellular carcinoma. The product necessitates a specialized Delivery System for ensuring direct delivery of radiolabeled glass particulates into the targeted liver tumour via hepatic artery, which is supplied along with the radioactive dose. Although successfully commercialized a couple of years back, technical challenges remained in ensuring the direct and safe delivery of radioactive glass particulates to the targeted cancerous liver tissue using the developed delivery system. To address the previous design concerns, design modifications were introduced to the delivery system to ensure reliable delivery of entire intended dose into the target tumor.

Methods: Three one-way medical check valves were integrated to ensure unidirectional flow of saline, preventing any possibility of backflow. A pressure release safety valve was added to vent saline if the vial pressure exceeds 2 bar, thereby avoiding the risk of vial rupture and tubing leakage failures. Luer locks from the plunger-needle tubing connection were eliminated to minimize dead volume and resulting loss of radioactivity at the luer lock interface. A Y-shaped tubing with needle-free valves configuration was added which allowed simple and efficient priming of the tubing set prior to connection with the catheter, reducing operator dependency.

Results: The improved configurations has eliminated the earlier failure modes, enabling robust operation under clinical conditions. The clinical SPECT/ PET images obtained post administration indicated high activity localization at the targeted liver cancerous tissue with minimal residual activity losses in tubing and injection vial <10%.

Conclusions: Thus, the above design modifications have collectively enhanced the safety, reliability and efficiency of [^{90}Y]Y-glass microsphere (Bhabhasphere) administration during TARE procedures.



Optimizing the capacity of the delay tank to safely dispose of the excreta of I-131 patients in a two-bed radioiodine therapy ward

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Radioiodine (I-131) is extensively used in nuclear medicine for treatment of differential thyroid cancers and benign thyroid disorders. Following administration, a significant fraction of administered activity is excreted through urine, feces and other body fluids within the first 24-72 hours. Due to its high gamma energy (364 KeV (84%)) and beta energy (610KeV (89%)), improper disposal of I-131 contaminated excreta poses radiological hazard to the public and environment. To mitigate these risks, radioiodine therapy wards are mandated to store patients' excreta in delay tanks, allowing for decay of radioactivity before release into the public sewer. This study aims to optimize the delay tank capacity for a two bedded radioiodine therapy ward to ensure that the discharge concentration of I-131 remains within limit ($<0.6 \mu\text{Ci/L}$) prescribed by AERB [1,2].

Our department admits four radioiodine patients every week. maximum amount of I-131 that each patient can receive is 125mCi. The delay tank's accumulated activity after 60 days (ideal storage duration) is 337mCi. Applying 60-day decay factor (0.0052), final retained activity is 1.75mCi. With waste water volume of 7200L, corresponding concentration is $0.23 \mu\text{Ci/L}$ which is within prescribed limit. Even with higher administered activity of 150mCi per patient (600mCi/week), the final effluent concentration is $0.29 \mu\text{Ci}$ while at 400mCi/week, it is $0.19 \mu\text{Ci/L}$ both remaining below regulatory thresholds. It is seen that increasing delay tank capacity from 6000 litres to 7500 litres provides an effective and safe strategy for handling I-131 excreta in a two bedded radioiodine therapy ward. This approach ensures compliance with radiation safety standards, increased operational efficiency in higher patient throughput and shorter turnaround times for storage.

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Assessment of External Dose Rates from ^{18}F -FDG–Injected Patients Undergoing PET/CT Imaging and Their Implications for Public Radiation Protection

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Radiation exposure of patients during PET–CT whole-body investigation was evaluated. Different parts of the body were scanned using Fluorine-18 (^{18}F), which emits higher energy photons (511 keV) and has a half-life of 109.8 minutes. From a radiation protection point of view, it is essential to measure the external dose during and after injection of FDG radiopharmaceuticals to patients. Radiation exposure measurements were taken for 30 patients at different time intervals-5, 30 and 55 minutes and at 5, 25, 50, 100, and 200 cm. Values were tabulated and evaluated. For measurement, an ionization-based Fluke survey meter was used. Patients were injected with 229 ± 31 MBq of ^{18}F (FDG) via the intravenous route. They remained in the Nuclear Medicine Department (isolation room) for 60 ± 10 minutes after injection. External dose measured near the intravenous injection site at the time of administration was about 5.8 mSv/min. External radiation dose measurements taken at 5 cm, 25 cm, 50 cm, 100 cm, and 200 cm were 4.14 mR/hr, 2.04 mR/hr, 1.36 mR/hr, 0.73 mR/hr, and 576 $\mu\text{R/hr}$ respectively, 5 minutes after injection. The corresponding values at 30 minutes were 3.46 mR/hr, 1.91 mR/hr, 1.20 mR/hr, 0.60 mR/hr, and 428 $\mu\text{R/hr}$, and at 55 minutes were 1.51 mR/hr, 1.14 mR/hr, 0.688 mR/hr, 377 $\mu\text{R/hr}$, and 300.8 $\mu\text{R/hr}$, respectively. Before the patient was discharged, they requested to wait an additional 30 minutes after the scan was completed (total time: 80 minutes). At that point, the measured dose rate at a distance of 2 meters was 210 $\mu\text{Sv/hr}$, and the results were consistent with the findings of Jamer et al., Aldousari et al. and Eckerman et al. [1,2,3]. ^{18}F has high photon energy, its relatively short half-life makes it an ideal radioisotope for PET/CT imaging. The dose rate decreases further when the patient is well hydrated. At the time of discharge approx. 80 min after injection, patient's external dose was about 210 $\mu\text{R/hr}$ at 2 m, which is about 10 percent of the background radiation level, it is negligible compared with public dose limits 1 mSv/y.

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Establishing a facility for the preparation of freeze-dried kits for the formulation of ^{99m}Tc radiopharmaceuticals ensuring GMP compliance

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Radiopharmaceuticals play a vital role in diagnosing and treating cancers and several major diseases. In daily nuclear medicine practice, PET-CT and SPECT-CT are the primary imaging modalities, with technetium-99m (Tc-99m) radiopharmaceuticals serving as the mainstay for SPECT imaging. These preparations are made by adding $^{99m}\text{TcO}_4^-$ to a freeze-dried kit containing an excess amount of ligand, reducing agent and other excipients, followed by incubation under validated conditions. In India, these radiopharmaceuticals are supplied by BRIT; however, many centres increasingly procure the same formulations from abroad, which reflects a gap in domestic supply capacity. This highlights the need to strengthen indigenous manufacturing to ensure consistent national availability. To support this need, we established India's first private ^{99m}Tc freeze dried kit manufacturing facility with GMP certification.

The facility is designed in accordance with European GMP and Indian Pharmacopoeia standards, incorporating Class C (ISO 7) clean room for reagent preparations and sterile glassware storage, Class B laboratory and Class A (ISO 5) laminar airflow systems for aseptic formulation. Sterile filtration and controlled lyophilization are carried out using a GMP-compliant freeze drying unit to ensure reproducibility and sterility. Each batch undergoes comprehensive QC testing, including physicochemical parameters, endotoxin content, sterility, pH, and radiochemical purity, supported by structured stability studies [1,2]. Using this controlled workflow, we have successfully formulated multiple ^{99m}Tc cold kits including MDP, DTPA, DMSA(III), MIBI, EC, SC, and Mebrofenin. Over the past three years, more than 100 batches are produced with consistent quality and quality compliance. Our experience demonstrates that meticulously designed infrastructure, stringent quality systems, and disciplined regulatory compliance can establish a robust, indigenous radiopharmaceutical manufacturing system. This facility represents a significant advancement in India's radiopharmaceutical capability and provides a scalable model for future domestic production.

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Optimization of Radiolabeling & assessment of In-Vitro stability of [¹⁷⁷Lu]Lu-DOTA-Girentuximab targeting CA-IX in Renal cell Carcinoma

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Girentuximab is a chimeric monoclonal antibody with high affinity to a protein called carbonic anhydrase IX (CA-IX) which is over-expressed on clear cell renal cell carcinoma (ccRCC). Taking advantage of theranostic properties of [¹⁷⁷Lu]Lu ($t_{1/2}$ -6.7 days, $E_{\beta\text{max}}$ ~ 497keV, E_{γ} 208keV), [¹⁷⁷Lu]Lu-DOTA-Girentuximab was prepared to target CA-IX overexpressing tumor cells. This study describes the optimization of conjugation of Girentuximab with bifunctional chelating agent and subsequent radiolabeling with [¹⁷⁷Lu]LuCl₃ followed by quality control of final Radioconjugate. Girentuximab (5.0 mg in 90 μ L, 34.35 nM) was conjugated with p-SCN-Benzyl-DOTA (189 μ g in 18.9 μ L, 343.5 nM) at 1:10 molar ratio. pH of the reaction mixture was adjusted to ~8.0 with 0.2 M NaHCO₃-Na₂CO₃ buffer (pH ~9.2) and incubated at 24°C for 2 hours, followed by 18 hours at 4°C. The conjugate was purified using a PD-10 desalting column equilibrated with 0.2 M CH₃COONa buffer (pH ~5.5). For radiolabeling, ~ 100-150 mCi of ¹⁷⁷LuCl₃ (SA: 14–22 mCi/ μ g, pH ~2.0) was transferred to the reaction vial, and the pH was adjusted to 6.0–6.5 using 0.2 M Sodium Acetate solution (pH ~8.0). It was mixed with purified conjugate (F4) and incubated at 37°C for 90 minutes. The [¹⁷⁷Lu]Lu-DOTA-Girentuximab was purified using a PD-10 desalting column equilibrated with 0.2 M CH₃COONa solution. L-ascorbic acid (~60 mg/0.5 mL in Sodium Acetate) was added as a stabilizer. The mixture was diluted with saline and filtered using a sterile 0.22 μ m PES membrane. The final radioconjugate's physical appearance was clear and colorless, with pH between 5.0 and 6.0. Radioactive concentration was 8-10 mCi/mL, and radiolabeling yield was >72%. Radiochemical purity (RCP) was estimated to be >98% by radio-TLC (SG-60F₂₅₄, 0.1 M Citrate Buffer, pH 5.0, R_f: 0.0–0.1). *In vitro* stability was confirmed for up to 7 days post-radiolabeling (RCP: >98%) when stored at –20°C. Endotoxin limit was determined to be <25 EU/mL. The present study reports the successful optimization of the preparation of [¹⁷⁷Lu]Lu-DOTA-Girentuximab, with high RCP and favorable radiolabeling yield. Quality control and stability studies confirmed that the established procedure is robust and reproducible for synthesizing [¹⁷⁷Lu]Lu-DOTA-Girentuximab for targeted radioimmunotherapy of CA-IX-expressing tumors and supports progression towards clinical translation after *in vitro* and *in vivo* evaluation.

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Optimized Radiolabeling Protocol of Patient Doses of [²²⁵Ac] based Radiopharmaceuticals for Targeted Alpha Therapy

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Targeted Alpha Therapy (TAT) using [²²⁵Ac] based radiopharmaceuticals are getting prominence for treating micrometastatic and refractive malignancies [1]. Actinium-225 with four high energy alpha particles (5–9 MeV) and high linear energy transfer (LET, 40-100 keV/μm) in short range of 50–100 μm allows selective tumor cell destruction, without damaging the surrounding healthy tissues. The present study describes the development of single protocol optimized for radiolabeling of DOTA-TATE, PSMA-617, JR-11 and FAP-2286 with [²²⁵Ac]AcCl₃. The quality control procedure for each of the radiolabeled product has been established and validated.

[²²⁵Ac]AcCl₃ (in 0.04 M HCl) obtained from ITM, Germany was used in the study. Aseptically about 150 μCi (in ~100 μL) of [²²⁵Ac]AcCl₃ was transferred to a reaction vial containing each of the ligand (~100-150 μg, concentration; 1 μg/μL) and sodium ascorbate buffer (1 mL, sodium ascorbate: 160 mg and ascorbic acid: 40 mg). Each of the reaction mixture (pH: ~4.5) was incubated for 25 minutes at 95°C and after cooling loaded on to preconditioned light / plus tC18 Sep-Pak cartridges. The loaded light/plus tC18 cartridge (for each of the products) was rinsed with 5mL of water to remove unlabeled [²²⁵Ac]Ac³⁺. Finally, each of the products were eluted from the cartridge using 2 mL of 70% aqueous ethanol and diluted with sterile, pyrogen free saline. The Radio Chemical Purity (RCP) for each of the products were ascertained by radio-TLC (SG-60°A), 0.05M Citric acid.

The physical appearance of all the radiolabeled product {[²²⁵Ac]Ac-DOTA-TATE, [²²⁵Ac]Ac-PSMA-617, [²²⁵Ac]Ac-JR-11 and [²²⁵Ac]Ac-FAP-2286} were clear and colorless with pH in the range of 5.0–6.0, while Radio Active Concentration (RAC) were 10-13 μCi/mL. The R_f (measure of radiochemical purity) for each of the product ranged between 0.0-0.1. Each of the product was found to be stable (RCP: >98%) up to 48h post radiolabeling on storage at 4°C and sterile and endotoxin limit (EL) were <25EU/mL.

The present study depicts the optimization of the single radiolabeling protocol for single patient dose formulation of various [²²⁵Ac]Ac-based radiopharmaceuticals namely [²²⁵Ac]Ac-DOTA-TATE, [²²⁵Ac]Ac-PSMA-617, [²²⁵Ac]Ac-JR-11 and [²²⁵Ac]Ac-FAP-2286 with consistent Radio Chemical Yield (RCY) and RCP. The optimized radiolabeling protocol was consistent and reliable, further can be deployed in hospital radiopharmacy centers towards clinical translation of TAT.

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Therapeutic Multiple Patient Dose Formulation of Ready-to-Use [^{177}Lu]Lu-FAP-2286 using Carrier Added, Low Specific Activity [^{177}Lu]LuCl₃: Pre-clinical Evaluation for Clinical Translation

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Fibroblast activation protein (FAP)-targeted radioligand therapy using [^{177}Lu]Lu-FAP-2286 has emerged as a promising option for advanced solid tumors [1]. The present study describes an optimized radiolabeling protocol for preparing multiple ready-to-use clinical doses (4–5 doses) of [^{177}Lu]Lu-FAP-2286 using carrier-added, low-specific-activity [^{177}Lu]LuCl₃ (~14 mCi/ μg), along with a comprehensive quality-control and pre-clinical evaluation. *In-vivo* distribution studies of [^{177}Lu]Lu-FAP-2286 provides necessary impetus towards its clinical translation and further use as FAP-TRT in patients.

Formulation of clinical doses of [^{177}Lu]Lu-FAP-2286 carried out using ~850 mCi [^{177}Lu]LuCl₃ with a 2-fold molar excess of FAP-2286 in gentisic acid/acetate buffer, followed by incubation at 100 °C for 60 min (pH ~4.2). The product was diluted to a RAC of 24–25 mCi/mL and sterile-filtered. RCP was confirmed by radio-PC/HPLC, with endotoxin by gel-clot BET assay and sterility tests meeting specifications. In-vitro stability (up to 168 h at –20 °C) and in-vivo bio-distribution were evaluated in SCID mice bearing A549 tumor xenografts [2].

Using low-specific-activity [^{177}Lu]LuCl₃, ~836 mCi of [^{177}Lu]Lu-FAP-2286 (n=11) was obtained with ~98.5% RCY, corresponding to 4–5 patient doses. The final product was clear, pale yellow (pH ~4.5), with a RAC of ~24 mCi/mL and RCP >98%. It was sterile, had endotoxin levels <25 EU/mL, and showed a specific activity of ~0.85 mCi/ μg . In SCID mice with A549 xenografts, SPECT/CT imaging demonstrated high tumor uptake (15.35±1.2% at 3 h; 10.21±0.9% at 24 h).

An optimized protocol for multi-patient, ready-to-use [^{177}Lu]Lu-FAP-2286 formulation using low-specific-activity [^{177}Lu]LuCl₃ was successfully established for treating FAP-expressing solid tumors. This work supports the feasibility of delivering cost-effective FAP-TRT routinely in high-volume hospital radiopharmacy settings.

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Mo-99 Production Experiments Using Neutron Reflector and Multiplier in IPR 14 MeV Neutron Generator

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An accelerator based 14 MeV neutron generator has been commissioned at Institute for Plasma Research (IPR), Gandhinagar, Gujrat, India with a maximum neutron yield of 1×10^{12} neutrons per second. The neutron generator facility is designed to conduct fast neutron interaction experiments including the production of radioisotopes for medical applications [1,2]. Preliminary simulation studies were conducted to test the feasibility and maximum production yield of various radioisotopes under the optimum operational conditions. Mo-99m production by $^{100}\text{Mo} (n,2n) \text{Mo}^{99\text{m}}$, was studied by MCNP simulation models. Neutron multiplier and reflectors were considered to increase the neutron flux in the irradiation regions. Maximum production capacity was determined by considering isotopically enriched samples [3].

Presently, demonstration experiments were conducted to produce Mo-99m. Samples containing few grams of molybdenum trioxide powder (MoO_3) and molybdenum metal plate were used. The neutron yield was maintained to produce the radioactivity above the minimum detection limit of the HPGe detector, while keeping the dead time low. Following four irradiation experiments were conducted for both type of samples: 1) using bare neutron source, 2) with lead as neutron multiplier, 3) with HDPE as reflector, 4) with lead and HDPE both as reflectors. HDPE is considered for its moderating properties that can enhance the production yield by facilitating $^{98}\text{Mo} (n,\gamma) ^{99\text{m}}\text{Mo}$ reaction [4]. New simulation studies were conducted using PHITS to replicate the experimental conditions. The neutron flux at the sample location was determined by foil activation method. Later it was used to access the increment in neutron flux by the reflector and multipliers.

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Imaging of Congenital Anomalies of the Kidney and Urinary Tract (CAKUT) with Radionuclide Scintigraphy: A Pictorial essay.

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Congenital anomalies of the kidney and urinary tract (CAKUT) constitute nearly 50% of all congenital malformations and include a broad range of abnormalities that may present before or after birth. These anomalies frequently involve defects in renal number, form, and position, including renal agenesis, supernumerary kidney, ectopic kidney, fusion anomalies, dysplastic kidney, and polycystic kidney disease, along with obstructive and reflux-related conditions such as UPJO and VUR. Radionuclide scintigraphy, comprising Tc-99m DMSA cortical imaging, Tc-99m EC or Tc-99m DTPA (Tc-99m, $t_{1/2} = 6 \text{ h}$ γ -140 keV) dynamic renography, and radionuclide micturating cystography (RNC), plays a critical role in evaluating renal morphology, cortical integrity, drainage patterns, and differential renal function. A retrospective analysis of pediatric and adult patients was performed. Tc-99m DMSA scans were acquired using a 3–5 mCi (111–185 MBq). Dynamic renography using 3–5 mCi of Tc-99m EC or Tc-99m DTPA evaluated renal perfusion, parenchymal function, and drainage patterns. Radionuclide micturating cystography (RNC) was performed in selected cases using ~1 mCi (37 MBq) of Tc-99m DTPA diluted appropriately. All studies were acquired on a dual-head gamma camera equipped with NaI(Tl) detectors (Siemens Symbia T / GE Discovery NM/CT) using LEHR collimators. A broad spectrum of congenital anomalies was documented, including renal agenesis, supernumerary kidney, horseshoe and L-shaped kidneys, ectopic kidneys (abdominal, pelvic, thoracic, and crossed fused), pancake kidney, polycystic kidney disease, multicystic dysplastic kidney, duplex collecting systems, and vesicoureteral reflux. Characteristic scintigraphic patterns enabled differentiation of functioning vs. non-functioning kidneys, identification of fusion variants, and evaluation of obstruction and reflux. Radionuclide scintigraphy offers comprehensive anatomical and functional assessment of CAKUT and remains indispensable for accurate diagnosis and clinical management. Familiarity with scintigraphic patterns enhances diagnostic confidence and supports optimal patient care.

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Radiolabelling and Quality control of ^{99m}Tc -TRODAT-1 at Hospital Radiopharmacy, RMC for Clinical use

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TRODAT-1 is a tropane derivative of dopamine transport ligand. It is specifically designed to bind to dopamine transporters (DAT) in the striatum. The radiopharmaceutical tagged with the ^{99m}Tc works in the SPECT imaging which mainly helps to assess dopaminergic neuron health, making it a valuable tool in diagnosing and differentiating Parkinson's disease and related disorders. However, the preparation of [^{99m}Tc]TRODAT-1 is challenging owing to instability of the precursor and some of the side products formed which compromises radiochemical yield, purity and reproducibility in-house. TRODAT-1 Kit was procured from Board of Radiation and Isotope Technology [BRIT product profile-TCK-55]. The preparation was done as per the Manufacturer protocol, briefly, the kit was taken from -20°C and kept at room temperature before use. ^{99m}Tc was freshly eluted from $^{99}\text{Mo}/^{99m}\text{Tc}$ generator and 45-50 mCi was aseptically injected into the vial. The vial was cooked for 1 hr 10 min in an Insta-potmake electric pressure cooker. At the end of heating cycle, the pressure was released, and the vial was cooled. The quality control of [^{99m}Tc] TRODAT-1 was performed by the Chromatography method TLC (SG-60⁰A), acetone, saline & administrated to the patients. The physical appearance of radiolabeled product was clear and colorless, pH ranged between 5.0–6.0, RAC in between 9-10 mCi/mL, Radiolabelling Yield >95%. The RCP was estimated >95% & the *in-vitro*-stability was 4 hrs post-radiolabeling (RCP: >95%) at room temperature (25°C). Six batches of [^{99m}Tc]TRODAT-1 was successfully prepared with consistent yields and met the stringent requirements for radiochemical purity (>95%), sterility, and a physiological pH, confirming its suitability for clinical use in dopamine transporter imaging. The feedback received from RMC Clinic demonstrated expected bio-distribution at the clinical level. This study illustrates the experience gained in preparation of [^{99m}Tc] TRODAT-1 using BRIT supplied cold kit.



Regulatory Approach for Safety Review of Supra-Major I-131 Therapy: First-of-a-Kind Treatment in India.

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Iodine-131 is an important therapeutic radioisotope in nuclear medicine for cancer treatment. In sodium iodide form, it selectively accumulates in the thyroid, enabling effective treatment of thyroid cancers. As metaiodobenzylguanidine (I-131 MIBG), it is used for neuroendocrine tumours such as neuroblastoma. In India, high-dose therapy (HDT) using I-131 ranges from 100–300 mCi, and shielding adequacy of HDT facility is assessed by AERB for up to 300 mCi/isolation ward/week. Recently, AERB received a proposal from a licensed HDT facility for supra-high dose I-131 MIBG therapy to treat a high-risk neuroblastoma patient. This study elaborates the regulatory approach followed for safety review, for issuance of permission for supramajor dose I-131 therapy in the existing HDT facility.

The proposal involved administering a supra major dose (800–1200 mCi) of I-131 MIBG to a patient in an isolation ward originally assessed for a maximum of 300 mCi/week. Facility intimated that for the supra-dose treatment, adjacent rooms and the room directly above and below would remain vacant. AERB evaluated shielding adequacy, radiation levels around the HDTward, waste management systems, and radiation monitoring arrangements. The isolation ward was made of 25 cm RCC walls, 30 cm RCC floor and ceiling, a 4 m floor-to-ceiling height, and a high-capacity delay-and-decay tank. Additional mobile lead shields were placed near the patient bed to reduce radiation level at entrance door and corridor. AERB carried out a theoretical assessment for expected radiation levels for maximum proposed activity. NMF was instructed to submit a radiation survey report using 400 mCi, along with an SOP addressing shielding adequacy, contamination control, and personnel safety.

The survey results were reviewed by AERB and found consistent with theoretical estimates. AERB granted conditional approval for a single supra-high dose, with the requirement of real-time monitoring of the procedure by AERB personnel. The supra-major dose I-131 MIBG therapy was successfully administered and the procedure completed in full compliance with regulatory requirements. Radiation survey measurements confirmed that exposure levels in rooms above and below the treatment room remained at background levels, while adjacent rooms reached permissible limits by the second day. The patient was safely discharged on Day 5, after meeting the discharge limit of ≤ 50 $\mu\text{Sv/h}$ at 1 meter. This instance represents a demonstration of inclusive and adaptive regulatory approach of AERB, wherein supporting the cause without compromising radiation safety requirements.

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Ambispective Strategies for Radiation Safety in Self-Shielded and Bunker-Type Medical Cyclotron Facilities

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The rapid growth of medical cyclotron technology and the increasing number of cyclotron facilities in India necessitate the continual enhancement of radiation safety practices beyond the existing regulatory frameworks. Radiological and operational challenges differ significantly between self-shielded and bunker-type cyclotrons. These include neutron activation management, shielding performance, airborne activity control and lifecycle planning. This study presents a unique, experience-driven assessment drawn from the complete design and over eight years of continuous operation of a self-shielded cyclotron facility. The insights from this experience were systematically applied to the design, construction, commissioning, and decommissioning preparedness of a new bunker-type cyclotron facility.

The core strategies implemented include optimised vault and plug-door geometry to minimise neutron streaming, computational shielding validation to ensure predictable radiation fields, enhanced ventilation zoning and airborne activity control, and a strengthened safety interlock architecture with two-step authorisation. To ensure GMP-compliant radiopharmaceutical production, cleanroom zoning, controlled material/personnel flow, and continuous environmental monitoring were integrated into the facility design. Additional improvements include an integrated real-time process-logging system supporting rapid diagnostics and root-cause analysis, optimised preventive maintenance methodologies, and lifecycle-oriented construction practices designed to reduce activation, limit personnel dose, support efficient decommissioning, and accommodate future expansions.

Evidence from retrospective operational experience in the self-shielded facility includes the occupational effective doses below 2 mSv/y, equivalent doses below 6 mSv/y, no radiation-related safety incidents, a production failure rate of <1%, and consistent regulatory compliance. Combined with prospective modelling and regulatory validation for the new bunker-type facility, these findings provide an ambispective evidence base confirming the robustness and transferability of the proposed safety strategies. The approaches outlined are broadly applicable and readily adopted by existing, emerging, or upgraded cyclotron facilities. These insights highlight how operational experience, when systematically embedded in regulatory documentation and facility planning, can elevate radiation safety management from basic compliance to sustained excellence.



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In-House Radioassay TPOAb Reference Intervals for Improved Diagnostic Concordance in Autoimmune Thyroid Disease and Differentiated Thyroid Cancer

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Thyroid peroxidase antibodies (TPOAb) serve as key immunological markers for detecting thyroid autoimmunity and hold additional value in evaluating thyroid dysfunction in both benign and malignant conditions [1]. Establishing assay-specific reference intervals is therefore essential for accurate clinical interpretation, particularly when comparing radioisotope-based methodologies. This study evaluated the diagnostic concordance of TPOAb measured using an in-house magnetic particle (MP) radioassay and a commercial Immunotech RIA kit. Both assays were applied to patients with autoimmune thyroid disease (AITD; n=48), differentiated thyroid cancer (DTC; n=92), and control subjects (n=55). Concordance between the two methods was assessed using the assay-specific normal ranges; 12 IU/mL for the Immunotech kit and 8 IU/mL for the in-house MP-radioassay. Diagnostic concordance was defined as the degree of agreement between positive and negative classifications across the two assays within each clinical group.

In the AITD group, concordance reached 85.41%. Twenty-five samples were positive and 16 negatives on both assays. Discrepancies included 3 samples testing positive only with the Immunotech kit and 4 samples positive only with the in-house radioassay. Among control subjects, concordance was high at 98.18%; 3 samples were positive and 51 negatives across both methods, with a single discordant sample positive only on the in-house assay. In the case of thyroid cancer patients (n=92), 95.6% concordance was seen where 10 samples tested positive and 78 samples tested negative by both assays, whereas 4 samples were positive by the Immunotech kit but negative by the in-house MP-radioassay.

The results of this study demonstrate that classical method-comparison metrics alone may not capture true clinical agreement, particularly when assays differ in analytical platforms and cut-off definitions. Incorporating diagnostic concordance provides a more clinically meaningful measure of comparability. The strong agreement observed across groups highlights the sensitivity and specificity of the in-house magnetizable cellulose MP-radioassay and supports its use as a reliable, cost-effective radioisotope-based tool for TPOAb assessment in diverse thyroid disorders [1].

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Role of PET-CT imaging in Diagnosis of Zoonotic Diseases in Laboratory Animals

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Encephalitozoon cuniculi can cause latent disease, especially in lagomorphs and many wild and domestic animals in various countries. This infection is important for veterinary and public health because it is caused by a potentially zoonotic and opportunistic pathogen. This study investigated subclinical disease pathology in rabbits by comparing findings from PET-CT imaging with serological titers in rabbit samples. which may be useful in early predicting the disease in clinically healthy rabbits. In this study, total (n=9) were included and subjected for seropositivity of E. cuniculi infection in clinically healthy rabbits(n=9). Animal(n=4) showed higher titers were undergone for PET-CT Imaging by using [18F] FDG, 500 μ Ci activity by intravenous injection. Rabbits that developed symptoms and had a positive titer were euthanized, and a necropsy was conducted (n=2). Serum creatinine levels were quantified, and histopathological analyses were performed on all vital organs from the affected rabbits. Study observation of Serum enzyme-linked immunosorbent assay (ELISA) tests showed that 4 (44.4%) of 9 rabbits were seropositive against E. cuniculi. PET-CT imaging showed increased brain (Max SUV 2.4 \pm 0.29), Focal Liver (Max. SUV 2.0 \pm 0.29) and kidneys (Max SUV 3.4 \pm 1.1) uptake were significantly higher in seropositive animals. Increased kidney uptake with abnormally distended urinary bladder indicative of kidney damage. Gross lesions showed brain congestion, necrotic kidney with grey cloudy urine were confirmed the infection by necropsy. Histopathological findings in the kidney, degenerative changes and E. cuniculi spores were identified in the tubule and brain. Elevated levels of serum creatinine levels were found to have a significant relationship with the serological status and PET-CT imaging findings in affected rabbits. In conclusion, the brain and kidneys were the most affected organs in encephalitozoonosis in rabbits. This study revealed that PET-CT imaging would be useful for the evaluation of early changes in subclinical rabbit infection with E. cuniculi in conjunction with the routine ELISA method to increase diagnostic accuracy, clinical interpretation for timely treatment in the animals.

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Production of Useful Radioisotopes from Nuclear Waste for Non-Power Applications

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High-level liquid waste (HLLW) from spent nuclear fuel reprocessing plants contains fission products that serve as a valuable source of radioisotopes for non-power applications in healthcare and industry. India's closed nuclear fuel cycle strategy, employs advanced techniques such as solvent extraction, ion-exchange chromatography and selective precipitation to isolate radionuclides like cesium-137 (^{137}Cs), strontium-90/yttrium-90 ($^{90}\text{Sr}/^{90}\text{Y}$) and ruthenium-106 (^{106}Ru) with over 99% purity [2]. For ^{137}Cs , calix[4]arene-crown-6 in isodecyl alcohol-dodecane enables recovery, followed by encapsulation into glass pencils each having activity of about 11.1 TBq (300 Ci). Over 200 such sources have been used blood irradiators (BI-2000), delivering 30 Gy dose in 3 minutes to prevent graft-versus-host disease. As compared to the cobalt-60 (^{60}Co)-based blood irradiators, ^{137}Cs -based irradiators require lower shielding and better cost-efficiency, and thus have been deployed in more than 15 different hospitals in India [2]. Yttrium-90 (^{90}Y) is obtained by milking ^{90}Sr separated via TEHDGA and CMPO-based extraction. Annually, about 15 lots batches of ^{90}Y -acetate (each having activity: 140 mCi (5.18 MBq)) are produced for radioembolization therapy of liver cancer and bone metastases, meeting European Pharmacopoeia standards ($<10^{-6}$ Ci $^{90}\text{Sr}/\text{Ci}$ ^{90}Y) [2]. Ruthenium-106 (^{106}Ru), extracted through RuO_4 oxidation and CCl_4 stripping, is used in RuBy plaques for treating choroidal melanomas. Over 50 patients have benefited in India from personalized brachytherapy using in-house produced plaques delivering a dose of 100 Gy at tumour apex over a period of 35 hours [2]. This "waste-to-wealth" approach reduces volume of HLLW and promotes self-reliance. Recovered radioisotopes support industrial radiotracing, non-destructive testing and quality control. Future integration with thorium fuel cycles promises enhanced production of eco-friendly tracers and gauges [1,2].

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Radiomic features from Baseline ^{18}F -FDG PET/CT for Early Prediction of Treatment Response in DLBCL: A Threshold-Based Decision Model

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Radiomics applied to baseline ^{18}F -FDG PET/CT provides a quantitative framework for characterizing tumor heterogeneity in Diffuse Large B-Cell Lymphoma (DLBCL)[1]. In this study, radiomic features were extracted from baseline PET/CT scans of fifteen patients using an IBSI-compliant workflow and systematically evaluated for their association with treatment response, defined by end-of-treatment Deauville scores. After preprocessing, variance filtering, and correlation-based redundancy reduction, univariate analyses (Spearman correlation, Mann-Whitney U testing with FDR correction) and ROC evaluation identified a small subset of highly discriminative features across intensity, heterogeneity, and textural domains. Among these, SUV_{peak}, Mean Absolute Deviation (MAD), GLCM ClusterShade, and GLSZM Small Area Emphasis (SAE) demonstrated the strongest separation between responders and non-responders, reflecting complementary dimensions of metabolic burden, intralesional heterogeneity, and fine-texture structural organization.

Using these features, a threshold-based decision model was developed to classify patients according to baseline radiomic signatures. Each feature exhibited a clear, ROC-derived separation boundary, and a composite rule requiring agreement in at least two high-risk directions produced consistent stratification. When applied to the full cohort, the model achieved a sensitivity of 92% for identifying non-responders and a specificity of 86% for identifying responders. These findings highlight that spatial-intensity heterogeneity metrics derived from baseline PET/CT carry meaningful prognostic information in DLBCL[3]. The proposed decision-rule framework offers an interpretable and clinically accessible foundation for early risk stratification and supports the broader integration of PET radiomics into response-adaptive lymphoma management strategies.

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Avidin –biotin based immunoradiometric assay (IRMA) procedure for Luteinising Hormone (LH) based on novel magnetizable cellulose particles containing manganese ferrite core

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Serum measurement of human luteinizing hormone (LH) is essential for the diagnosis and management of wide range of fertility related disorders as it provides crucial information regarding ovulatory function, menopausal status and endocrine abnormalities [1]. We describe magnetic particle and avidin–biotin interaction based immunoradiometric assay (IRMA) for LH. Anti-LH antibodies directed against two different epitopes of LH were used. Biotinylated, monoclonal anti-LH antibody is used as a capture antibody, whereas ^{125}I labelled monoclonal anti-LH antibody is used as detector antibody. Avidin bioconjugated to magnetizable cellulose particles containing manganese ferrite ($\text{Mn}_{0.1}\text{Fe}_{0.9}\text{Fe}_2\text{O}_4$) core [2] using carbonyl diimidazole activation method acted as a solid phase separation system. Biotinylation of anti-LH antibody was carried out using the caproyl derivative of biotin N-hydroxysuccinimide ester. Anti-LH antibody was radioiodinated with ^{125}I using conventional Chloramine-T oxidation method [3]. The specific activity of the radiolabelled antibody was maintained between 10-13 $\mu\text{Ci}/\mu\text{g}$, which is about one atom of ^{125}I per molecule of antibody. Advantage of spacer arm of caproyl derivative of biotin (biotinamido N-hydroxysuccinimide ester) was used to minimize the possible steric hindrance generally associated with binding of four biotinylated protein molecules to a single avidin molecule. The strategic use of magnetizable cellulose with Mn doped ferrite core with enhanced magnetic responsiveness of the particles improved the efficiency of magnetic separation resulting in a marked reduction in non-specific binding. Exceptionally high binding efficiency of avidin-biotin interactions, optimal specific activity of tracer and use of magnetizable cellulose with Mn ferrite core led to LH IRMA with better assay features. The developed assay has the sensitivity of 0.2 mIU/mL and standard range up to 200 mIU/mL to cover all the physiological and clinical need. All other analytical and clinical validation parameters such as variations, recovery, dilution parallelism, correlation with established method etc. as determined using standard assay methods were found to be well within acceptable limits. This assay can be used for routine analysis of clinical samples.



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A Universal Protein A Driven Immunocapture Approach Enabling Rapid and Cost-Efficient Isotopic Assays for Autoantibody and Hormone Analysis

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Protein A, a cell-wall component of *Staphylococcus aureus*, exhibits strong and highly specific affinity for the Fc region of immunoglobulins from multiple species, enabling its broad and longstanding utility in immunochemical techniques [1]. Traditionally, it has been employed in immunoassays as a separating reagent for bound/free ligand discrimination and as a universal tracer. More recently, advances in Protein A-based solid supports have further expanded its use in analytical platforms that require rapid, selective, and oriented immunoglobulin capture, providing a foundation for streamlined assay development.

Here, we present a novel assay format that leverages recombinant Protein A coupled to magnetic particles or polystyrene tubes as a solid-phase immunoabsorbent for the development of assays targeting TPO autoantibodies in autoimmune thyroid disease. Building on this versatile platform, we are also developing radioimmunoassays for microalbuminuria, aimed at detecting early renal damage, and for total T4 to assess thyroid function, using Protein A-coated tubes as a robust and reproducible capture phase. These applications demonstrate the adaptability of a Protein A-driven system to analytes of diverse biological relevance while maintaining a common underlying workflow.

Conventional diagnostic kits require antigen- or antibody-specific solid-phase coatings for each analyte, which increases production complexity, manufacturing time, and overall cost. In contrast, our universal immunocapture strategy allows detection of a wide range of autoantibodies or antibodies using a single Protein A-based solid phase. This unified approach eliminates the need to prepare multiple analyte-specific surfaces and offers the added advantage of oriented Fc-specific antibody immobilization, thereby ensuring optimal preservation of antibody activity and enhancing assay performance.

In conclusion, this innovative Protein A-driven platform provides a versatile, scalable, and cost-efficient approach that can be readily adapted to both isotopic and non-isotopic assay systems, including fluorometric, chemiluminescent, and enzyme-based formats. Emerging advances in Protein A affinity materials and membrane-based capture technologies further support its potential to streamline and modernize future immunodiagnostic development [2].



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Centralized Monitoring of Radiation Instrument using Network and Web Application

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Board of Radiation and Isotope Technology is primarily involved in production and supply of radiation sources used in various industrial, medical and research application. Various radiation sources are handled at facilities like Hot Cell, Radiopharmaceutical laboratories, radiography devices facilities etc. Monitoring of work place is crucial for safety of personnel, for protection of an environment and security of sources. In addition, centralize monitoring of radiation workplace provides useful input for handling any radiation emergency.

For centralize monitoring, all radiation monitors needs to be integrated into the single network. Modern radiation monitors support MODBUS over TCP/IP protocol and with it is now possible to integrated Modbus supported device into TCP/IP network seamlessly [1, 2].

At BRIT, Centralize monitoring system is demonstrated by integrating the radiation monitor with the network and hosting an application on a server. An automated script runs as a scheduled task on the server and it reads/collect information like device downtime, radiation level, alerts, alarms etc. from device's specified holding register. The collected data is inserted into backend database for monitoring and further analysis [1, 2].

Web application developed using PHP and MYSQL is used for data visualization and monitoring, generation of reports for compliance and safety audits, reporting of alert and notification. The current implementation provide a strong foundation for scalable deployment and it can be further enhanced by adding advanced analytic using machine learning.

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Design of compact 6/4 MeV RF Linac for Indigenous Cargo Scanner

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Dual-energy electron linear accelerators (linacs) offer a substantial improvement in cargo scanning systems for national security by delivering high-penetration, energy-selective imaging that enhances material identification and threat detection [1]. This paper explores the use of a dual-energy linac operating in the S-band at a frequency of 2856 MHz and incorporating a $\pi/2$ bi-periodic structure with on-axis coupling to ensure efficient beam acceleration and energy modulation [2]. The electron gun generates interlaced initial beam distribution, with cathode voltages of 20 kV and 13 kV for the 4 and 6 MeV energy respectively. A suitable bi-periodic accelerating structure has been designed with 9-1/2 accelerating cells and 9 coupling cells. The entire structure has been optimized with respect to acceptance, to reduce the energy spread and the tail effect of beam pulse [3]. The designed Q, shunt impedance and R/Q are 16000, 71.5 M Ω /m and 113 Ω . The beam dynamics simulation shows rms beam size of ≤ 2 mm at the target location and the energy spread of $\pm 5\%$ for both 6 and 4 MeV output beam.

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Indigenous Development of 2-Dimensional Position Sensitive Neutron Detector for Imaging Applications

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A 2-Dimensional Position Sensitive Detector (2-D PSD) based on multiwire structure [1,2] and delay line-based position encoding is developed for neutron imaging. Position of neutron arrival over the sensitive area is encoded through delay line readout method. 2D PSD has sensitive area of 90 mm x 90 mm and filled with ^3He gas. The stack of three multiwire grids is a heart of the detector, consists of Anode and X-Y readout grids. Anode consists of an array of $10\ \mu\text{m}$ \varnothing gold plated tungsten wires and X-Y cathode frames are made up of arrays of $30\ \mu\text{m}$ \varnothing gold-plated tungsten wires. Imaging is obtained using pulses from anode as trigger and delay between pulses from X and Y grids, forms a matrix. The histogram built over the time indicates the intensity profile image. Position resolution of 2D PSD is 1 mm x 1 mm and determines the accuracy of image reconstruction.

2D PSD is designed for low efficiency, to study online intensity variation of neutron beams from neutron scattering instruments at Dhruva reactor [3,4]. It offers wide range of applications from nuclear industry to medical imaging. It is being scaled up to sensitive area of 640 mm x 640 mm and high efficiency (85%) by increasing ^3He gas pressure. Challenges in scaling up involves fabrication and assembly of multiwire grid with desired precision. An Automated Grid Winding Machine is indigenously developed for precision of grid and minimize manual intervention. The machine caters to the accuracy of $\pm 50\ \mu\text{m}$ of wire and $1\ \mu\text{m}$ of position read.

2-D PSD is accurate and effective over the traditional photographic method and shows better dynamic range of intensity. It is specifically useful for medical imaging involving neutron sources, such as BNCT. Indigenous technology enables to tailor-make the design for specific application.

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Design and Development of an Integrated Automated System for Decayed Source Removal from Industrial Radiography Devices

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Industrial gamma radiography is a key non-destructive testing (NDT) technique used to detect internal flaws in engineering components [1, 2]. The Board of Radiation and Isotope Technology (BRIT) plays a vital role in development, manufacturing, and servicing of indigenous industrial radiography devices, including the safe removal and disposal of decayed radioactive, in compliance with national and international radiation safety requirements [3]. The existing conventional equipment for the removal of decayed industrial radiography sources involves extensive manual handling, leading to higher radiation exposure and lower operational efficiency. With nearly a thousand devices are getting processed annually, the management of disused or decayed Ir-192 sources has emerged as a significant operational and radiological safety challenge [4]. To address this challenge, BRIT has developed an integrated, remotely operable, and fully automated system for the Decayed Source Removal.

The system significantly reduces manual intervention and occupational radiation exposure, while expediting the overall decayed source removal process. The system comprises of device loading & unloading station, motorised conveyor system, hydraulic lifting mechanism, a lead-shielded enclosure, and hydraulic source-cutting arrangement etc. The enclosure equipped with lead glass windows is provided with high-definition cameras to facilitate real-time visual monitoring of the source-cutting operation on a remote display. A series of sensors and switches are integrated into a robust PLC-based control system for the precise, remote & automated operation.

This paper highlights the design considerations and challenges involved in the development of state-of-the-art system for Decayed Source Removal, aimed at achieving safer and more efficient management of decayed sources in industrial radiography.

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Radiotracer Investigation for Flow Distribution Analysis in the Feed-Effluent Heat Exchanger System of a Diesel Hydrotreater Unit

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A radiotracer investigation was conducted at diesel hydrotreater unit of a leading petroleum refinery of India, to assess the flow distribution and diagnose potential flow maldistribution in the feed-effluent heat exchanger system. The system comprises two parallel trains (A and B), each containing four brench lock heat exchangers (BLEs) arranged in series. Despite the symmetrical design and identical process conditions of both trains, plant observations indicated a significant temperature variation between the two trains, indicating possible flow channelling or shell-side fouling within the heat exchangers.

To quantify the flow distribution [1,2], a radiotracer study was executed by the Board of Radiation and Isotope Technology (BRIT) using Molybdenum-99 (Mo-99) as a radiotracer, which is having a gamma energy of 760 keV and a half-life of 66 hours. Two separate tracer injections (0.5 Ci and 1.0 Ci) were carried out into the common feed header under normal operating conditions. The passage of the tracer was monitored using collimated radiation detectors positioned at strategic points across the common header and both trains. The recorded detector responses were analysed using transit time and area-under-curve methods to determine flow rates and residence times.

The results consistently indicated unequal flow distribution, with Train-A carrying approximately 41–48% and Train-B carrying 60–64% of the total feed flow. The experimentally determined mean residence times (MRTs) across heat exchangers 1E (Train-A) and 1F (Train-B) were 61–65 seconds and 177–185 seconds, respectively. The significantly lower MRT in Train-A, compared to the theoretical value of 190 seconds, implies the existence of channelling or dead zones, likely caused by fouling on the shell side.

The study effectively demonstrated the utility of radiotracer techniques for non-intrusive, online diagnostics of flow behaviour in complex refinery process systems. The results provided quantitative evidence of flow maldistribution, enabling targeted corrective maintenance actions. It was recommended that the findings may be further verified through gamma scanning or other conventional methods to validate the identified flow irregularities.

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Characterization of hydrodynamics in fluidized bed reactor using radioactive particle tracking and machine learning approach

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The fluidized bed reactor is one of the most effective reactors for gas-solid processes, including pyrolysis, combustion, and gasification. The industrial application of this reactor is limited by several time and length scales constraints. These industries require an efficient multiphase reactor to achieve a high product yield. The primary issue in scaling up this reactor is the hydrodynamics. Various invasive and non-invasive techniques have been developed to identify these scales. The present study adopts a non-invasive radioactive particle tracking (RPT) technique for the development of a fluidized bed reactor ($D_r = 0.05, 0.1, 0.2$ m). The RPT was conducted based on prior investigations in a cold flow reactor employing glass beads (solid) and air (gas) [1]. The movement of a solid particle ($d_p = 0.35$ mm) has been tracked utilizing a Cobalt-60 (^{60}Co) ($t_{1/2}$: 5.27 y, γ : 1.17 MeV, 1.33 MeV, Activity: 450 μCi) radioisotope incorporated within the glass microsphere. This radioactive microsphere functions similarly to that of the glass beads and is monitored using eight NaI(Tl) scintillation detectors mounted at four distinct axial positions. The RPT data was acquired under varied working conditions, encompassing a range of superficial gas velocities from 0.1 to 1.25 m/s. The acquired data was analyzed using a position reconstruction algorithm to determine solid velocity, turbulence parameters, granular temperature, and shear stress. The solid radial velocity exhibits no significant fluctuations, whereas the axial velocity of the solid increases by 2 to 50% in the axial direction. The velocity vector illustrates the local recirculation patterns, quantifying the backmixing of solids and gases. Backmixing is a critical parameter that determines the quantity of steam consumed in the bed, hence mitigating cost penalties. The bed expansion measured from RPT data showed the 10 to 15 % global gas holdup in the reactor. Moreover, a machine learning algorithm has been developed to simplify the complex RPT process, utilizing calibration data alone to determine the precise positions of the radioactive microsphere (tracer particle). This step minimizes the significant time requirement caused by the Monte Carlo algorithm during position reconstruction [2].



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Evaluation of solid distribution in an elevated temperature gas-solid fluidized bed using gamma-ray densitometry

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Gas-solids fluidized beds are widely used in industrial process such as gasification, boilers, drying, granulation etc. However, in most of these applications the bed is operated at higher temperatures. Therefore, it is vital to investigate effect of temperature on solid distribution, which is critical for efficient heat and mass transfer.

In the current work, gamma-ray densitometry technique was used to measure the solid distribution inside an elevated temperature range-(50, 100, 150, and 200 °C) gas-solid fluidized bed. The experiments were performed in a 0.169 m inner diameter and 2 m height gas-solid fluidized bed. The ratio of solid bed height to column diameter was maintained 4 in all the experiments. To perform the gamma-ray densitometry experiments, both cesium-137 source (activity:50microcuri, energy 0.6617 MeV) and NaI(Tl) scintillation detector were mounted diametrically opposite in a moving carriage. The carriage was designed in such a way that it can move in both horizontal and vertical direction to scan the column radially and axially. The chordal average volume fraction of solids was measured for different temperatures (50, 100, 150, and 200 °C) and gas inlet velocities (2, 2.5 and 3 u_{mf}). In order to estimate the average volume fraction, the radiation intensities (counts/10 min) were recorded at three different process conditions i.e. empty system, system filled with solids and during fluidized conditions. The Able inversion technique was used to convert the chordal average solid volume fraction to radial average solid volume fraction [1]. These experiments will be performed.

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Investigation of Flow-Patterns in a Hot Fluidized Bed Using Radioactive Particle Tracking Technique

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Gas-solid fluidized beds are widely used in various industries such as chemical, petrochemicals, pharmaceutical, power plants, nuclear, etc. due to its better heat and mass transfer characteristics. However, the design and scaleup of such beds are still based on some heuristic rules. This is mainly due to the lack of flow dynamic data at desired conditions. To the best of authors knowledge, limited data is available for high temperature fluidized bed reactors. Also, no systematic studies are reported in literature on investigation of velocity fields of solid is within fluidized beds operated at high temperatures [1].

In the current work, radioactive particle tracking technique was used to investigate the solid flow fields within a high temperature fluidized bed reactor. Experiments were performed in a 3-inch diameter and 1.5 m long gas-solid fluidized bed reactor. The solid velocity fields were measured at different gas inlet velocities (U/U_{mf} : 2, 2.5 and 3) and temperatures (50, 100, 150 and 200 °C). The total bed mass is kept constant (3.6 kg) in all the experiments. Scandium-46 (activity 600microcurie, energy 0.8&1.2MeV) radioisotope uniformly doped within a glass bead was used as a tracer particle and 12 scintillation detectors strategically mounted and staggered around the bed were used to track the motion of the tracer particle during fluidization[2, 3]. Data was acquired at a frequency of 50 Hz. From the acquired data, the solid mean axial velocities, axial and radial rms velocities and granular temperature were estimated for all the conditions to find the effect of gas velocity and temperature on fluidized bed behavior. The data was compared with results of cold flow studies. It was found that the bed temperature significantly changed the solid flow field inside the fluidized bed.

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Time-Series Analysis of Radioactive Particle Tracking Data for Flow Regime Characterization in Gas-Liquid Stirred Tank Reactors

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Accurate characterization of flow regimes in gas-liquid stirred tank reactors (STRs) is critical for the design, scale-up, and optimization of multiphase mixing systems. This study investigates three-dimensional liquid flow fields in a lab-scale dual impeller gas-liquid STR ($T = 0.19$ m), equipped with radial and mixed flow impellers. A non-invasive Radioactive Particle Tracking (RPT) technique was used to capture detailed flow behavior under varying operating conditions. In RPT, a gamma source of Scandium-46 ($500\mu\text{Ci}$) is used to trace the liquid flow path. Using the Monte Carlo reconstruction code, the instantaneous position of the neutrally buoyant particle is found [1]. Further, velocity vector plots, mean liquid velocity, and turbulent kinetic energy (TKE) profiles were analyzed to evaluate the hydrodynamic influence of impeller configuration and impeller spacing. To further understand the chaotic nature of the flow, time-series data from the tracked particle were processed, using Kolmogorov entropy, following the approach of Nedeltchev et al. (2003) for bubble columns [2]. This entropy-based method enabled identification of flow regimes across different impeller speed and superficial gas velocities, and impeller-to-impeller spacing to impeller diameter ratio (S/D). Additionally, the individual contributions of the lower and upper impellers to local Kolmogorov entropy were assessed, revealing their distinct roles in flow and bubble dispersion. The integration of RPT measurements with Kolmogorov entropy analysis provides a robust framework for understanding complex flow patterns and enhancing hydrodynamic design in dual impellers STRs.

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ARTEMIS: A Robotic System for Autonomous Inspection and Digital Twin Generation of Nuclear Components

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This work proposes the development of ARTEMIS: an Autonomous Robotic Team for Environmental and Material Inspection and Simulation. Since the structural integrity of critical components like steam generators, pressure vessels, and primary coolant piping is paramount to the safe and extended operation of nuclear power plants. Also the current non-destructive evaluation (NDE) methods [1,2], while effective, are often labor-intensive, require significant human presence in radiologically controlled areas, and generate discrete data points that are challenging to integrate into a holistic asset management model. The core of the ARTEMIS system is a custom-designed, magnetically adhered crawler robot capable of traversing the complex vertical and curved ferromagnetic surfaces prevalent in nuclear facilities. This platform can be equipped with a multi-sensor payload specifically selected to gather data for both geometric modeling and component health assessment. A **Light Detection and Ranging (LiDAR)** scanner will capture high-fidelity 3D geometry, while a pulsed-eddy current array sensor will be used to map wall thickness and identify areas of corrosion or erosion [3]. Our sensor choice is unique, as it does not require any couplant and can operate through thin layers of insulation or coating. Simultaneously, an on-board gamma spectrometer will collect radiation field data, providing a crucial radiological context for further inspection.

The innovation of ARTEMIS lies in its integrated data processing pipeline. The raw sensor data can be streamed to a central server where a dedicated software framework fuses the geometric point cloud with the spatially registered thickness and radiation measurements. This fusion automatically constructs a "living" digital twin—a dynamic 3D model of the component where visual color maps intuitively display areas of degradation and elevated radiation [4,5]. Furthermore, this model won't merely be visual, future work explores development of an interface to feed the real-world thickness data directly into a finite element analysis (FEA) model. This will allow us to move beyond simple condition assessment to predictive modeling, calculating the component's remaining useful life based on its actual, measured state rather than conservative design assumptions [6]. This work will enable us to provide a tangible step towards fully autonomous, data-driven integrity management, with the potential to significantly reduce outage, minimize personnel radiation exposure, and inform life-extension decisions for the existing nuclear fleet.

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Characterization of Cow Dung Cakes: Powder X-Ray Diffraction, Radioactivity and X-ray fluorescence study

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Cow dung is a natural by-product of bovine digestion, it has long been accepted as a versatile energy resource [1,2,3]. for agricultural, environmental and industrial applications. Traditionally employed as a natural organic fertilizer and soil conditioner as it enriches soil fertility by delivering essential nutrients and enhances microbial activity. Apart from agriculture, it is one of the renewable energy sources and produces the energy as biogas production and contributes sustainable energy solutions and reduces reliance on fossil fuels. Its antimicrobial properties have also been harnessed in rural sanitation practices and eco-friendly construction materials, where cow dung has been used in building applications such as plastering, brickmaking, and insulation. However, its fibrous texture and binding qualities improve durability of construction. Moreover, it regulates indoor temperature and reduce reliance on synthetic materials. In the present work, we report our results on powder XRD, XRF and Radioactive experiments on cow dung, keeping in mind cow dung's wide applicability for sustainable and ecofriendly usages. The radioactivity measurements showed the safety usage, elemental analysis and powder XRD showed the nano-crystalline nature of the sample. The radiation attenuation protection capabilities have also been explored. The details of the work will be presented in this paper.

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Performance evaluation of a suitable over pack for safe transport of Low Dose Irradiator cask under impact loading

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Low dose irradiator, which contains Cesium-137 radio-isotope sources, is an equipment used to give controlled amount of radiation dose to a targeted object. These equipment are used in hospitals for blood irradiation and also in research laboratories for radiation study purposes. The irradiator consists of source housing which houses the Cesium-137 source in the form of sealed source pencil, drawer sub assembly and a driving unit. These equipment need to be safely transported in public domain as it houses radioactive sources. To ensure safe transport of these equipment loaded with radiation sources, an over pack is design to protect it from the damaging effect in the event of any untoward accident. As per regulatory requirement [1], the package which consists of the cask and the radioactive content needs to show its conformance against hypothetical accident loading conditions of transport such as 9 meter drop on an unyielding surface and 1 meter drop on a rigid punch. So, design of an over pack which can safely prevent the equipment from the damaging effect of the impact is paramount. This paper discusses the effectiveness of the over pack under impact load using finite element based numerical technique.

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Evaluation of gamma contribution in Am-Be neutron calibration field

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Americium-Beryllium (Am-Be) serves as a commonly utilized neutron source across diverse applications within the nuclear sector. This source exhibits an extended half-life of 433 years and demonstrates a substantial neutron yield of 2.2×10^6 n/s.Ci. The neutrons generated by Am-Be sources display a broad energy spectrum, spanning from 0.025 eV to 11 MeV, with a mean energy of 4.5 MeV. These characteristics make it particularly suitable for calibrating neutron survey meters. The Indira Gandhi Centre for Atomic Research (IGCAR) has initiated plans to establish a neutron calibration facility utilizing a sealed Am-Be source with an activity of 185 GBq. The precise neutron emission rate was determined using a manganese sulphate (MnSO_4) bath setup located at the RSSD, BARC. An important consideration when working with Am-Be sources is the inherent presence of gamma radiation within the neutron field, which can influence the measurements obtained from neutron detection instruments. Therefore, it becomes essential to quantify the gamma radiation's contribution to the neutron ambient dose equivalent rates. This study focuses on assessing the gamma contribution by determining gamma flux spectra and calculating the gamma dose equivalent within the Am-Be neutron field. Mowlavi and Koochi-Fayegh (2004) and, Craft (1989) have reported the gamma to neutron intensity ratio in the Am-Be neutron field [1,2]. The experimental setup was conducted in a spacious room measuring $8 \times 8 \times 5$ m, with measurements performed on an elevated platform 1.5 m above ground level to minimize scattering effects. Neutron dose rate measurements were performed using an Atomtex neutron rem counter at distances ranging from 100 to 200 cm, with measurements taken at 25 cm intervals. Gamma ray spectroscopy was conducted using a $2'' \times 2''$ NaI (TI) detector, which revealed three energy peaks at 3.4 MeV, 3.9 MeV, and 4.4 MeV. Two distinct methodologies were employed to calculate gamma ambient dose equivalent rates from the acquired spectra: one based on the G(E) function and another utilizing ICRP Publication 74 conversion factors. Comparative analysis of these two methods was in good agreement, with results differing by less than 5%. The findings indicate that gamma radiation contributes approximately 2.5-3.3% to the total neutron ambient dose equivalent rate within the Am-Be neutron calibration field across the measured distance range of 100-200 cm.

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Monte Carlo study on determination of residual activity produced in D-T neutron generators used for industrial purpose

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Neutron generators (NGs) are widely used in industry and research applications for activation analysis, radiography, and well-logging etc. In India, over 100 institutions are using neutron sources for production, testing, and analysis. The structural materials typically used in D-T generators are stainless steel (SS), copper, titanium or tantalum etc. This study determined the residual activity through simulation in the structural materials due to a 14.1 MeV collimated neutron beam, with maximum neutron emission rate of 1×10^8 n/s, with a typical operation time of 2,000 h, followed by a cooling period of 1 day. This could be achieved at an acceleration voltage of ~ 110 kV and a beam current of $80 \mu\text{A}$. The open-source FLUKA code was used for the simulation and analysis by using a cylinder of diameter and height of 1 cm each of SS, Cu, Ti, Ta materials. Combination of RESNUCLE and DCYSCORE cards were used for scoring the induced activity. Residual activity in structural materials results from reactions like (n,γ) , (n,p) , (n,α) , and $(n,2n)$ producing various radio-isotopes. The radioisotopes along with the activity concentration ($\mu\text{Ci/gm}$) shown in bracket for SS are ^{28}Al (0.53), ^{51}Cr (1.55), ^{56}Mn (2.6), ^{54}Mn (0.17), ^{55}Fe (0.5), ^{57}Ni (0.05), ^{58}Co (0.47), ^{57}Co (0.26), ^{52}V (0.69). Whereas isotopes along with the activity concentration produces for Ti are ^{45}Ti (0.05), ^{45}Ca (0.71), ^{46}Sc (0.81), ^{47}Sc (0.82), ^{48}Sc (2.76). In case of Cu and Ta, isotopes produced are ^{65}Ni (0.23), ^{64}Cu (8.5), ^{62}Cu (9.3), ^{60}Co (0.03) and ^{182}Ta (0.07), ^{180}Ta (11.5), ^{181}Hf (0.03), ^{178}Lu (0.004), respectively. Overall dose equivalent rate is found for SS surface as 10.6 mSv/h and uncertainty in the simulation is below 1%. Neutron activation in a D-T generator produces various radioisotopes of half-life from few mins to 5.27 years in structural materials and hence requires cooling and long-term storage before handling.

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Beyond Disposal: An Integrated Approach to Recycling and Repurposing Disused Category-I Cobalt-60 Sealed Sources in India

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India's extensive utilization of sealed radioactive sources (SRS) demands robust and effective management of disused sealed radioactive sources (DSRS) to uphold radiation safety and environmental protection. The Board of Radiation and Isotope Technology (BRIT) plays a pivotal role in pioneering initiatives to optimize DSRS management in India. This paper outlines the best practices followed in India for managing Category-I Cobalt-60 DSRS. The core innovation is BRIT's comprehensive approach to recycle and repurpose DSRS with sufficient activity. This strategy has not only been internationally recognized, aligning with draft IAEA recommendations for DSRS management, but also provides a sustainable pathway for high-activity sources. Specifically, this paper highlights BRIT's achievements in recycling Cobalt-60 teletherapy sources, their repurposing for high-radiation field applications and recycling of disused Multi-purpose gamma irradiator sources. By adopting this multi-pronged, circular economy approach, BRIT is significantly contributing to the safe, secure, and responsible stewardship of DSRS in India. Future research and international collaboration will further enhance DSRS management practices.

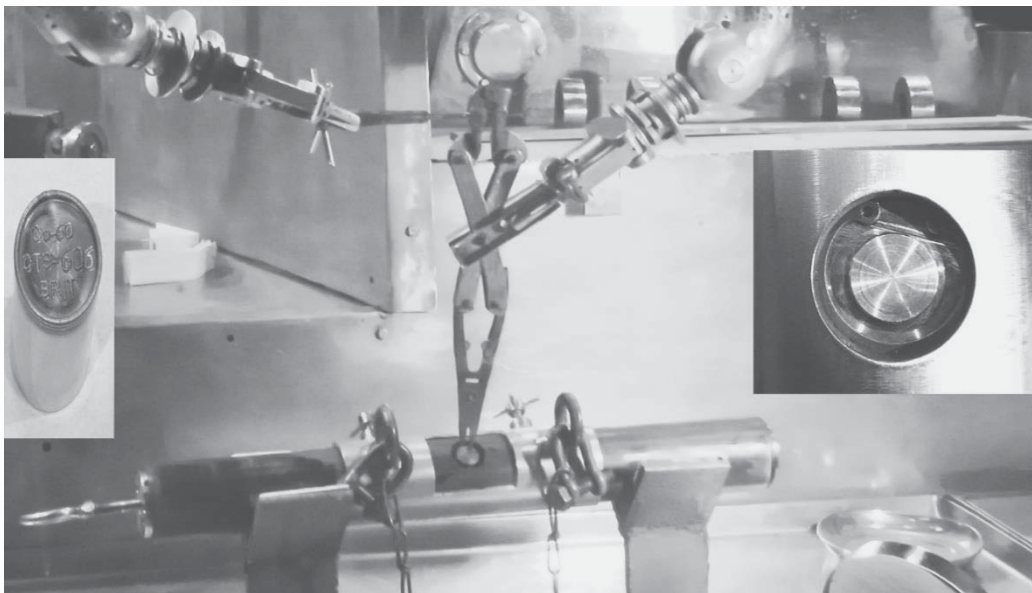


Fig. 1: Recovery of decayed Cobalt-60 Teletherapy Sources (CTS) from drawer in Hot cell

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Radiological Surveillance during Safe Transfer of a Disused Gamma Irradiation Chamber

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A very old Cobalt-60 based Gamma Irradiation Chamber, installed in a radiological laboratory, was taken up for source replenishment with a cobalt source possessing an activity of 2.4 kCi as on March, 2001. Over the years, radioactive decay of that replenished source led to a reduction in output; by the year 2023, the chamber's source could deliver a rate insufficient for ionizing samples efficiently and rendering it disused due to prolonged experimental exposure time and machine ageing. The measurement of the present irradiation dose rate offered by the Gamma Chamber was imperative before planning for its disposal. It was carried out by Fricke Dosimetry as described in [1]. Absorbance values of the Mohr's salt based Fricke solution were measured spectrophotometrically at different irradiation times, showing a good fit. The dose rates from the Co-60 source were calculated thereafter from these absorbance values. The average dose rate was found to be 0.1879 kGy/h with a standard deviation of 3.6%. The theoretically computed dose rate was 0.1803 kGy/h, which matched well with the experimental value. The activity of the source as on April, 2024 with a half-life of 5.27 years is calculated to be 115 Ci.

The detailed plan outlining procedural steps, safety controls, and transport arrangements, was submitted to the Atomic Energy Regulatory Board (AERB) for approval. Exhaustive radiation mapping and structural tests like Dye Penetration Test confirmed the Gamma Chamber's integrity which was necessary for obtaining the shipment approval certificate from AERB for transporting 115 Ci of Co-60 source. After the authorization, the outer containment of the Gamma Chamber was safely removed, the sealed source was placed in a shielded container, and transported in an approved type B(U) package for disposal [2]. Comprehensive documentation, radiation surveys, and dosimeter monitoring ensured exposure levels remained below regulatory limits, demonstrating strict adherence to radiological safety standards and regulatory compliance.

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Evaluation of Gross Alpha and Beta Radioactivity in water sources of Visakhapatnam, Andhra Pradesh, India

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This study aims to evaluate natural radioactivity in water sources of Visakhapatnam located along the eastern coast of India. Gross alpha and beta activity serves as a primary screening tool to establish radiological levels before detailed radionuclide specific analyses [1] in non-emergency conditions. Around 1300, 40 and 130 water samples from 165, 20,40 ground, surface, supply locations respectively were collected during the years 2016-2025 periodically in all seasons from Visakhapatnam rural and urban areas covering around 1500 SqKm. Water samples were analyzed for gross α and β activities by standard procedure [2] using the instrument alpha/beta Radiometer UMF-2000 by DOZA with a semiconductor detector of high-resistivity Al-doped silicon. The system was manufactured to count in simultaneous mode (counting both α and β activities at the same time) and it was calibrated using standard sources [²⁴¹Am for alpha and ⁹⁰Sr for beta of equal concentrations]. The background and samples were counted for 2 hours. The minimum detectable activity computed for gross alpha and gross beta are 1 mBqL⁻¹ and 100 mBqL⁻¹, respectively. Efficiency of the instrument was 35% for alpha counter and 25 % for beta counter.

Gross α activities recorded were in the range 0.001-0.11 BqL⁻¹, 0.001-0.01BqL⁻¹, 0.001-0.05 BqL⁻¹ and Gross β activities were <0.1 to 0.51 BqL⁻¹, <0.1 to 0.49BqL⁻¹, <0.1 to 0.22 BqL⁻¹, in ground, surface, drinking water. In few ground water locations gross alpha activity was slightly more than 0.1BqL⁻¹ but lesser than WHO drinking water limit 0.5BqL⁻¹. The quantitative differences observed in the sampling region are due to geological and geographical conditions as well as concentrations of radioactive elements present in the surrounding rocks etc. The results showed that gross alpha and gross beta activities in the aquatic region of the study area did not exceed international and national standards and were in comparable range with data available from other parts of India and the world [1,3 4]. To the best of our knowledge, this is the first systematic study of natural radioactivity in aqueous media of study region. The database established serves as baseline which can be used to evaluate possible future changes and is also useful in terms of public health guidance and further monitoring requirements.

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Secondary neutron quantification from Al ($^1\text{H},n$) system in a proton accelerator based medical isotope production facility

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In recent decades, number of proton cyclotrons has increased significantly for ^{18}F radioisotope production to ensure accessible and affordable healthcare. They typically operate between 10-20 MeV with currents up to 200 μA [1] for production of radiopharmaceuticals such as ^{18}F -FDG (fluorodeoxyglucose), ^{18}F -NaF (sodium fluoride) etc. [2]. Aluminium (Al) is a key element often used as energy degrader or component of vacuum chambers due to its low residual radioactivity generation potential, good machinability and high thermal conductivity [3]. However, the secondary neutrons emitted due to partial beam loss on these materials can have significant impact in radiation protection practices. Hence, the secondary neutron fluence (ϕ) and ambient dose equivalent ($\text{H}^*(10)$) rates during proton interaction on a 0.1 mm thick Al-foil has been experimentally measured at BARC-TIFR Pelletron facility, Mumbai to assess the possible radiation concern considering widespread use of Al in medical accelerators. Certain studies involving Al($^1\text{H},n$) system [4,5] has been reported, however the studies at proton energy range between 10-20 MeV has not been performed.

Present study investigates the neutron spectra, ϕ and $\text{H}^*(10)$ during tantalum collimated proton interaction with Al-target at energies between 12 to 20 MeV. Analysis shows that the fraction of low energy neutrons (<1 eV) remains constant ($\sim 12\%$), while the fast fraction (>100 keV) decreases from 63% to 59% with increasing proton energies. Experiment estimates that for a typical medical accelerator operating at 100 μA beam current with 1% beam loss in Al structures, the measured neutron $\text{H}^*(10)$ rate at 1 m from the target varies with energy from 4.51 to 71.40 mSv/h with ϕ variation between 5.81×10^3 and 1.02×10^5 $\text{cm}^{-2}\cdot\text{s}^{-1}$. Assuming a typical ^{18}F -FDG production cycle, the estimated neutron fluence variation would be $\sim 1.05 \times 10^7$ to 1.83×10^8 cm^{-2} indicating the need of accounting Al during shielding design and possible activation impacts during decommissioning.

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Comparison of Air Activity Measurements between Spot Air Sampler and Continuous Air Monitor in Presence of Short-Lived Radionuclides at Uranium Oxide Facility, Kalpakkam

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Continuous Air Monitors (CAM) and Spot Air Samplers (SAS) are two important devices used in nuclear facilities to assess airborne radioactivity in the occupational environment. While both instruments are effective in monitoring long-lived radionuclides, significant differences are often observed in their readings when short-lived radionuclides such as the decay products of radon and thoron are present. Typically, a CAM operates at a flow rate of around 30–50 litres per minute, whereas a SAS functions at a much higher flow rate of about 1000 litres per minute. Despite the CAM filtering a larger air volume over a long period, the total activity measured on its filter paper is often lower than that observed on the SAS filter collected for only a few minutes. This difference arises because short-lived progeny such as Po-214 and Po-212 (alpha emitters) and Pb-214 and Bi-214 (beta emitters) decay rapidly during the extended sampling period of the CAM. By the time the CAM filter is analysed, much of the short-lived activity has decayed, leaving only long-lived daughters such as Pb-210, Bi-210, and Po-210 to contribute to the count rate. In contrast, the SAS, which collects air over a short period (typically less than five minutes), captures the instantaneous activity of both short- and long-lived radionuclides before significant decay occurs. Spectrometric analyses using HPGe and alpha spectrometry confirm this behaviour, showing a full spectrum of short-lived isotopes in SAS filters, whereas CAM filters show primarily long-lived species. Mathematically, the difference can be explained using the decay equation $A = C Q (1 - e^{-\lambda t})$, where longer sampling durations (large t) lead to greater decay losses for short-lived isotopes. Therefore, SAS provides a snapshot of the total airborne activity at a given time, while CAM reflects the time-averaged concentration dominated by longer-lived radionuclides. Although relying solely on SAS data could overestimate airborne concentration, the CAM when properly calibrated and with a suitable alarm set point serves as a reliable indicator for real-time workplace safety and early warning against airborne contamination.

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Prompt and delayed radiation quantification during ^{89}Zr production through 14 MeV ^1H on natural Y target

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Cancer Diagnostics using positron emission tomography is dominated by ^{18}F isotope and the global production requirements is met through accelerator pathway [1]. However, diagnosis of slow pharmacokinetic processes is difficult using ^{18}F due to its short half-life. ^{89}Zr (half-life: 78.41 h) has gained significant popularity in the last decade for slow pharmacokinetic investigations and commercialisation of clinical grade ^{89}Zr is emerging [2]. Considering the future requirements and usage potential, it is worth evaluating the necessary radiation protection concerns during production and process optimisation for efficient shielding design of the accelerator based ^{89}Zr production facilities.

Accelerator based ^{89}Zr production with metallic or yttrium (Y) compounds have been reported previously for estimating interaction cross-sections and production yields [3, 4]. However, studies regarding secondary neutron yield, ambient dose equivalent, $\text{H}^*(10)$ and possible activation of structural/ shielding material from the radiation protection perspective have not been performed. Present work estimates the neutron yield and $\text{H}^*(10)$ using FLUKA simulations followed by experimental validation with 14 MeV proton bombardment on thick ^{89}Y target. The experiment was performed at BARC-TIFR Pelletron linac facility for a cumulative proton charge of 13.9 mC and neutron $\text{H}^*(10)$ along with induced activations in the target was measured. The neutron ambient dose equivalent was measured to be 51.89 ± 8.97 and $63.01 \pm 0.54 \mu\text{Sv} \cdot \mu\text{C}^{-1}$ at 88 cm from target at 90° and 45° direction with respect to the incident proton beam. The neutron yield per incident proton has been evaluated to be $\sim 1.58 \times 10^{-3}$. The target activation indicated presence of ^{89}Zr (dominant isotope), ^{88}Zr and ^{88}Y with specific activities of 1.1×10^8 , 1.7×10^5 and $3.8 \times 10^3 \text{ Bq g}^{-1}$ respectively, immediately after the irradiation. The FLUKA simulation estimated $\text{H}^*(10)$ and activation estimates corroborated well with the measurements. The study indicates the need for ensuring efficient radiation protection strategies and selection of constituents having low activation potential during shielding design.

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Dosimetric Evaluation of Medical LINAC-Based Blood Irradiation using Gafchromic HD-V2 Film

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Transfusion-associated graft-versus-host disease (TA-GVHD) is a rare but fatal complication of blood transfusion, caused by an immunologic attack by donor T lymphocytes on recipient tissues. Irradiation of blood components with ionizing radiation effectively inactivates residual lymphocytes, mitigating the risk of TA-GVHD [1]. Although self-shielded gamma irradiators exist for this purpose, their accessibility is limited in the hospitals. The medical linear accelerators (LINACs) due to their wide availability in the radiotherapy department of a hospital and its ability to deliver the radiation dose with high precision, is also used for blood irradiation. This study investigates the dosimetric accuracy of medical LINAC-based blood irradiation using Gafchromic HD-V2 film. A Polymethyl Methacrylate (PMMA) phantom with the provision of simultaneous irradiation of four blood packets was fabricated. Computed tomography (CT) images of the phantom with blood packets were acquired. A conventional AP-PA plan with the prescription dose of 25 Gy at the midplane of the blood packet was made on the acquired CT data using Radiotherapy Treatment Planning System (TPS). The approved treatment plan was delivered using 6 MV X-ray from a medical LINAC. Each blood packet was sandwiched between two films each measuring 6×5 cm². For calibration, the films were irradiated with doses ranging from 4 to 32 Gy using the same LINAC, where the delivered dose was predetermined. The EPSON 10000XL flatbed scanner was used to digitize the films. Both irradiated and control films were scanned together in landscape orientation 24 hours after irradiation to minimize inter-scan variability. A calibration curve correlating pixel values of the irradiated film to the corresponding dose was generated using indigenously developed film dosimetry system. The crossline and inline profiles of the films as well as 2D dose distribution of the films were evaluated. The maximum and minimum doses were found to be 23 Gy and 31 Gy respectively (within the acceptable window of 15 Gy to 50 Gy) which are sufficient to inactivate lymphocytes while minimizing damage to other blood components [2]. Gafchromic HD-V2 film based dosimetry confirmed that the delivered dose and dose distributions are within the prescribed tolerance for the blood irradiation procedures.

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Scalable α - $\text{Al}_2\text{O}_3\text{:C}$ Synthesis with Improved Defect Control for OSL Dosimetry

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The well-known OSL phosphor $\text{Al}_2\text{O}_3\text{:C}$ was initially synthesized on a large scale by us using a patented process, which involved melting high-purity Al_2O_3 in an argon atmosphere at 2080 °C [1]. However, this method had significant drawbacks, including substantial material loss (~40%) and difficulty in determining the correct furnace shutdown conditions, which required manual intervention. These issues were primarily caused by the deposition of alumina ash on the crucible, which obstructed the pyrometer and reduced process control. To address these limitations, a modified protocol was developed that significantly improves the phosphor's stability, reproducibility, and yield. The key revision was performing the melting in a high-vacuum environment (10^{-5} mbar) instead of an argon atmosphere. This change eliminated combustion-related alumina loss, previously caused by residual oxygen in the argon that led to flame formation and material burn-off. Furthermore, the absence of flame prevented pyrometer obstruction, resulting in better reproducibility and eliminating the need for manual intervention. The OSL sensitivity of the phosphor synthesized with this new method was comparable to commercial $\text{Al}_2\text{O}_3\text{:C}$, confirming its suitability for dosimetry. The vacuum process has been successfully optimized for large-scale production. Additionally, tests showed that in-house prepared undoped Al_2O_3 yielded the same TL/OSL sensitivity as commercial alumina when melted in the vacuum furnace. This indicates that the source of the alumina has minimal influence on defect generation, and using in-house material can significantly reduce production costs. Thus, the modified protocol provides an efficient, reproducible, and cost-effective route for large-scale synthesis of $\text{Al}_2\text{O}_3\text{:C}$ OSL phosphor for radiation dosimetry applications.

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Use of LoRaWAN IoT architecture in Realtime Personnel Dose Monitoring

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External radiation dose monitoring is an important aspect of occupational radiation protection and dose control. An Internet of Things (IoT) architecture using LoRa™ communication network is developed for real-time monitoring system of personnel dosimeters at the Beach Sand Mineral Unit of IREL (India) Ltd at Chavara, Kerala. This unit is a Naturally Occurring Radioactive Material (NORM) industry under DAE, India engaged in production of minerals such as - ilmenite, rutile, zircon, sillimanite, monazite, etc. The major radiologically significant component in this BSM unit is Monazite - the principal ore of Rare Earths and Thorium. During Monazite handling, it is imperative to employ radiation safety measures to mitigate the potential hazards of ionizing radiation [1]. This advanced personnel dose monitoring system integrates the sensitive and energy-efficient BG51 sensor (semiconductor Si PIN Diode radiation detector with dose rate range of $0.01\mu\text{Sv h}^{-1}$ – 100 mSv h^{-1} ; sensitivity of $5\text{ cpm}/\mu\text{Sv h}^{-1}$; energy response 50 keV - 3 MeV) with a modular communication board of low-power microcontrollers, IoT module (LoRa module of 1W Ebyte E220 series) and flexible 5dBi antenna of 865-867 MHz. Each compact and lightweight (<100 g) personnel tele-dosimeter or PTD is also equipped with internal 4000 mAh Li ion rechargeable battery, large OLED display (1.3", 128 x 64 px) and automotive grade temperature and humidity sensors all housed in an ABS enclosure of IP65 classification. Each PTDs displays and transmits cumulative dose (in μSv), radiation dose rate (in $\mu\text{Sv h}^{-1}$), date & time, % battery status, system temperature ($^{\circ}\text{C}$) and % humidity data at programmable frequency through LoRa modulation. LoRaWAN networks operate in a star topology that involves end-devices, gateways, a network server and communication links with different purposes [2]. The data generated by each PTDs is digitized, end-to-end encrypted, time stamped, and periodically transmitted to an 8 channel RAK Wireless LoRa Gateway, which forward data to server PC at HP Unit to decode, secure storage, visualization, alert handling and dose control/management. Customised software named IRRMS (Integrated Realtime Radiation Monitoring System) is also developed for data reception and processing in Python-Django framework for LINUX Operating System. This first of its kind system facilitates real-time personnel monitoring by secure data collection, display, recording, storage, analysis and evaluation to achieve automation in occupational dose monitoring and control.

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Evaluation of thermoluminescence of 50 MeV Carbon ion irradiated $\text{LiMgPO}_4:\text{Eu}^{3+}$ phosphors for medical dosimetry

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The study of the thermoluminescence (TL) properties of pure and Eu^{3+} -doped LiMgPO_4 powders irradiated with 50 MeV C^{6+} ions has been conducted, with an emphasis on their usability as dosimeters. The materials were obtained through the solution combustion method, and X-ray diffraction (XRD) was used to confirm the production of a crystalline orthorhombic phase with an average crystallite size of approximately 84 nm. The TL glow curves of the irradiated samples were measured with fluorescence from 1.74×10^{11} to 1.78×10^{12} ions·cm⁻². The Eu^{3+} -doped LiMgPO_4 phosphor at a concentration of 0.1 mol% Eu^{3+} exhibited a very prominent TL peak at about 412 K and two more peaks at approximately 479 K and 544 K; this behavior was similar to that observed in rare-earth-doped phosphates [1]. The TL intensity was found to be linear with changing ion fluence, which confirms its potential applicability in high-dose ion beam dosimetry. The kinetic parameters, such as activation energy (E) and order of kinetics (n), were obtained through the glow-curve convolution deconvolution (GCCD) method, which yielded a matching theoretical fit with the experimental data. The energy loss and ion penetration profiles were analyzed with Monte Carlo simulations based on the SRIM-2013 code, thus corroborating the experimental fluence–response trends [2]. The shaped TL curve, linear response, and reproducibility of $\text{LiMgPO}_4:\text{Eu}^{3+}$ even under Carbon ion irradiation imply its capability of being a dependable thermoluminescent dosimeter for carbon beam radiation therapy applications.

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Thermoluminescence Response of Dy³⁺ Activated Ca₇Mg₂(PO₄)₆ Phosphors under Gamma Irradiation

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This study investigates the thermoluminescent properties of nanocrystalline calcium magnesium phosphate doped with dysprosium (Ca₇Mg₂(PO₄)₆: Dy³⁺). This nano phosphor has been synthesized via a combustion method, and the dopant concentration has been optimized at 0.2 mol% based on the thermoluminescence (TL) intensity emitted after irradiation with a 200 Gy gamma dose in samples doped with different dopant concentrations. The synthesized nanopowder was characterized by using Powdered X-ray diffraction (P-XRD), Field Emission Scanning Electron Microscopy (FESEM) with Energy Dispersive X-ray Spectroscopy (EDS), and TL. The TL response was evaluated after exposure to ⁶⁰Co γ -irradiation, and a linear response was observed between 3 Gy and 2 kGy; the measurements confirmed that the response was dose-dependent. To study thermoluminescence, several features were examined using Chen's peak technique, a foremost rise technique [1]. It was clear from this material, after studying the linearity of the different dopant concentrations produced for gamma rays, that Ca₇Mg₂(PO₄)₆: Dy³⁺ holds considerable potential for use in gamma-ray dosimetry as a reliable means of radiation detection [2].

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Dosimetric parameters evaluations for BC-188 sources fabricated with a combination of lower and higher activity ^{60}Co inner capsules

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BRIT is supplying BC-188 ^{60}Co -sources (11.1 mm dia. x 451 mm ht.) to the gamma radiation processing facilities (GRAPFs) which are used for medical sterilization and food irradiation. Each source, also termed as source-pencil owing to its dimensions, comprises of two inner source capsules, of nearly same source strength. This ensures uniformity of radiation emission along the length of the source pencil. The source activity is usually measured, at a specified distance, from the source inside the dedicated hot-cells. And this measured activity, assumed to be uniformly distributed over the length of the source pencil, is considered in theoretical estimations of dosimetric parameters for the gamma irradiation facility [1].

The ^{60}Co required for the fabrication of industrial irradiator sources is obtained from the power reactors of India [2]. Depending on the irradiation positions of the Adjustor rods (^{59}Co target for neutron activation), in the reactor core and the irradiation period, the total activity obtained in ^{60}Co sub-assemblies vary over a range and this is reflected in the source activity of each retrieved inner ^{60}Co capsule. To fabricate the BC-188 sources of desired total activity, two inner capsules are chosen from the total lot available. Recently, there was a proposal to utilize a combination of a lower and a higher source activity of inner capsules for fabrication BC-188 sources. To study the case, it is assumed that BC-188 sources are fabricated, each of total 13 kCi activity with one inner capsule of 3 kCi and the other of 10 kCi. Each inner capsule is assumed to have an active length of 200 mm.

This study discusses the output from the proposed combination of lower and higher source activity of inner ^{60}Co capsules in the fabrication of BC-188 pencils. Theoretical estimations show that the effect of such a combination on the dose uniformity ratio (DUR) in the product processed in GRAPF is minimal and hence can be loaded in the facilities.

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Estimation of dose to driver for an Indigenous Drive-Through Cargo Scanner

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Cargo scanners are required in large numbers in Indian seaports and border check posts for screening to ensure efficient and secure movement of goods across borders. Cargo scanners use X-rays produced by linear electron accelerator (LINAC) for scanning. Dual energy X-ray based Cargo Scanner (moving gantry) is developed and demonstrated by BARC [1]. The 4 mm wide fan beam from LINAC, scans cargo slice by slice. The Drive-Through version with a maximum output of 2 Gy/min at 1m is being designed, which involves the cargo driven by driver during scanning. Here, beam is triggered after the driver cabin moves away from the scan region and driver receives dose only due to scattered radiation. This paper presents estimation of dose to driver during the scan by the proposed drive-through scanner.

Monte Carlo simulations [2] of the collimated X-ray spectra (6/4 MeV) of indigenous drive-through scanner falling on the Cargo were performed for quantifying driver dose by scattered photons from cargo material. The collimated beam from the LINAC is further collimated by secondary and tertiary collimators before falling on the cargo. Dose to the driver depends on area of the scatter, attenuating/scattering by cargo material, X-ray output and cargo speed. The dose to driver for cargo moving at speed of 1.1 m/s is estimated as 0.1 to 0.2 μSv per scan which is within the regulatory limits. The cargo with hydrogenous material is the most conservative as both scattering and the transmission of X-rays are maximum as compared to that of steel. Also, dose to driver decreases on increasing cargo speed. Measured dose to driver in a similar facility with 0.8 Gy/min X-ray output was less than 0.1 μSv per scan and found comparable with the estimated dose. This will be validated once the system is installed.

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Estimation of uncertainty in the True Dose-Rate Value at Reference Point in Neutron Instrument Calibration at IGCAR

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Indira Gandhi Centre for Atomic Research (IGCAR) has established standardized reference neutron fields for the calibration of neutron measuring instruments. The Radiation Standards Section (RSS) at Bhabha Atomic Research Centre (BARC), the designated institute for ionizing radiation metrology in India, carried out the standardization of a 185 GBq²⁴¹Americium-Berilium neutron source using their transfer standard. The certified emission rate of the source was determined to be 8.85×10^6 n/s with a standard uncertainty of $\pm 2.38\%$ [1]. During this standardization, the scattering contribution in the IGCAR facility was evaluated in accordance with ISO 8529, based on which three dose-rate values (250 μ Sv/h, 100 μ Sv/h, 75 μ Sv/h) as calibration points were established [2]. The middle dose-rate value (100 μ Sv/h) was adopted as the reference point for defining the calibration factor at the IGCAR neutron calibration facility. Reliable calibration of neutron measuring instruments demands accurate evaluation of the true dose rate at reference point and its associated uncertainties. In this study, the overall uncertainty in the true dose rate at the reference point was estimated in accordance with the *Guide to the Expression of Uncertainty in Measurement (GUM)* methodology [3]. The evaluation considered all relevant contributing factors, including the source emission rate, air attenuation, room in-scatter and out-scatter, source-to-detector, anisotropy, and fluence-to-dose conversion factors [4]. The calculated type B standard uncertainty in the reference dose rate was 8.22 %, with the dominant contribution arising from scattering effects. This analysis establishes a systematic and traceable methodology for uncertainty estimation in neutron measuring instruments calibration at IGCAR, ensuring conformity with national metrological standards and providing a robust basis for the reliable calibration of neutron dose-measuring instruments.

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Radiation Dose Assessment for Occupational Workers and the Public During Routine Operations in a Radionuclide Facility

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Iodine-131 remains one of the most widely used radionuclides in nuclear medicine, especially for the treatment of thyroid cancer. Due to the limited domestic production of ¹³¹I, bulk quantities are imported and formulated to fill the gap of production and supply. The imported bulk ¹³¹I is handled, formulated, and dispensed in dedicated hot cell facilities. Since, ¹³¹I is a long-lived β^- emitter with volatile characteristics, maintaining strict radiation safety practices is essential to protect both workers and the public [1]. These include routine radiation surveys, swipe tests, worker dose monitoring, airborne contamination checks, and environmental release assessments. The objective of this work was to evaluate radiation doses to occupational staff and the surrounding environment during routine operations. The study was conducted at our Iodine-131 dispensing facility, Molecular Radionuclide Pharmacy Pvt.Ltd., Ernakulam, Kerala. Workers routinely handle unsealed I-131 solutions inside shielded hot cells for dispensing the clinical doses. Also, they involve in quality control of I-131 and dispatching the radioactive packages. Given these tasks, regular radiation dose evaluation is necessary. Data were collected from January to October 2025. Occupational assessment included pocket dosimeters, whole-body and wrist TLDs, and airborne monitoring using a Staplex sampler. Public dose assessment relied on continuous exhaust-stack monitoring with GM counters and scintillation detectors. Environmental parameters such as negative pressure inside hot cells and adequate stack airflow were routinely verified. Across three quarters in 2025, worker exposures were well controlled. Most whole-body and extremity doses recorded 0.0 mSv as per TLD report, remaining below detection limit (BDL). Across three quarters in 2025, occupational exposures were well-controlled. One worker recorded a quarterly wrist TLD dose of 1.57 mSv during January–March which was attributed to a problem-solving issue of a returned consignment which was handled behind an L Bench in a fume hood, however, the chest dose to this worker was BDL. Public exposure data showed consistently low exhaust-stack readings (0.1–0.4 μ Sv/h) due to charcoal filter bank installed the hot cell, confirming controlled and safe environmental releases. Overall, the findings demonstrate that with disciplined safety practices and well-maintained engineering controls, both occupational and public radiation doses remain effectively managed in our I-131 dispensing facility.

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Baseline Radio-elemental Analysis of Soil Samples for ANURIB Project Site, Kolkata, India

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A baseline radiological analysis was carried out to evaluate the natural radio-elemental concentration in soil samples collected from the ANURIB (Advanced National Facility for Unstable and Rare Isotope Beams) project site at Rajarhat, Kolkata, India. The primary objective of the project is applications of radioactive ion beams in basic and applied sciences. The study reported here aims to establish the depth-wise activity concentration of naturally occurring radionuclides, ^{238}U , ^{232}Th , and ^{40}K and to provide a reference database for future environmental radiological surveillance and regulatory compliance.

Soil samples were collected from three depths (3 m, 9 m, and 26 m) from ground level and analyzed using a HPGe detector (Make: BSI; Model GCD-30 185). The radionuclides were identified and quantified using their characteristic gamma-ray lines appearing at 1764.6 keV (Bi^{214} for ^{238}U series), 2614.5 keV (^{208}Tl for ^{232}Th series), and 1460.8 keV (^{40}K) in the spectrum [1]. The measured activity concentrations ranged of ^{238}U , ^{232}Th and ^{40}K ranged from 12 ± 4 to 29 ± 11 Bq-kg⁻¹, 31 ± 8 to 53 ± 12 Bq-kg⁻¹, and 508 ± 47 to 633 ± 57 Bq-kg⁻¹, respectively. The lower values corresponding to the 3 m depth and the higher values to the 26 m depth, indicates an overall increasing trend with depth.

To assess the radiological hazard, the Radium Equivalent Activity (R_{eq}) was also calculated for each sample. The R_{eq} values were found in the range of 95-154 Bq-kg⁻¹ which is well below the recommended safety limit of 370 Bq-kg⁻¹ as per UNSCEAR guidelines [2].

This baseline study establishes a reliable and baseline reference dataset for radiological safety and environmental surveillance during the operational phases of the ANURIB facility in future.

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Isotopic Characterization of Gross Beta Constituents in Stack Effluents from a PHWR Reprocessing Plant

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The primary objective of reprocessing plant is to recover depleted uranium and plutonium from spent PHWR fuel. As per regulatory requirement, monitoring of airborne particulate radioactivity released through gaseous effluents in reprocessing plants is mandatory. The total gross beta activity in the stack effluent is estimated based on particulate activity collected on GF/A filter papers. For accurate source term assessment, it is essential to identify and quantify the specific radionuclides contributing to this gross activity. Accordingly, a methodology has been developed to identify and quantify the major contributors to gross beta activity in the stack effluents of the reprocessing plant.

Airborne particulates were collected from the stack monitoring system on GF/A filter papers. The filters were subjected to complete acid leaching to extract the associated radionuclides. Prior to radiochemical separation, the leachate was analysed by gamma spectrometry using a pre-calibrated N-type HPGe detector to quantify gamma-emitting radionuclides. Sr-90 was separated using calix-crown resins, employing tracer techniques for yield determination. The eluent obtained from calix-crown resins were subsequently analysed by liquid scintillation counting [1].

Gamma spectrometric analysis confirmed the presence of Cs-137 while no other radionuclide peak has been observed for gross beta constituent. The relative contributions of the identified radionuclides to the total gross beta activities are presented in Figure 1. The developed methodology provides a highly sensitive and reliable framework for comprehensive isotopic evaluation of airborne radioactivity in reprocessing plant environments. This approach enables accurate determination of source terms and facilitates dose apportionment, thereby supporting improved assessment of radiological impact and ensuring compliance with regulatory requirements.

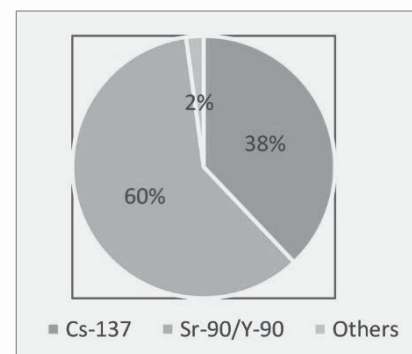


Figure 1: Gross Beta constituents

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Development and Validation of Method for measurement I-129 Activity in Iodine Sampling Cartridges

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Accurate determination of Iodine-129 activity in gaseous effluent is essential for monitoring radiological releases and ensuring compliance with safety standards. I-129 is one of the long-lived fission product released from nuclear fuel reprocessing plants. In the gaseous effluent, I-129 is sampled using silver-impregnated activated charcoal cartridges. I-129 decays by beta emission (154.4 keV) to stable Xe-129, which de-excites through a 39.6 keV gamma emission (7.5%) and internal conversion to the ground state. Direct efficiency calibration of high-purity germanium (HPGe) detectors using direct charcoal cartridges is challenging due to the non-uniform distribution of I-129 within the cartridge matrix. To overcome this limitation, a systematic approach was developed for accurate estimation of I-129 activity.

The charcoal from each cartridge was dislodged, homogenized, and weighted. Ten aliquots of the homogenized charcoal were prepared, crushed, and measured in a disc geometry using an HPGe detector (N-type, 35% relative efficiency, 300 μ m Be window). Detector efficiency calibration for this geometry was carried out using a mixed standard source containing Am-241, Cs-137, and Co-60. The activity of I-129 in each aliquot was determined from its gamma spectrum, and the average value was taken as the representative activity for the cartridge. This procedure was repeated for fifteen cartridges.

The HPGe spectrum of I-129 obtained from one of the aliquots is shown in Figure 1. The measured activities were validated against results from another laboratory that is using an established reference method [1]. The results show good agreement within $\pm 5\%$. For routine monitoring, dislodging of charcoal is impractical, so a correlation factor was established between direct cartridge counting and the activity derived from dislodged homogenized aliquots. The value of correlation factor found 2.20. Fig.2 shows the result used for correlation.

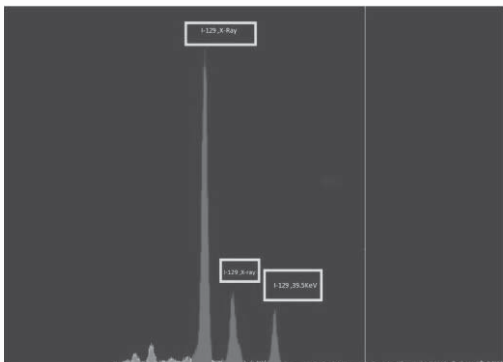


Fig. 1: HPGe spectrum of I-129

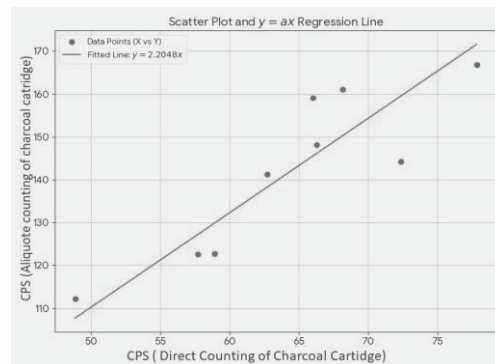


Fig. 2: Correlation between direct indirect counting

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Development of a new procedure for analysis of high active tritium liquids

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Heavy water is used as a coolant as well as moderator in PHWRs. During the operation, the coolant and moderator get irradiated producing tritium in both the primary heat transport system (PHT) and moderator system. Because of the long half-life the tritium, activity builds up to high concentrations in the heavy water. The concentration of tritium activity is analysed at regular intervals as per the established procedure. In the existing procedure, for high active tritium analysis, the sample is diluted to 10^5 times and analysed [1]. In this study a new procedure for analysis of high active liquid tritium samples is standardized and compared with the existing procedure. In the new method, it was observed that only 0.1 ml of high active solution can be used and a dilution of 10^4 times was performed in 100 ml water and 0.1 ml sample from this diluted solution for measurement purpose after proper mixing. The new procedure is developed to reduce the amount of radioactive waste generated during analysis and automation is used for adequate mixing of sample to reduce the time taken for analysis. The advantages mentioned above were achieved without compromising on the accuracy of results in analysis of activity. A TDCR (Triple to double coincidence ratio) based Liquid Scintillation Spectrometer-LSS system was used for the analysis [2, 3].

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Study on Seasonal variation of Indoor Radon and Thoron at Reprocessed Uranium Storage Facility

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The study analyses seasonal variations of indoor ^{222}Rn and ^{220}Rn levels in a reprocessed uranium storage facility. Measurements were conducted by deployment of RAD7 monitors at a height of 1.5m at three indoor locations of storage facility for 24h×3days on monthly basis over two years for both ventilated & non-ventilated conditions to capture monthly and seasonal cycles and to estimate implications for occupational exposure. Seasonal variation of ^{222}Rn and ^{220}Rn levels were assessed. The Annual effective dose to radiation workers from ^{222}Rn and ^{220}Rn was calculated based on indoor occupancy of 1 to 3h/d and using dose conversion factor of 6.7×10^{-6} mSv/Bqhm⁻³[1] and 107×10^{-6} mSv/Bqhm⁻³[2] by assuming equilibrium factor of 0.4 and 0.02 (UNSCEAR2000). The GM of annual average indoor ^{222}Rn concentration in the storage facility for non-ventilated conditions was 604.09 Bq/m³ (GSD 1.18) in 2023-24 and 619.47 Bq/m³ (GSD 1.17) in 2024-25, while for ventilated conditions, it was 76.52 Bq/m³ (GSD 1.63) and 71.87 Bq/m³ (GSD 1.58), respectively. For ^{220}Rn , the GM values in non-ventilated conditions were 27.34 Bq/m³ (GSD 1.12) and 27.61 Bq/m³ (GSD 1.11) for 2023-24 and 2024-25, respectively. In ventilated conditions, the GM for ^{220}Rn were 8.91 Bq/m³ (GSD 1.36) and 8.35 Bq/m³ (GSD 1.34) for the same periods. The annual average of ^{220}Rn in the facility for non-ventilated and ventilated condition for both the period is less than 38% and 92.35% of IAEA-BSS (2014) and national regulatory reference and ^{222}Rn in non-ventilated condition lying in the range of ICRP103(2007) reference level of 600 Bq/m³ while for ventilated condition, it is less than the ICRP126(2014) recommend value of 100-300 Bq/m³. The Indoor ^{220}Rn concentration in winter season for the year 2023-24 and 2024-25 is ranged from 617.90-848.73 Bq/m³ and 605.78-828.74 Bq/m³ respectively for non-ventilated condition while for ventilated condition it was ranged from 74.41-184.92 Bq/m³ and 61.97-153.21 Bq/m³ respectively which are higher among all season and lower in summer season and is ranged from 469.12-581.79 Bq/m³ and 501.11-605.07 Bq/m³ for non-ventilated condition and for ventilated condition it was ranged from 39.27-61.05 Bq/m³ and 27.66-64.10 Bq/m³ respectively. The ^{220}Rn concentration in winter is not significantly higher and shows weak seasonality in both cases of ventilation due to its short half-life. Seasonal patterns of indoor ^{222}Rn were observed under constant air changes in ventilated conditions. The results highlight that effective ventilation management significantly reduces ^{222}Rn and ^{220}Rn levels, minimizing worker exposure, especially during colder months. The annual inhalation dose



for 1-3 hours of daily occupancy in ventilated conditions during the monitoring periods (2023-24 & 2024-25) ranged from 0.05-0.93 mSv/y for ^{222}Rn and 0-0.03 mSv/y for ^{220}Rn , which are significantly lower than the doses in non-ventilated conditions. These doses are well below the reference level and consistent with other exposure scenarios.

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Estimation of Radioactive content in Fertilizers available in the local Markets of Chengalpattu District and Radiation Hazard Indices

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Human beings are continuously exposed to radiation from cosmic radiation from space or naturally occurring radioactive materials on earth which is generally referred as background radiation. Fertilizers are chemical substances, which are added to soil either in organic or inorganic form for plant growth and also to provide with essential nutrients. Nutrients essential for plant growth is broadly classified as Primary nutrients & Secondary nutrients. Nitrogen (N), Phosphate (P) & Potash (K) are called as primary nutrients. Two types of chemical fertilizers are available in local market of India with different compositions NPK (Nitrogen, phosphorus & Potassium) and DAP (Di ammonium Phosphate). Since fertilizers contain radioactive elements they are included among Naturally Occurring Radioactive Material (NORM). Crops absorb these radionuclides through the fertilizers. When human beings and cattle's consume these agricultural products, the radionuclides enter the food chain posing health risks. The main objective of this study is (i) To evaluate the specific activity levels of natural radionuclides in fertilizers available in the local markets of Chengalpattu district of Tamil Nadu. (ii) To assess radiological risk by calculating the radiological parameters

Samples were collected from the local markets of Chengalpattu, Tamilnadu. The samples were of both organic and inorganic. The samples around 1 kg was collected in the zip lock cover and labelled by their names. The fertilizer samples were grinded to powder, sieved through the sieve of 2mm and packed in plastic bottles. The specific activity of NORM (Naturally Occurring Radioactive Materials) K-40, Ra-226 and Th-232 were measured using HpGe (High Purity Germanium) based gamma spectrometer.

The study revealed that the NORM content and thus hazard index values are always higher for phosphate fertilizers and gypsum. The specific activity of the ⁴⁰K and ²³²Th is less than the UNSCEAR reported world average. The radiological hazard indicators are higher for phosphate fertilizers; the indicators are less than the recommended values in other fertilizers. There may be a continuous accumulation of NORM content in soils if the NORM removal process does not happen through natural processes like rain. Further, the NORM uptake in plants and the ingestion route exposure must also be studied.

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Safety and Security Lessons from Incidents of Loss of Industrial Radiography and Well Logging Sources in India

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Industrial Radiology (IR), which utilizes ionizing radiation such as gamma rays, X-rays, and neutron beams, plays a vital role in quality control, defect detection, and structural assessment across various industries through non-destructive evaluation (NDE) of critical structures and components [1]. Commonly used gamma sources for this purpose are Co^{60} , Ir^{192} , Se^{75} etc. The non-destructive evaluations are usually carried out either in shielded enclosures or in work-shops, industrial facilities etc. For this the radiography devices with source are transported from one place to another frequently through public domains. These devices can be transported following transport regulations² stipulated by AERB. Transporting Gamma Radiography exposure devices through public domain involves proper packaging and anchoring of the device in vehicles with further marking and labelling on the vehicle also. These gamma radiography devices housing Co^{60} , Ir^{192} , Se^{75} etc. are generally meet transport package regulations for Type- B(U) or Type-A [2].

Well logging is an evaluation technique, which provides fast and detailed data for subsurface and structural mapping of geological formation for exploration of mineral resources particularly oil, gas and coal [3]. The well logging operation involves the use of sealed radioactive sources and portable mini-neutron generators in suitable logging tool for oil exploration. The different techniques like Neutron-Neutron (n-n) Logging, Neutron-gamma (n- γ) logging, Gamma-Gamma (γ - γ) logging are used for detection purpose. The commonly used gamma and neutron sources for this purpose are ^{137}Cs , $^{241}\text{Am-Be}$ and D-T generators. Similar to the industrial radiography these sources are frequently transported from one place to another through public domains, usually in Type-A packages.

Given the use of high specific activity sources and potential consequences of any lapse in control, the licensee is required to obtain approval from the Competent Authority prior to the transport of radiography devices and well-logging sources. The Radiological Safety Officer (RSO) must ensure safe movement of Industrial Gamma Radiography Exposure Devices (IGREDs) and verify that packages containing radiography sources are properly packed, labelled, and declared as per national and international transport requirements for radioactive material [4].

Despite these regulatory provisions, two incidents of loss of radioactive sources during transport were reported to AERB. In both cases, although the packages were eventually recovered intact, it was observed that members of the public who encountered the packages were unable to recognize the radiation warning markings and therefore did not immediately alert authorities. Following investigation, AERB directed all the licensees of the respective practices to additionally implement stainless-steel tags with legible and durable radiation-warning signs (trefoil symbol with



hazard cautions engraved in English, Hindi, and the local language) to be securely attached to IGREDs and well-logging source packages. This measure aims to enhance recognisability and improve public response during unforeseen events.

This paper presents case studies of the two incidents of loss of radioactive sources involved in these applications during transport and field operations in India. The incidents highlight deficiencies in physical security measures, inadequate anchoring of transport packages, and certain vulnerabilities associated with road transport. Actions taken by the AERB, lessons learned, and resulting regulatory enhancements are discussed. The study emphasizes the importance of a strengthened safety culture, robust transport practices, and greater stakeholder awareness to prevent recurrence.

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Strengthening Radiation Safety through Comprehensive Safety Assessment Report of Radiotherapy Facilities

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Safety assessment is the process of evaluating the safety of a radiation facility and identifying and quantifying its potential impact on health and the environment. Strengthening radiation safety in radiotherapy facilities requires a systematic and proactive approach to identifying and managing risks associated with high-energy radiation equipment and complex treatment procedures. A safety assessment report describes the measures that would be implemented in a radiotherapy facility to restrict the exposure of radiation workers and public from radiation sources/equipment and undue dose to patient to ensure radiation safety during radiotherapy treatment in normal working conditions and in off-normal scenarios. SAR is to ensure that the facility, equipment, shielding, and procedures are designed and operated with adequate safety for patients, radiation workers and the public.

As per Rule 21(3) of Atomic Energy (Radiation Protection) Rules, 2004, every licensee shall establish written procedures and plans for controlling, monitoring and assessment of exposure for ensuring adequate protection of workers, members of the public and the environment and patients, wherever applicable. In addition, as per clause 4.2.2.3 of AERB Safety Code "Regulation of Nuclear and Radiation Facilities - AERB/SC/G", one of the requirements for an applicant (radiation facility) is "Safety Analysis Report and relevant documents shall be submitted to the Regulatory Body to facilitate a systematic review and assessment of procedures". Recently AERB has developed a guiding document to help the user institution which is helpful for the radiotherapy facilities for the preparation of safety assessment report.

Key elements of safety assessment report includes safety assessment for shielding adequacy of radiotherapy installation, safety assessment during normal working conditions and off-normal conditions (e.g.: source stuck, wrong dose delivery, failure of safety interlocks, non-adherence to operational safety procedure etc.), control measures during operation and storage of radiotherapy equipment/sources, safety assessment during transport of the radiotherapy sources, management of disused source, decommissioning of radiotherapy equipment etc. At present the guiding document for safety assessment report prepared by AERB are being used by the radiotherapy facilities. It is used to identify, analyze and mitigate the severe risks associated with delivering high doses of ionizing radiation to patients. A thorough safety assessment verifies that the facility design provides adequate protection to patients, workers, and the public by evaluating shielding adequacy, equipment performance, workflow, and emergency preparedness. It is also a regulatory requirement to maintain compliance with national standards and to demonstrate that the facility meets all safety and quality norms prescribed by authorities such as the AERB. Ultimately, safety assessment builds a strong



safety culture, minimizes risks of accidental exposure, and ensures consistent, high-quality radiotherapy treatments.

Safety assessment report is essential for proactive risk estimation and prevention, justification and optimization of radiation doses, regulatory compliances and licensing, developing the safety culture in radiotherapy department and its continuous improvement.



Requirement of Radiation Protection Program (RPP) for Radiotherapy Facilities: Strengthening Radiation Safety

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Radiation Protection Programme is designed to demonstrate management responsibility for protection, safety and optimization using management structures, policies, procedures and organizational arrangements. As per Rule 21(3) of Atomic Energy (Radiation Protection) Rules, 2004, every licensee shall establish written procedures and plans for controlling, monitoring and assessment of exposure for ensuring adequate protection of workers, members of the public and the environment and patients [1]. Radiotherapy institutions currently provide key components of the Radiation Protection Programme (RPP) to the AERB at different stages of the licensing process. However, it was realised that a comprehensive RPP, covering all required safety elements is more useful while reviewing the application pertaining to issuance licence for operation of radiotherapy equipment. Therefore, AERB developed a guiding document which will be helpful for the radiotherapy facilities for preparation of RPP.

Key elements of the RPP includes description of management structure with assignment of responsibilities for radiation safety; a complete list of personnel involved in the radiotherapy facility along with details of the equipment and radiation sources; an education and training programme on safe operation of facility, with provisions for maintaining training records; Standard Operating Procedures for all activities related to radiotherapy treatment; the designation of controlled or supervised areas in the facility; a health surveillance programme for occupationally exposed workers; the constitution of a Local Safety Committee to ensure occupational and radiation safety; emergency preparedness plans; methods for periodically reviewing and auditing the performance of the RPP; a security plan for radiation sources; and procedures for decommissioning radiotherapy equipment and managing disused sources.

At present the guiding document prepared by AERB are being used by the radiotherapy facilities. A Radiation Protection Program (RPP) is essential in radiotherapy facilities because it establishes clear procedures for dose monitoring, shielding design, equipment quality assurance, safe handling of radioactive sources, and emergency preparedness. By defining responsibilities, ensuring regulatory compliance, and promoting a strong safety culture, the RPP minimizes radiation risks, prevents accidental exposures, and supports consistent, high-quality patient care. Overall, it forms the backbone of safe radiotherapy operations and ensures that therapeutic benefits are delivered without compromising safety. The RPP also supports Human and Organizational Factors (HOF) by providing a comprehensive, well-documented framework that helps new personnel to quickly understand the facility's safety practices, roles, and responsibilities, ensuring continuity even when staff change. By maintaining regulatory compliance and fostering a strong safety culture, the RPP minimizes radiation risks, prevents accidental exposures, and supports consistent, high-quality patient care.



An effective Radiation Protection Program (RPP) aims to ensure the safety of patients, workers, and the public by keeping exposures ALARA and within regulatory limits. It establishes clear procedures, documentation, and a strong safety culture including HOF aspects to support consistent and safe radiotherapy operations. It also ensures proper quality assurance, incident management, and emergency preparedness to prevent and control radiation risks.

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Impact of Revised International Regulations for Safe Transport of Radioactive Material in India

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Regulations for safe transport of radioactive materials in India are primarily governed by the Atomic Energy Regulatory Board (AERB)'s code AERB/SC/TR-1 formulated in 1986 based on the guidelines formulated by International Atomic Energy Agency (IAEA) standards (1985 edition) [1,2]. These guidelines are reviewed and revised from time to time. The code AERB/SC/TR-1 was later revised in 2016 and identified as AERB/NRF-TS/SC-1 (Rev.1) [3]. The revised code contained advanced and improved regulations aligned with the IAEA SSR-6, 2012 edition [4]. Subsequent to the publication of the revised AERB code, IAEA further revised its IAEA SSR 6, 2012 edition and published a revised edition in 2018 titled IAEA SSR-6 (Rev. 1) superseding IAEA SSR 6, 2012 edition [5]. Therefore, before revising and implementing the revised IAEA guidelines in India, a detailed feasibility study was carried out to identify key changes that would impact the transport of radioactive materials in India. Some of the major changes that has large impact on transport of radioactive material includes:

1. Requirement for package design to consider ageing mechanisms.
2. Shipment after storage
3. Packages meeting the 1996-2012 editions are allowed for transport until December 31, 2025, and thereafter with multilateral approval.
4. No new manufacturing of packaging meeting the 1996-2012 SSR-6 editions is permitted to commence after December 31, 2028.
5. No new manufacturing of special form radioactive material with unilateral approval by the Competent Authority under the 1985 and 1996-2012 editions is permitted to commence after December 31, 2025.

The impact of the revision in IAEA SSR-6 Rev. 1 on packages used for the transport of radioactive materials in radiation facilities needs to be assessed and package designers and licensees/consignors need to be accordingly sensitised. The designers must now incorporate newly introduced ageing mechanisms in the package design to ensure long-term safety and regulatory compliance [6]. This will facilitate smooth and uninterrupted international shipments of radioactive materials and align with evolving global safety standards.



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Performance tests of different models of handheld XRF gauges

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X-Ray Fluorescence (XRF) techniques are used to measure the energy of the characteristic fluorescent X-rays emitted, for qualitative and quantitative analysis of element. Cabinet types of XRF units are used in many institutional laboratories, where samples are brought to the laboratory for analysis [1]. Similarly, for in-situ applications handheld XRF units are used for positive material identifications (PMI), which is a quick and real-time evaluation. Use of handheld XRF gauge at site involves sorting scrap metal, verifying alloys, screening for heavy metals in soil, testing precious metals and checking the composition of consumer goods/raw materials in various industries. Nowadays bench top/handheld-XRF units are coming to the market in India, which is operated at high electrical power. Hence, thorough assessment is necessary from radiological safety point of view.

Atomic Energy Regulatory Board (AERB) is the regulatory authority, who ensures that use of ionizing radiation in India does not cause undue risk to the health of people and environment. So any radiation generating equipment prior to use in India, need to be approved by AERB [2]. Applications for grant of Type Approvals were received for 14 different models of handheld XRF at AERB, from a manufacturer. The performance tests of each model of the handheld XRF unit were carried out at supplier's facility. Various test viz. kV, mA, dose, dose rate, interlocks and safety systems were carried out on these models of the above handheld XRF units. Based on the test report, Type Approvals were granted by AERB, for the above models of handheld XRF gauges. This paper discusses about, various testing methods adopted during the evaluation process, which would serve as guideline to the others. Also, this paper discusses about the additional safety precautions to be adopted for specific models of handheld XRF units (which emits higher backscatter radiation) during use of the equipment.

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Monte Carlo Simulations of High Energy Proton Beam

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High-energy proton in the range 70 MeV-235 MeV are used for treatment of cancers especially for the pediatric cancers, ocular cancers, brain tumors, head & neck cancers and those near the vital organs. Protons is a charged particles and hence it deposits large amount of energy with a small thickness of tissue (due to its Bragg Peak). Thus, proton has the advantage of depositing high radiation dose within the small tumor volume and there is no exit dose associated with it. Also, the surrounding organs and healthy tissues are spared. This reduces the radio-toxicity and other side effects associated with the treatment. The number of Proton Beam Therapy facilities are increasing in India and hence there is a need to acquire more data, for many radiation protection applications in the country.

The FLUKA (FLUktuierende KAskade) Monte Carlo beam transport code was used to simulate a 235 MeV therapeutic proton beam, incidenting on a homogeneous water phantom of size 40 cm x 40 cm x 40 cm (which replicates a patient) [1]. The spallation and fragmentation reactions associated with such high energy proton serve as the source of high-energy secondary particles. These secondary particles emitted are not desirable and increases the risk towards the secondary cancer. Hence, for many future radiation protection challenges associated with therapeutic proton beam, ideas about the emitted secondary particles are desirable, through these basic simulations. Thus, this simulation focuses mainly on characterizing the secondary radiations viz. proton, neutron and gamma radiations emitted after interaction of 235 MeV proton beam with water (tissue) medium. Proton, Neutron and Gamma spectral fluence, energy spectrum and angular distribution of the above secondary particles emitted after interaction, were studied through Monte Carlo simulation.

The simulation data acquired would further help for estimation of ambient dose equivalent, dose estimation of the secondary organs, secondary cancer risk assessment, treatment planning, study of DNA damage pattern and many other future radiological protection challenges. The simulation data is also helpful for developing a new analytical model (based on the modified Moyer Model), which is a quicker method for estimation of biological shielding, for the treatment room.

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Regulatory Inspection of Radiation Facilities in India

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Radiation sources such as radioisotopes (^{60}Co , ^{137}Cs , ^{192}Ir , ^{75}Se , ^{241}Am , $^{99\text{m}}\text{Tc}$, ^{85}Kr etc.) and radiation generating equipment (X-ray machines, accelerators etc.) are being used in multifarious applications in industry, medicine, agriculture and research for societal benefits. There are 649 Radiotherapy facilities, 528 of Nuclear Medicine facilities, 190 of Research / Academic Institutions using Sealed / Unsealed Sources, 73282 Diagnostic Radiology facilities, 768 Industrial Radiography facilities, 1278 Nucleonic Gauge facilities, 55 Well Logging facilities, 47 Radiation Processing facilities, 110 Gamma/X-Ray Irradiation Chamber facilities, 22 Medical Cyclotron Facilities, 11 Research Accelerator Facilities and 22 Container Scanning facilities etc. that are being used in India. In order to ensure radiation safety, Atomic Energy Regulatory Board (AERB), Mumbai, regulates these varied kinds of Radiation Facilities in a graded approach manner, commensurating with the hazard potential associated with them. Regulatory Inspections (RI) is one of the key processes of the AERB through which it ensures that the activities performed by the Licensee during all the phases (viz. siting, construction, commissioning, operation, decommissioning, and release from regulatory control) of the life cycle of Nuclear and Radiation Facilities are executed in compliance with the conditions of the License and relevant safety requirements. In this paper, AERB, India's approach for Regulatory Inspection (RI) of Radiation Facilities (RFs and international practices on RI of RFs are discussed.

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Characterization of Radiation Absorption Behaviour of Banana Leaves and Stems for Green Shielding Solutions

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Shielding of nuclear radiations is an important component of radiation safety aiming to reduce personnel exposure to ionizing radiation. Well known radiation shielding materials are Lead, water, concrete, etc. Recently, natural fibers have received lot of interest for the development of composite materials for radiation shielding due to their sustainable, biodegradable, eco-friendly and economic properties as natural resources [1]. Natural fiber is also used for reinforcement of concrete, aluminium sheet etc., to improve their performance as a radiation shielding materials [2]. Natural fibers could be extracted from different plants (e.g., cotton, hemp, jute, flax, ramie, banana etc.) and animals (chicken feather, hair, etc.). Researchers also studied the moisture content effect of banana leaves to absorb radio frequency. Aim of the present work is to study the radiation absorption properties of environmentally friendly natural material such as banana leaves and stems. Banana leaves and stems were divided into circular ring pieces. Banana leaves and stems of various degrees of thickness were prepared by stacking one circular ring to another for the experimental work. Gamma radiation over a wide energy range (59.6 to 1332 keV) and beta radiation from a pure beta emitter were used to study the attenuation characteristics. The nuclear parameters such as total mass attenuation coefficient (μ/ρ), linear attenuation coefficient (μ) for gamma rays, Half Value Layer (HVL) were calculated for banana leaves and stems. Mass attenuation coefficient (μ/ρ) and linear attenuation coefficient (μ) of banana leaves and stems were compared with other shielding materials like aluminium, polyethylene and copper. Results indicate that these natural materials also exhibit promising shielding capabilities against beta radiation. This study contributes to understand the shielding effectiveness of banana fibers for potential use in composite radiation-shielding materials. Future work will extend to evaluating the neutron absorption behaviour of banana leaves and stems, considering their high moisture content.

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- µSv/hr - .01 to 1000
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- CPM - 0 to 350,000
- CPS - 0 to 5000

Accuracy

Referenced to Cs137/Co-60 Typically ±15%

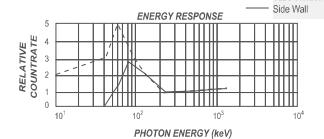
Size: 140 X 68 X 33 mm (5.5 X 2.7 X 1.3 in.)

Energy Sensitivity

- 3340 CPM/mR/hr referenced to Cs137
- Detects Alpha down to 2 MeV.
- Detects Beta down to .16 MeV; typical detection efficiency at 1 MeV is approx.25%.
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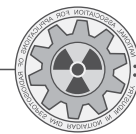
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Experience.... Our Expertise



ABOUT US:

Over 58 years of experience in the field of Non-Destructive Testing having operations in India, GCC, Africa and expanding worldwide.

The hard work, sincerity and dedication put together have brought us to its present standing with the inclusion of all the NDT test methods under our wing. This includes test methods like Radiography (Conventional and Advanced), Ultrasonic (Manual and Automated), Magnetic particle, Liquid Penetrant, Eddy Current Etc.

There is not a single project of typical nature in India for which IXAR has not worked and thus vast experience gained, is the base of its full confidence to undertake any challenging job irrespective to size and technical complexities.

Ixar strives for excellence in the concept of quality, soon realized the fruit of popularity and is certified with ISO 9001:2018, IXAR strives ahead to acquire latest technology to cope with the present day challenges in the field of NDT.

Today, IXAR is established leader in the field of Non-Destructive Testing methods all over India and in some part of the world. As on date company has dedicated staff strength of more than 1000 employees under its various wings.

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OUR SERVICES:

- Cross country Pipeline using Crawlers
- Conventional Radiography using X-ray & Gamma
- Close proximity Radiography using Se-75
- Automated Ultrasonic Testing (AUT)
- Phased Array Ultrasonic Testing (PAUT)
- Time Of Flight Diffraction Technique (TOFD)
- Long Range Ultrasonic Testing (LRUT)
- Short Range Ultrasonic Testing (SRUT)
- In-Tank Robotic Inspection
- Internal Rotary Inspection System (IRIS)
- Eddy Current Testing (ECT)
- Remote Field Eddy Current Testing (RFT)
- Pulsed Eddy Current Testing (PEC)
- Magnetic Flux Leakage (MFL)
- Remote Visual Inspection (RVI)
- Positive Material Inspection (PMI)

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