
# 2024 INTERNATIONAL TOPICAL MEETING ON NUCLEAR APPLICATIONS OF ACCELERATORS

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# Book of Abstracts

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# Accelerator Facilities

Abstract # 197

## Applications of GANIL research activities and techniques

Fanny Farget[1], François Chevalier[2], Gilles De France[1], Eloïse Dessay[1], Anne-Marie Frelin[1], Clara Grygiel[2], Isabelle Monnet[2], Yvette Ngono-Ravache, Patricia Roussel-Chomaz[1]

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GANIL has been celebrating the 40th anniversary of the first experiment that ran in 1983 with an 40Ar beam acerated with two cyclotrons at the energy of 44 MeV per nucleon. Since this first exciting period, GANIL has undergone a continuous evolution and some major upgrades, guided by the needs expressed by users, to remain at the forefront of research in accelerator-based science.

The abundances of elements observed on earth or in space is the result of a large number of processes driven by the fundamental interactions and properties that bind the constituents of the atomic nucleus. Some of these nuclear processes are reproduced on earth, not only at accelerators such as GANIL, but also in the nuclear industry, whether for energy or medical purposes. In this respect, GANIL can make important contributions to improving the knowledge needed for sustainable development or improving safety margins in the field of nuclear data of interest for energy or health applications, in particular the production of innovative radioisotopes for nuclear medicine.

The study of radiation on living organisms is part of the development of new cancer therapy techniques. The instrumentation developed at GANIL offers modern dosimetry techniques for hadrontherapy. Last but not least, the study of the effects of radiation on the behavior of matter enables us to investigate new materials and more durable electronic components for nuclear and space industries.

Present activities and projects for developing the applications of GANIL activities will be discussed.

Abstract # 144

# TRIUMF accelerator applications for the benefit of Canada and the world

Alexander Gottberg

*TRIUMF, Canada*

For 50 years, TRIUMF has stood at the frontier of scientific understanding as Canada's Particle Accelerator Centre. Driven by two made-in-Canada cutting edge accelerators - the world's largest cyclotron, and our new high-power superconducting linear accelerator - we continue to ask the big questions about the origins of the universe and everything in it.

With over five decades of experience in the production of accelerator-based secondary particles for science, TRIUMF also ensures that Canada remains on the leading edge of supplying radioisotopes, neutrons, photons, and muons enabling fundamental science in the fields of nuclear, particle and astrophysics, as well as solid state and medical applications, cancer research, electronics radiation testing and particle detector development.

ISAC-TRIUMF is the only ISOL facility worldwide that is routinely producing radioisotope beams in the high-power regime in excess of 10 kW. TRIUMF's current flagship project ARIEL, Advanced Rare IsotopE Laboratory, will add two new target stations providing isotope beams to the existing experimental stations in ISAC I and ISAC II at keV and MeV energies, respectively. This will put TRIUMF in the capability of delivering three RIBs to different experiments, while producing radioisotopes for medical applications simultaneously – enhancing the scientific and socio-economic output of the laboratory significantly.

Together with commercial and public partners, TRIUMF generates 2M+ patient doses of medical radioisotopes per year to contribute to diagnostics and treatments of patients in Canada and worldwide. Driven by a set of in-house designed cyclotrons, delivering from 13 MeV to 500 MeV protons, a great variety of medically relevant isotopes from C-11 to Ac-225 are produced for R&D and application. Direct radiation therapy applications are developed using both, the 50-500 MeV cyclotron, as well as a 10-30 MeV electron linac. Both systems can produce ultra-high dose rate radiation pulses for Flash radiotherapy studies. Radiation damage studies are performed in a range of radiation fields. Material displacement damage is characterized in materials for nuclear fission (SMR, ADS), fusion and accelerator applications in high dose environments. Low-dose neutron fields are used or made available to industry to study radiation effects in electronics.

Abstract # 124

## New capabilities at the ATLAS facility

Ben Blomberg, Brahim Mustapha, Jerry Nolen

*Argonne National Laboratory, USA*

The Argonne Tandem Linear Accelerator System (ATLAS) at Argonne National Laboratory is a heavy ion linac that can accelerate beams of all stable ions from hydrogen to uranium and many radioactive isotopes. ATLAS has the flexibility to deliver accelerated beams to several end stations with a wide range of energies and beam currents, and it is now in the process of upgrading to a multi-user facility. Once upgraded, the linac can accelerate two beams simultaneously and deliver them to different end stations. This upgrade will allow ATLAS to increase the total number of approved experiments each year. ATLAS is a DOE national user facility whose primary purpose is nuclear physics research. However, with the increased available beam time provided through the multi-user upgrade and the facility's range of existing and newly added capabilities, ATLAS is an attractive option for various applications. These include radiation damage studies for nuclear energy materials and high-power targets as well as isotope production R&D. In this contribution, we present an overview of the ATLAS multi-user upgrade and highlight some of the new applications it will enable.

Abstract # 94

## VEGA - status and future among laser Compton scattering facilities

Catalin Matei

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The high brilliance Variable Energy GAmma (VEGA) System under implementation at Extreme Light Infrastructure - Nuclear Physics (ELI-NP) in Romania, uses a storage ring as an Inverse Compton Scattering (ICS) source. The storage ring is filled by a warm linear accelerator with a maximum energy of 800 MeV. A laser system drives a high-finesse optical cavity to resonantly build-up pulsed laser power. Mono-energetic gamma-ray beams are produced via Compton backscattering of laser pulses off the relativistic electron beam in the storage ring. The high-brilliance narrow-bandwidth γ-ray beam will be delivered with energies up to 19.5 MeV, a spectral density higher than 5×103 photons/s/eV, bandwidth of 0.5%, and linear polarization higher than 95%. The VEGA LINAC installation is foreseen to be finalized in 2024. Details of the status of the storage ring, interaction laser system, and challenges for completing the system will be highlighted.

We present the status of the VEGA System at ELI-NP and also its place among other laser-Compton scattering (LCS) sources of monoenergetic γ-ray beams which are operational around the world. The discussion will also emphasize ELI-NP efforts to develop diagnostics instruments and metrological procedures for measuring the VEGA system γ-ray beam parameters.

This work was carried out in part under the contract PN 23 21 01 06 sponsored by the Romanian Ministry of Research, Innovation and Digitalization.

Abstract # 177

## EUROpean laboratories for accelerator-based sciences

Navin Alahari[1], Maria Colonna [2], Ilias Efthymiopoulos[3], Marko Mikuz[4]

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EURO-LABS (EUROpean Laboratories for Accelerator Based Sciences) is a pioneering Horizon-Europe project to build the foundations for creating synergies and collaborations between the Research Infrastructures (RIs) of the Nuclear and High Energy communities. This endeavour is enhancing Europe's potential for successfully facing the new challenges in the coming decades.. The three communities are those engaged in Nuclear Physics and accelerator/detector technology for High Energy Physics, involved in curiosity-driven research and its technical and societal offshoots. The large and diverse community of users have access to a panorama of facilities, where they can choose the most appropriate state-of-the-art RI(s), with expert support, among 47 facilities, varying from modest to large ESFRI facilities spread over 12 countries. Within EURO-LABS a broad and focused joint training activity, including hands-on experience at the RIs, is also offered. This is very important to develop diverse skills of the next generation researchers, for the optimal exploitation of the substantial number of RIs for scientific and technological discoveries and beyond. In this talk an overview of the facilities accelerators and a brief flavour of the collaborative R&D being carried out by the super community of Europe’s Super Community of Subatomic Researchers will be presented.

Abstract # 136

## IAEA activities in support of sustainable development of accelerator facilities and the IAEA Ion Beam Facility Project

Sotirios Charisopoulos, Kalliopi Kanaki, Danas Ridikas, Natko Skukan
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Due to their unique analytical and irradiation capabilities, ion beam accelerators play a major role in solving problems of modern society related to environmental pollution and monitoring, climate change, water and air quality, forensics, cultural heritage, agriculture, development of advanced materials for energy production via fission or fusion, and many other fields. Moreover, particle beams delivered from almost 20.000 accelerators worldwide are used for industrial applications and high-tech services resulting in business revenues in the billion-dollar scale, which clearly demonstrates the decisive contribution of particle accelerators to the increase of competitiveness of economies worldwide and the welfare of modern society in general. In this context, the IAEA Physics Section implements various activities in support of accelerator-based research and applications that focus on:

- promoting the utilization of accelerators in support of applied research in almost all fields with high societal and economic impact,
- enhancing utilization of existing accelerator infrastructures by enabling facility access for scientists from developing countries without such facilities,
- assisting scientists from developing countries in carrying out feasibility and infrastructure assessment studies and establishing new accelerator facilities.
- assisting Member States in installing, operating and maintaining their accelerator facilities and associated instrumentation

In addition, a feasibility study for an ion beam accelerator facility (IBF) at the IAEA laboratories in Seibersdorf was performed in order to assess the interest of Member States in using this facility. Forty Member States have quantified their needs through replies to a properly designed questionnaire. The analysis of the questionnaires showed high demand in training in accelerator technologies and associated Ion Beam Analysis (IBA) techniques, as well as in analytical services in almost all areas of IBA applications. An appropriate accelerator design, matching the IAEA’s programme for capacity building and provision of products and services across many fields of interest for the Member States, was identified.

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

This presentation aims at disseminating the IAEA tools and activities in support of accelerator-based research and applications are implemented. Moreover, details on the feasibility study, the instruments, and facilities to become available through the IBF project, including preliminary estimates of the resources, will be presented.

Abstract # 160

## The CNAO center and experimental facility: development and upgrades


Marco Pullia

*CNAO Foundation, Pavia, Italy*



CNAO is one of the four centres in Europe, and six worldwide, offering treatment of tumours with both protons and carbon ions. Besides clinical activity, CNAO has also research and education as institutional purposes and for this reason in addition to the three treatment rooms, the CNAO center is equipped with an “experimental room” dedicated to experimental activities, which is also available to external researchers. Typical research subjects range from radiobiology to biophysics, from space research to detector development and basic nuclear physics.

The CNAO synchrotron provides energies between 115 and 400 MeV/u for carbon ions (corresponding to a Bragg peak depth of 3 to 27 cm in water) and between 63 and 227 MeV for protons (corresponding to a Bragg peak depth of 3 to 32 cm in water). An additional ion source was recently installed that will provide additional ion species (He, Li, O and Fe) for research and possibly for clinics in a second stage. Its commissioning will start at the beginning of 2024.

The experimental room is equipped with the same scanning system used in the treatment rooms and according to the needs of the experiment to be performed the experimental beamline can be arranged in four different configurations depending on the space required downstream the target or the dimensions of the scanning field. Furthermore, access to a biological laboratory with all the necessary equipment can be provided.

Finally, an accelerator based BNCT facility is under construction that will provide an additional treatment modality.

Abstract # 162

## Conducting Ion Beam Irradiation Experiments in Candidate Core Structural Materials at the Michigan Ion Beam Laboratory

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*University of Michigan, USA*

Ion beam irradiation has the potential to be used as a surrogate for neutron irradiation of candidate core structural materials. Ion beam irradiation offers materials damage levels not accessible by neutron irradiation in test reactors due to time and cost constraints. However, a reproducible ion beam irradiation experiment requires close control of irradiation parameters and conditions, such as ion beam current, temperature, vacuum, and contamination control.

The Michigan Ion Beam Laboratory (MIBL) at the University of Michigan in Ann Arbor, Michigan, USA, is a charter laboratory of the NSUF (National Scientific User Facility) and plays a significant role in supporting the U.S. DOE Office of Nuclear Energy mission. MIBL houses 3 MV and 1.7 MV tandem accelerators and a 400 kV single-ended accelerator. MIBL provides single, dual, and triple beam irradiation capabilities and single and dual beam in situ capabilities in a 300 kV transmission electron microscope (TEM). The lab can conduct irradiations with large beam fluences, ultra-high vacuum chambers, and full remote control of irradiation conditions. At MIBL, experimental conditions are controlled to within very tight specifications. This presentation will focus on the features of conducting well-controlled ion beam irradiation experiments at MIBL. A brief introduction to the control and data acquisition system will be presented.

Abstract # 134

## High current accelerator-based neutron sources - The HBS project for a next generation neutron facility

Thomas Gutberlet[1], Johannes Baggemann[1], Thomas Brückel[1], Jingjing Li[1], Klaus Lieutenant[1], Eric Mauerhofer[1], Ulrich Rücker[1], Jörg Voigt[1], Paul Zakalek[1], Olaf Felden[1], Ralf Gebel[1], Andreas Lehrach[1], Oliver Meusel[2], Holger Podlec[2]

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Accelerator driven neutron sources with high brilliance neutron provision present an attractive alternative to classical neutron sources of fission reactors and spallation sources to provide neutrons for science and industry. With the availability of high current proton accelerator systems, a novel class of such neutron facilities can be established termed High-Current Accelerator-driven Neutron Sources (HiCANS). Basic features of HiCANS are a high current proton accelerator, a compact neutron production and moderator unit and an optimized neutron transport system to provide neutrons with high brilliance and a full suite of high performing epithermal, thermal and cold neutron instruments for various applications.

At the Jülich Centre for Neutron Science a project to develop, design and demonstrate such a novel high-current accelerator driven neutron facility termed High-Brilliance neutron Source (HBS) has been established. The project aims at the construction of a scalable neutron source for a user facility with open access and service according to the various and changing demand of the scientific as well as industrial communities. Embedded within an international collaboration with partners from Germany, Europe and Japan the Jülich HBS project offers flexible solutions to a broad range of scientific and industrial applications. The conceptual design as well as the technical design of HBS as blueprint of a HiCANS facility was published recently in a series of reports.

We will present the current status of the project, progress made and next steps regarding proton accelerator, neutron target and moderators and beam delivery systems. Recent milestones and its impact on the vision for future neutron landscape will be outlined.

Abstract # 191

# Development of HINEG Series High Intensity Steady Neutron Sources


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Neutron sources are the important experimental platform for the R&D of advanced nuclear energy systems, especially for the development for fusion systems. Series High Intensity Steady Neutron Sources (HINEG), comprising three phases (HINEG-I, HINEG-II, and HINEG-III), have been developed in China for different missions including neutronics design validation, materials & components irradiation test, nuclear waste burning and nuclear technology applications, etc. This contribution reports on the recent progress and status of HINEG projects.

HINEG-I , which has already operated, is a D-T fusion neutron source with the yield of 6.4×1012 n/s, and has been coupled with the Lead-based Zero Power Reactor CLEAR-0. It can provide neutrons exactly the same with fusion reactors. Series experiments have been carried out on HINEG-I, including neutronics performance test of TBM blanket, measurement of leakage spectra from Pb and Pb-Bi, irradiation damage testing for laser crystal, etc.

HINEG-II includes two sources, HINEG-IIa and HINEG-IIb. HINEG-IIa is a high-voltage electrostatic accelerator-based D-T neutron source with neutron yield over 1013n/s. HINEG-IIb is a cyclotron-based spallation neutron source with neutron yield more than 1014n/s. These two sources are aimed to provide multi-type of neutron spectrum including fusion-like neutron spectrum and high neutron intensity for radiation damage mechanism study, advanced reactor technology validation, and extended nuclear technology application research, etc. The construction and assembly of the two sources of HINEG-II are on-going.

HINEG-III is high flux steady state neutron source with the intensity of 1017-1018 n/s. It will be coupled with a subcritical reactor with neutron flux higher than 1015 n/cm2/s. HINEG-III is a multi-purpose neutron irradiation platform for irradiation testing of fuel, material and components for advanced reactors. The conceptual design of HINEG-III is on-going.

HINEG is an open platform to provide high intensity neutron beams. We sincerely welcome all kinds of cooperation and participation from affiliations and colleagues all over the world.

Abstract # 198

# MYRRHA and its driver accelerator

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MYRRHA is the first Accelerator Driven System (ADS) to be built, consisting of a subcritical nuclear reactor driven by a high-power linear accelerator, for the demonstration of transmutation of nuclear waste at pre-industrial scale. With the subcritical concentration of fission material, the nuclear reaction is sustained by the particle accelerator only.

The MYRRHA design for an ADS is based on a 4mA, 600 MeV CW superconducting proton linac. The first stage towards its realization is called MINERVA and was approved in 2018 to be constructed by SCK CEN in Belgium. This consist of a 4mA 100MeV superconducting linac as well as two independent target stations, one for radio-isotope research and production of radioisotopes for medical purposes, the other one for fusion materials research. The extension of the superconducting linac to 600 MeV is in the conceptual design stage, with a planned implementation until the early 2030s.

This contribution presents the main design choices and current status of the overall project parts (civil engineering, particle accelerator and target facilities).

Abstract # 108

# Shielding experiment of neutrons and muons from the beam dump using 2-8 GeV electron beam at JLAB

Noriaki Nakao[1], Keith Welch[2], Mark Wiseman[2], Adam Stavola2, Pavel Degtiarenko[2], Toshiya Sanami[2], Nobuhiro Terunuma[2], Yu Morikawa[2], Yasuhito Sakaki[2]

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For advanced shielding design of high energy electron accelerators such as ILC, accuracy of nuclear model and data base used in the theoretical simulations should be validated with the experimental data. For this purpose, shielding experiment of secondary neutrons and muons generated from the beam dump was performed using 2.2, 4.3, 6.4 and 8.45 GeV electron beams at JLAB. The beam dump consists of aluminum and circulated water coolant. In the concrete shield upstream of the beam dump, there are three vertical penetration holes reaching the beam line level 10 m down from the ground level. The concrete shield thicknesses at the three holes are 91, 273 and 570 cm, and aluminum activation detectors were placed in the penetration holes during the irradiation. After the irradiation, gamma rays from the produced Na-24 radionuclides were measured and attenuation profiles of the production rates through the shield were experimentally obtained. Monte Carlo simulations with the experimental conditions were also performed, and they were generally agreed within a factor of 2. From the simulation analyses, Na-24 nuclides were produced by mainly neutrons, and the production rates were exponentially attenuated through the shield for 2.2 and 4.3 GeV electron beam. On the other hand, for 6.3 and 8.45 GeV electron beam, it was found that the contribution to the Na-24 productions due to negative muons were dominant at 570 cm, the thickest location.

This experiment project is performed as the collaboration between KEK and JLAB under the support by the USA-DOE.

Abstract # 156

## Design of an 0.8 A, 300 kV Accelerator of positive Hydrogen ions

Vadim Dudnikov[1], Mary Anne Cummings[1], Rolland Johnson[1], Milorad Popovic[2]

[1] *Muons, Inc., USA,* [2] *FNAL USA*

The design and construction of an 0.8 A, 300 kV accelerator of positive hydrogen ions is presented. This system consists of an RF positive ion source with AlN discharge chamber and uses a multi-aperture four electrode extraction system for ion beam generation. Six 50 kV power supplies, connected in series, can produce 300 kV for beam acceleration.

Abstract # 104

# Recent facility upgrades and the broad range of research and industrial applications of the heavy-ion microprobe beamlines at ANSTO

Ryan Drury, Stefania Peracchi, Zeljko Pastuovic, David Button, Michael Mann, David Cohen, David Child

*ANSTO, Australia*

This talk/poster presents the current capabilities and recent facility upgrades at the Centre for Accelerator Science (CAS), within the Australian Nuclear Science and Technology Organisation (ANSTO). Two of our accelerators are equipped with heavy ion nuclear microprobes, capable of focussing and scanning ion beams with micron-level precision. More than 20 ion species can be selected for testing (from H to Au), at energies up to 100 MeV, with continuous beam currents from pA to μA, or in single ion regimes. The recent addition of an ambient air chamber to one microprobe allows for the rapid exchange of samples and enables the testing of biological samples and other materials which can be damaged by vacuum. A new development in our scanning technologies allows for the synchronisation between the of rapid and precise EM scanning and the wider range linear stages on which the sample is affixed, combining the strengths of both methods. This allows for more complex scan patterns to be performed and minimises downtime. CAS scientists and external researchers have recently performed studies involving the effects of space radiation on microchips, satellite photovoltaic technologies, emerging dosimetry technologies, passive (solid) and active (electromagnetic) shielding techniques, and health & radiobiology. ANSTO accepts merit applications/proposals from researchers in universities, research organisations, and industry.

Abstract # 100

## Radiation studies for BDF/SHiP as a proposed CERN High Intensity North Area experiment

Giuseppe Mazzola, Claudia Ahdida, Luigi Salvatore Esposito, Rui Franqueira Ximens, Matthew Alexander Fraser, Tina Griesemer, Rebecca Ramjiawan

*CERN, Switzerland*

The Physics Beyond Colliders (PBC) is a CERN exploratory study aimed to fully exploit the scientific potential of its accelerator complex and infrastructure. To enhance and complement the physics program of the Large Hadron Collider experiments, PBC provides support to different working groups.

Among them, the Beam Dump Facility (BDF) is being considered as potential general-purpose fixed-target installation for the North experimental Area (NA). Operating with high intensity 400 GeV/c proton beam slowly-extracted from the Super Proton Synchrotron on a high-Z material target, BDF jointly with the Search for Hidden Particles (SHiP) experiment will focus mainly on the research for Feebly Interacting Particles, Light Dark Matter and tau neutrino physics.

BDF/SHiP has undergone a series of exhaustive radiation effect and radiological studies with the use of FLUKA Monte Carlo code to verify the feasibility of its implementation in the NA. In this regard, this work will focus on the results proving the compliance with the requirements set by the Radiation to Electronics risks and by the CERN Radiation Protection's code. In parallel, an optimisation and R&D of the facility design has been conducted, particularly for the mechanical and physics performance of the target.

The studies demonstrate the feasibility and the radiological optimisation of the BDF/SHiP design, which have resulted in the submission of the proposal as a High Intensity - NA experiment.

Abstract # 101

## Radiological characterization of the beam dumps and their surrounding shielding of the ISOLDE facility at CERN

Alice Formento, Elodie Aubert, Ana-Paula Bernardes, Nadine Conan, Alexandre Dorsival, Gerald Dumont, Jose Maria Martin Ruiz, Stefano Marzari, Simon Mataguez, Renaud Mouret, Fabio Pozzi, Heinz Vincke, Joachim Vollaire

*CERN, Switzerland*

ISOLDE is a CERN facility dedicated to the production of radioactive ion beams for applications in atomic physics, nuclear astrophysics, fundamental interactions, and life sciences. The 1.4 GeV proton beam, coming from the Proton Synchrotron Booster (beam power of 2.8 kW) impinges on a thick target kept at high temperature during irradiation. The generated radionuclides diffuse out of the target and are subsequently ionized, extracted and finally selected using a mass separator. About 60-70% of the primary proton beam does not interact with the target and is intercepted by a beam dump (one for each of the two target stations). The ISOLDE beam dumps are currently operating at their limit in terms of temperature and mechanical stresses and, therefore, their replacement is currently being studied.

To this extent, a radiological characterization, in terms of radionuclide inventory and residual dose rate, of the radioactive materials that will be removed during the dismantling phase, was performed. The presentation will focus on the methodology employed to characterize the various radioactive items (concrete shielding blocks, steel beam dumps, soil shielding); Monte Carlo simulations were performed with the FLUKA code distributed by CERN and, where possible, were benchmarked and complemented with information from experimental measurements. The study provides extensive information that are being used to plan the dismantling worksite, the potential elimination pathways and the required radiation protection measures necessary for safe removal, handling, transport and storage of the radioactive materials.

# Accelerators for Environmental Studies

Abstract # 71

# Electron Beam Treatment of Wastewater

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Global attention is increasingly focused on the challenges of environmental damage and the depletion of natural resources. Factors such as population growth, rising living standards, rapid urbanisation, and intensified industrial activities have collectively contributed to a significant increase in water pollution.

Radiation technologies have emerged as powerful tools in industry, agriculture, and scientific research. Ionising radiation, in the form of accelerated particles (electron beams), possesses the capability to ionise water molecules. This process generates active radicals from water molecules, which in turn react with harmful organic contaminants present in wastewater. These contaminants undergo degradation and transform into simpler chemical forms, making them more amenable to treatment through conventional methods.

The earliest studies on radiation treatment of waste materials primarily focused on disinfection, dating back to the 1950s. In the subsequent decade, these investigations expanded to include the purification of water and wastewater. Building upon laboratory research conducted in the 1970s and 1980s, the 1990s saw the establishment of several pilot plants dedicated to extended research. A ground-breaking milestone was achieved in 2005 with the construction of the first full-scale application, aimed at treating textile dyeing wastewater (10,000 m3/d) in the Republic of Korea, supported by the International Atomic Energy Agency (IAEA). This success was followed by the commissioning of a similar plant in China in 2020 (30,000 m3/d) to address the needs of textile industries. Practical applications of this technology have consistently affirmed its ease of use and effectiveness in treating large volumes of wastewater.

Furthermore, electron beam treatment demonstrates its utility in addressing emerging organic pollutants found in groundwater, such as fertilisers, pesticides, and pharmaceutical residues, which can lead to groundwater pollution and the subsequent contamination of water resources. A significant advantage of radiation technology lies in the fact that reactive species are generated in-situ during the radiolysis process, eliminating the need for the addition of chemicals. Moreover, these reactions can be conducted at relatively low temperatures, resulting in lower energy costs, minimal thermal damage to the system, and its products.

The IAEA is steadfast in its commitment to supporting non-power nuclear applications in its member states. This commitment includes organising Coordinated Research Projects (CRPs) and technical meetings with a specific emphasis on the preservation of water resources and environmental sustainability.

Abstract # 90

# Destruction of PFAS Using Electron Beam Technology

Charlie Cooper, Slavica Grdanovska

*FNAL*

Per-and polyfluoroalkyl substances (PFAS) are a broad group of specialty chemicals used in applications such as food packaging, personnel care products and stain resistant fabrics. PFAS are both thermally and chemically stable due to strong dipole moments in C-F bonds created by the highly electronegative fluorine atom. Some uses of PFAS, one of the most noted being aqueous film forming foam used at airports and tank farms to combat fire, have led to unintended release to the environment. PFAS, like perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS), are classified as persistent organic pollutants and as emerging pollutants of concern. Conventional water treatment technologies do not fully meet the needs of PFAS remediation, one of the largest problems being that technologies concentrate the PFAS into another state and do not destroy it. Electron beams can be used to create highly reactive oxidizing species, such as the hydroxyl radical (•OH), or strong reducing species such as hydrogen radical (•H) and solvated electron (eaq-) that can react with the PFAS to facilitate their decomposition. Results on e-beam destruction of PFAS from a recently completed 2-year collaborative study with 3M will be detailed.

Abstract # 82

# Synopsis of Studies Conducted at the Electron Beam Research Facility, Miami, Florida

William J Cooper

*University of California, Irvine*

The Electron Beam Research Facility, where most of the studies reported today were conducted, is located at the Miami-Dade Virginia Key Wastewater Treatment Plant, Miami, Florida. It was a High Voltage Engineering, 1.5 MeV Insulated Core Transformer (ICT), 50 mA horizontal-beam accelerator. Originally designed to treat wastewater biosolids (sludge) prior to land application, it had two additional inputs, secondary treated wastewater and potable water. It was designed to treat 120 gallons per minute of any of the three input streams; however, we conducted studies at between 100 and 150 gallons per minute.

To conduct batch studies, solutions of organic compounds were irradiated at 3-solute influent concentrations, 3-pH values, nominally pH = 5, 7, 9, and 4 doses. Studies with clay, 3 % by weight, were conducted at only one pH, nominally pH = 5. Two different tanker trucks, with a 3,000- or 6,000-gallon capacity, were used to make up solutions for these studies. The flow rate for all of the batch studies was 100 gallons per minute.

To demonstrate the technology at potential customer sites, we constructed a mobile system. This system was a High Voltage Engineering ICT, 500 KeV, 20 mA, self-shielded vertically mounted accelerator. This was built in a conventional 40 foot low-boy trailer. The system was transported to different locations in the US and shipped to Germany and France, three times, for on-site studies.

Abstract # 114

## Soil Remediation via Electron Beam Irradiation

David Staack, Ian Burress, John Lassalle, Suresh Pillai

*Texas A&M University, USA*

The high temperatures and reactive radicals generated during irradiation by electron beam can degrade or remove challenging contaminants such as petroleum hydrocarbons and per- and polyfluoroalkyl substances (PFAS). Reductions in hydrocarbon concentrations of up to 98.4% were observed for field soils using a 10 MeV, 18 kW accelerator; hydrocarbons of all weights were reduced, suggesting both thermal and non-thermal mechanisms of hydrocarbon decomposition and removal. Total petroleum hydrocarbon (TPH) reduction was also achieved at higher power densities using a 90 kW, 3 MeV accelerator (up to 96% reduced), showing promise for process scalability. Temperature-programmed oxidation and desorption characterization suggested the production of a form of non-desorbable carbon resembling biochar, a byproduct of pyrolysis that may improve soil health parameters when applied to soil. Additionally, qualitative characterization of process condensate shows a mixture hydrocarbons, carboxylic acids, and alcohols, which may have value as fuel or chemical feedstocks. During a comparative assessment of EBeam and thermal remediation methods, energy requirements for EBeam irradiation were shown to fall between indirect and direct thermal desorption for comparable reductions, with the added benefit of an electrical, potentially carbon-neutral power source. Reductions in concentration were also observed for PFAS compounds following irradiation with doses up to 2000 kGy, with perfluoroalkyl sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) reduced by 99.9% and 86.5%, respectively. Subsequent experiments have focused on upscaling of treatment. Design work has been performed to develop a mobile treatment facility, including simulation using the PUFFIn and PENELOPE Monte Carlo software packages for process optimization.

Abstract # 186

# Microplastic Release from E-Beam Sterilized Polymeric Materials Used in Contact with Aqueous Fluids

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The polymeric materials are extensively being employed for the various applications such as health care, storage, packaging materials for the foods, beverages, and saline etc. The most commonly used polymer in these applications are polyethylene terephthalate (PET) silicone rubber, polyurethane, due to their flexibility, low cost, biocompatible nature and other properties. However, these polymeric materials often need to be sterilized with ionizing radiations for all possible applications and enhancing shelf-life of liquids stored in the containers made-up of these polymeric materials. Microplastic / Nanoplastics have be released by these polymeric materials in contact with aqueous fluids in over a period of long exposure. Thus, released microplastics / nanopalstics pose the health hazards, may act as carrier of host of pathogens, may protect pathogens during sterilization and may also accumulate toxic elements. The extent of microplastic release can depend on factors such as the composition of material, sterilization method, and sterilization conditions. The ionizing radiations used for the sterilizations are expected to produce the changes in polymeric materials such as polymer chains scission and cross-linking depending upon the doses and dose rates. It is likely that these changes in the polymeric materials may enhance or suppress the microplastic release after sterilization when exposed to aqueous solutions. The microplastics significant release has been observed in the E-Beam Irradiated polymeric materials at 100 kGy dose (E-beam Energy: 3.5 MeV, E-Beam Current (Pulse Current) 250 mA, E-Beam Average Current: 1mA). This was attributed to E-Beam induced damage to the polymer matrix and formation of the particles as observed by Atomic Force Microscopy (AFM) in the surface morphology studies of the irradiated samples. Studies on microplastic release from PET after E-Beam irradiations, and subsequent implications of microplastics release as pathogen host and carriers has been carried out.

# Accelerators for Cultural Heritage

Abstract # 247

# Unveiling the Secrets of Cultural Heritage: Advancements in Non-Destructive Ion Beam Analysis at the New AGLAE Facility

Claire Pacheco

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Cultural heritage objects serve as invaluable links to our past, offering profound insights into human history, art, and civilizations. Preserving and understanding these artifacts requires non-invasive analytical methods capable of revealing their material composition and degradation mechanisms. Ion beam analysis (IBA) has emerged as a crucial field, bridging science and cultural heritage conservation, enabling a deeper understanding of these objects' hidden secrets.

Situated within the prestigious Le Louvre premises, the AGLAE facility – now known as New AGLAE following its automation in 2017 – stands as a cutting-edge platform entirely dedicated to non-destructive ion beam analysis dedicated to heritage science.[1]

Key techniques employed at the New AGLAE facility encompass Particle-Induced X-ray Emission (PIXE), Particle Induced Gamma-ray Emission (PIGE), Rutherford Backscattering Spectroscopy (RBS), among others. These techniques empower researchers to precisely ascertain the chemical composition and element distribution within artifacts, providing deeper insights into their craftsmanship, historical context, and preservation status.

Illustrative case studies featuring objects from diverse geochronological contexts and with varied research inquiries will underscore the indispensable nature of these IBA analyses in addressing human science issues without compromising the integrity of the artifacts.

Furthermore, the lecture will spotlight ongoing instrumental and methodological advancements, particularly in scientific image processing, leveraging machine learning algorithms to automate data processing and reduce computation time.

Lastly, while the preservation of tangible cultural heritage objects remains paramount, the lecture will outline the challenge of translating data acquired by the New AGLAE facility into digital cultural heritage. Progress towards concrete solutions to achieve this objective will also be discussed.

[1] The New AGLAE virtual tour: https://www.v36.fr/visite-virtuelle/220619-C2RMF/

Acknowledgement: The EquipEx New AGLAE was funded by the French ANR project ANR-10-EQPX-22.

Abstract # 135

# Addressing forensic challenges in artifact authentication and provenancing with nuclear analytical techniques

Nuno Pessoa Barradas[1] and Aliz Simon[2]

[1] *Instituto Superior Técnico, Universidade de Lisboa, Portugal,* [2] *IAEA, Vienna, Austria*

Nuclear analytical techniques (NAT), and in particular accelerator-based techniques such as Ion Beam Analysis (IBA) for elemental and molecular analysis and Accelerator Mass Spectrometry (AMS) for radiocarbon dating, have long been applied to cultural heritage forensics, involving the characterization, authentication, and dating of artefacts. Nevertheless, there is still a considerable gap between the accelerator scientists and the end users such as museums, and widespread adoption of nuclear techniques in this sector has never been fully exploited. Exceptions are, for instance, the accelerator laboratory located at the Louvre museum in Paris, France, which is exclusively dedicated to cultural heritage forensics.

The International Atomic Energy Agency has taken the lead in bridging the gap between the NAT and forensics communities, by coordinating the international efforts that would make NATs routinely applicable, reliable, standardised and easily accessible. An IAEA coordinated research project on utilizing nuclear analytical techniques in forensic science, which was implemented in 2017-22, had one entire work package dedicated to cultural heritage. The key results of the project were published in scientific papers, including a special issue of Forensic Science International on "Nuclear Technologies for Forensic Science".

The talk will provide an overview on capabilities and limitations of accelerator-based and complementary NATs to cultural heritage forensic problems. Case studies from the IAEA coordinated research project will be presented [1]. Finally, it will be shown how the same techniques and methods used for cultural heritage forensics can also be applied to other areas of forensic sciences.

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[1] A. Simon, N. Pessoa Barradas, C. Jeynes, F.S. Romolo, *Addressing forensic science challenges with nuclear analytical techniques – A review, Forensic Science International*, (in press) (2023)

Abstract # 175

# High-Energy Computed Tomography Scanning Reveals Ancient Sculpture's Secrets

Robert Maziuk and Stephen Halliwell

*VJ Group*

As part of research by a Conservator at the Museum of Fine Arts, Boston, of a 17th century Tibetan sculpture, details of the internals of the sculpture were needed to be determined non-destructively. The sculpture, a Buddhist deity known as "Vajrabhairava with consort Vajravetali" measured approximately 27" x 18" x 12". The sculpture was presumed hollow and made of several parts from copper and brass alloy that were joined during the final stages. The goal was to determine if the hollow body of the sculpture had any religious content such as scribes, relics, paper, or other items often encapsulated in such ancient sculptures.

We determined that our 6/9MeV industrial accelerator-based x-ray computed tomography (CT) system, normally used for inspection of aerospace flight hardware and other complex additively manufactured components would be able to penetrate the size and density of the sculpture and would reveal internal details with the required resolution and image fidelity.

The talk will discuss how the inspection technique was developed using a timesaving "flyby region of interest scan" from which the required system parameter settings were determined as well as the measures taken to eliminate any potential for ring artifacts, beam hardening artifacts, streaking, scatter radiation and noise.

The results together with correlation of image indications with likely artifacts caused by the manufacturing process will be provided and discussed.

Abstract # 133

## Synchrotron-Based X-Ray Fluorescence Analysis of Byzantine Plaster Figurines from Jordan Museum

Sahar al Khasawneh[1], Allayth Aldrabee[2], Kafa Al-Khasawneh[3], Messaoud Harfouche[4]

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Non-destructive analysis techniques became an important approach for the characterization of cultural heritage and conservation science. In this study, for the first time, Synchrotron-based X-ray Fluorescence (SRXRF) analysis, at the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME), was utilized to examine and analyze three Byzantine plaster figurines from Jordan Museum. Analysis was applied to identify the main composition of the body, the black drawings on the figurines and the mirror fragment on one of the objects. The results showed that the matrix of the body is composed of Calcium carbonate (plaster) and other inclusions were added to facilitate setting of the lime during hydrating. The black drawing on the objects was identified as wooden charcoal. Finally, results showed that the mirror is not a silicon based but a highly polished surface material composed of manganese (Mn), gallium (Ga) and lead (Pb).

# Accelerators for Material Science

Abstract # 68

# Application of accelerator techniques in characterization of wall materials for controlled fusion reactors

Marek Rubel[1], Daniel Primetzhofer[2], Eduardo Pitthan[2], Per Petersson[1], Sotirios Charisopoulos[3], Anna Widdowson[4]

*[1]KTH Royal Institute of Technology, Sweden, [2]Uppsala University, Sweden, [3]IAEA, Vienna, Austria, [4]UK Atomic Energy Authority, UK*

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

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

Quantitative results can only be obtained when based on robust nuclear data sets, i.e. stopping powers and reaction cross-sections. Therefore, the work has three equally important strands: (i) assessment of fuel inventory and modification of PFMC by erosion and deposition processes arising from plasma-wall interactions; (ii) determination of nuclear data for selected ion-target combinations; (iii) equipment development to perform cutting-edge research. In parallel, inter-laboratory comparisons (round robin tests) are carried out.

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

Abstract # 125

## Understanding the Irradiation-Induced Defects: New In-Situ Capabilities

Yongqiang Wang

*LANL, USA*

Energetic particle irradiation creates a multitude of metastable defects through atomic displacements in lattice structure and/or excitations/ionizations in electronic configurations of a material. These defects are then responsible for the microstructural evolution and property changes of the material, which often come down to a balance of kinetic processes that determine whether the material will recover or whether larger-scale extended defect aggregates such as voids and loops will form. Critically, the defects most responsible for this evolution – the fastest moving defects – disappear quickly once the radiation source is removed. Thus, post-mortem examination can only provide indirect evidence of their presence and is unable to characterize neither the nature nor properties of these defects.

To better understand the transient behavior associated with fast moving radiation-induced defects, we have developed an in-situ positron annihilation spectroscopy beamline and an in-situ electrochemical impedance spectroscopy system at LANL's Ion Beam Materials Laboratory that allow us to measure the vacancy-type defects and conductivity of the material as it is being irradiated. These capabilities can provide unprecedented insight into the kinetic nature of defects, both as the material approaches a steady-state defect concentration under irradiation and as it recovers once the irradiation source is removed. In this talk, I will discuss the status of these capabilities, their preliminary applications, and challenges.

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Abstract # 76

## Beam-On Effects in Nuclear Materials

Michael Short, Adria Peterkin, Alexis Devitre, Andrew Lanzrath, Angus Wylie, Ben Dacus, Kevin Woller, Wande Cairang, Weiyue Zhou, Zoe Fisher

*MIT, USA*

*In situ* accelerator materials science is poised to unlock far more information regarding how nuclear materials behave under irradiation, if utilized properly. Many of the questions which need answering for both fission and fusion power cannot be readily answered with increasingly rare neutron sources, nor do they need them at this stage. Before any neutron irradiation should take place, discovery of *relative* kinetics of radiation-induced microstructural changes, keyed to experimentally verified inference models of changes vs. dose is what can speed up the discovery, development, and deployment of nuclear materials by orders of magnitude.

In this talk, we highlight a few such areas where such inference models, linked to *in situ* measurements during ion irradiation, yield crucial new insights into material evolution during irradiation. We show how radiation can sometimes *slow* corrosion in molten salt and liquid lead, delocalizing it to become less severe from a crack propagation perspective. We demonstrate the onboard detection of tungsten fuzz evolution during combined irradiation and plasma attack at high temperatures, revealing the kinetics of its growth. Real-time picosecond ultrasonics during irradiation can reveal timescales of radiation-induced phase precipitation or dissolution. Finally, we tackle the effects of *in situ* irradiation on superconductivity in ReBCO, where deconvoluting the effects of beam heating from actual defects remains a challenge. In all cases, *in situ* irradiation experiments utilizing ion accelerators allows us to peer into the future of deployed nuclear materials, where they will be subject to all components of their respective reactor environments at once.

Abstract # 139

# Methodology and best practices on using TEM with in-situ ion irradiation for radiation damage studies

Anamul Haq Mir

*University of Huddersfield, UK*

Ion accelerators are commonly used to simulate the effects of radiation damage in nuclear materials and when coupled to a Transmission Electron Microscope (TEM) one can follow the dynamics of radiation damage, precipitation, formation of gas bubbles, etc at a microscopic scale in almost real-time. Therefore, in principle, one can develop a detailed picture of radiation damage buildup in a single experiment. This is a significant advantage over more traditional ex-situ ion accelerator setups where several bulk samples need irradiating followed by their systematic post-irradiation characterisation. Nevertheless, TEM with in-situ ion irradiation requires samples that are only tens to hundreds of nanometres thick and although the effects of electron beam damage can be reduced, they are unavoidable. One must thus be aware of the effects of high surface-to-volume ratio and electron beam effect. There are several examples where ex-situ and TEM with in-situ ion irradiation can show different effects which may be offset in either temperature or radiation damage level from one another.

This presentation will give an overview of the technical aspects of the TEM with in-situ ion irradiation technique and how it differs from more traditional ex-situ irradiation setups in terms of the dosimetry, ion beam homogeneity, surface effects etc. Several examples that highlight the excellent potential and flexibility of this approach and situations where TEM-specific effects can dominate and bias the results will be presented.

Abstract # 146

## Ion beam study of plasma interactions with materials in fusion reactors

Norberto Catarino[1], Marta Dias[1], Rodrigo Mateus[1], Jari Likonen[2], Anna Widdowson[3], Eduardo Alves[1]

*[1]IPFN, Instituto Superior Técnico, Portugal, [2]VTT Technical Research Centre of Finland, Finland, [3]UK Atomic Energy Authority, UK*

Accelerator based analytical techniques play a fundamental role on the study of plasma wall interactions in fusion tokamaks. Constant fluxes of energetic neutrals and charged particles lead to erosion and re-deposition processes as well as radiation damage on the walls. In addition, plasma disruptions could cause large thermal shocks melting or vaporizing the material in the chamber walls. In combination with all these effects fuel retention is a process always present which must be fully understood.
In the present contribution, we explore the capabilities of ion beam techniques to study retention and erosion effects of deuterium plasmas in the wall materials of JET tokamak. Samples from different areas of the chamber were analyzed with Rutherford and elastic backscattering spectrometry, nuclear reaction analysis as well as electron microscopy.

Results indicate a major deposition region on the top of divertor tiles (0, 1) with a large retention of 2H. The position of the plasma strike point influences the distribution and deposition in the divertor walls. In the chamber walls the central part of the limiter tiles show an enhanced erosion without no deuterium retention. Retention is mostly observed in the tile gaps and deposition occurs at the ends of the tiles. Additional studies were performed to get more insight on the effect of the presence of 4He, a fusion product present in the plasma, on the retention properties: With that in mind, we have produced and co-implanted a W-Ta alloy with 4He and 2H. The implantations were done at room temperature with 10 keV of He+ at a constant fluence of 5x 1021 at/m2 and 5 keV of D+ with fluences in the range 1020-1021 at/m2. The results show that the alloys implanted with He+ evidence surface blistering and nuclear reaction analysis shows that D retention is higher after sequential He+ and D+ implantation than for single D+ implantation.

The results will be discussed and a picture of the plasma effects on the chamber walls presented.

Abstract # 178

# Irradiation of High Entropy Alloy in Low Energy High Intensity Proton Accelerator (LEHIPA)

Poulami Chakraborty, S. C. Mishra, S. Neogy, R. Tewari, B. Vishwanadh

*BARC, India*

High-Entropy Alloys (HEAs) are an exciting class of materials formed by mixing 5 or more elements and can poses superior high temperature mechanical properties along with excellent irradiation and corrosion resistance. The superior radiation resistance of multicomponent HEAs can be attributed to the sluggish mobility of dislocation loops, formation of fewer voids as well as self-healing capabilities. In particular, HEAs constituted by refractory metals have been proposed as potential structural/functional materials for advanced fission and fusion reactors, primarily because their BCC based structure which offers better resistance to irradiation swelling. However, irradiation of certain BCC- HEAs have also resulted in segregation of atoms like Cr, V, etc at the grain boundaries which can lead to deterioration of mechanical properties. Thus it is necessary to understand the irradiation response of specific alloy compositions in order to explore their suitability for nuclear applications.

Study of radiation damage using high energy neutrons can closely mimic advanced reactor conditions, but also pose challenges related to limited availability of high energy neutron sources and handling of irradiated samples due to long term induced radioactivity. On the contrary, proxy ion beam irradiation can act as a better substitute owing to control over ion beam energy, dose rate, irradiation temperature, in addition to shorter irradiation time and comparatively less activation of irradiated specimens.

In the present study, the irradiation behaviour of a refractory based 35Nb25Ti25V10Al5Zr (at. %) HEA has been investigated using proton beam at the Low Energy High Intensity Proton Accelerator (LEHIPA) of BARC, Mumbai. LEHIPA consists of a 50 KeV ECR ion source, a 3 MeV radio-frequency quadrupole (RFQ) and a 20 MeV drift-tube Linac (DTL). The 3 MeV beam in the medium energy beam transport (MEBT) section of LEHIPA has been used for the irradiation experiments. Prior to irradiation, the HEA showed a multiphase structure with BCC phase as major and Al-Zr type intermetallic as minor constituents. In LEHIPA, the HEA was exposed to 3 MeV proton beam delivering an average current of ~ 1 µA for 68 h thus imparting a maximum damage of 0.5 dpa. The irradiated alloy was characterized using X- Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Electron back Scattered Diffraction (EBSD), Nano hardness tests and Transmission Electron Microscopy (TEM). Intermetallic content in the HEA was found to reduce significantly after irradiation resulting in the softening of the alloy samples. It is expected that radiation induced order-disorder transformation of the intermetallics is the major reason behind their dissolution into the BCC matrix.

The detailed results of the above study will be discussed in this paper.

Abstract # 74

# Applications of the RBI Tandem Accelerator Facility to fusion energy related research

Stjepko Fazinic, Stjepko Fazinic, Ivancica Bogdanovic Radovic, Iva Bozicevic Mihalic, Donny Domagoj Cosic, Toni Dunatov, Milko Jaksic, Georgios Provatas, Zdravko Siketic, Tonci Tadic, Milan Vicentijevic

*RBI, Zagreb, Croatia*

Through the Laboratory for Ion Beam Interactions, the Division of Experimental Physics of the Rudjer Boskovic Institute (RBI) operates and maintains the Tandem Accelerators Facility (RBI-AF), that physically consists of the 6 MV Tandem Van de Graaff and 1 MV Tandetron accelerators, including associated beam lines and nine end stations used mainly for nuclear materials modification and analysis studies. The accelerators can deliver various ions with energies from 0.1 to tens MeVs.

Recently the facility has been increasingly used to study fusion energy related materials. In this work an overview of the RBI-AF applications to the fusion energy related research will be presented. This includes our activities on Ion Beam Analysis of fusion plasma facing materials and the development and use of our Dual-Beam Irradiation Facility for Fusion Materials (Di-FU). The potential of the experimental setups will be demonstrated by presenting selected applications performed recently. Potential for further developments will also be discussed, including the need and availability of fundamental data necessary for analytical work.

Abstract # 157

# Increasing the electrical and mechanical strength of waveguide input/output windows

Fedor Klinov, Igor Milman, Oleg Riabukhin

*Ural Federal University, Russian Federaiton*

Radiation Sterilization Center of Ural Federal University working from 2015 in industrial area for sterilization of medical goods and processing of polymer materials. Linear accelerator produced by “Corad” company with 10 MeV E-beam energy and 1 mA current allow to irradiate about 50000 m3 of different production per year. One of the critical parts of LINAC is waveguide input/output window that can be mechanically damaged due multiple breakdowns forming from the vacuum or waveguide side of the window in permanent accelerator exploiting. We got this situation in our accelerator after three years of LINAC utilizing with ceramic waveguide window TH20674 of Thales Electron Devices company. This window became unusable due to through microcracks and loss of vacuum density. To restore the window, we have developed a coating on the base of polyvinyl acetate resistant to ionizing fields and microwave radiation. By forming of 1-2 mm layer of compound on the surface of the window from the wave guide side in liquid phase and subsequent drying we got smooth glassy coating that allowed us fully restore usability of wave guide window at nominal parameters of the LINAC. Thus, we found the method of waveguide window electrical and mechanical strength Increasing.

# Accelerators for Security and Forensics

Abstract # 67

# Radioisotope replacement with compact electron linear accelerators

Sergey Kutsaev

*RadiaBeam Technologies, LLC*

The replacement of radioactive sources with alternative technologies has been identified as a priority by international authorities, due to the risk of accidents and diversion by terrorists for use in Radiological Dispersal Devices. Many of these sources can be replaced with the X-rays produced by electron beams accelerated to MeV energies. However, the size, weight, and costs of electron linacs must be significantly reduced to be considered for radioisotope replacement.

RadiaBeam Technologies, LLC is developing a series of inexpensive compact electron accelerators in the 1–10 MeV range for radioisotope replacement such as Ir-192, Cs-137, and Co-60 for various applications. The dramatic level of miniaturization and cost-reduction was achieved thanks to the implementation of such innovative technologies as high-frequency magnetrons, split accelerating structure fabrication technology, and solid-state Marx modulators. In this talk, we overview RadiaBeam's compact linac developments, discuss the enabling technologies, and report on the current progress.

Abstract # 180

## Demands of Accelerator Performance to Support Industrial X-Ray Imaging

Stephen Halliwell and Robert Maziuk

*VJ Group*

For many years the inspection of parts and components by x-ray has been used in industrial applications, particularly to verify the integrity of safety critical items and to support product development. Today, the increasing use of high density “exotic” materials in complex structures made possible by additive manufacturing techniques requires the use of high-energy x-ray to fully penetrate the object. Analysis of the complex internal features of additively manufactured parts requires CT (computed tomography) scanning to provide volumetric data with increasingly high spatial resolution and contrast sensitivity.

CT techniques using current digital detectors and linear accelerators are summarized and a range of accelerator beam management techniques to minimize scatter radiation and maximize contrast to noise sensitivity are outlined, and the future performance requirements of accelerators to meet the future inspection performance demands are described.

These future needs will include likely conflicting demands for smaller targets, higher dose output, higher energy, and high reliability/availability.

Abstract # 196

## First experimental demonstration of Gamma-ray LiDAR with a quasi-monoenergetic photon source

Ryan Heller[1], Joshua Cates[1], Qiang Chen[1], Cameron Geddes[1], Benjamin Greenwood[1], Jason Hayward[2], Jay Hix[3], Robert Jacob[1], James Johnson3, Nicholas Parilla[1], Brian Quiter[1], Scott Thompson[3]

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*[3] Idaho National Laboratory*

The development of compact femtosecond MeV photon sources with controlled energy spread will enable powerful new modalities for active interrogation. One technique, so-called Gamma-ray LiDAR, has potential to produce a one-sided 3D image by studying the time of flight of backscattered gammas fired at a target under study. Previous experiments, including at the Idaho National Laboratory and the University of Tennessee, Knoxville have demonstrated the potential of such measurements, but were limited by the properties of bremsstrahlung base sources. We present the results of the first experimental campaign to demonstrate this technique using a monoenergetic photon source paired with precision timing detectors, at the BErkeley Lab Laser Accelerator (BELLA). Using our prototype system, we are able to clearly see meaningful backscatter time of flight signatures, reconstruct the depth of multi-layer targets, and measure the curvature of a dense spherical object through rastering of the gamma beam. In this contribution, we discuss the preliminary results of these measurements, the lessons learned, and the future development needed to realize a fieldable Gamma LiDAR system.

Abstract # 54

## Elemental characterisation of bulk materials using fast neutron beams at the n-lab, University of Cape Town

Sizwe Mhlongo, Andy Buffler, Tanya Hutton, Zina Ndabeni

*University of Cape Town, South Africa*

Developing methods to non-destructively determine the elemental composition of bulk materials is important in a broad range of contexts, including food and agriculture, coal and minerals processing, contraband detection, and nuclear regulation. Neutron-based techniques are advantageous as neutrons are highly penetrating, sensitive to low mass nuclei and produce characteristic secondary radiation for each nuclide. When a sample of unknown composition is exposed to a field of neutrons, with known intensity, energy and angular distribution, an array of radiation signatures which are characteristic of the sample composition is produced. These signatures may be in the form of prompt and delayed gamma rays, and scattered and transmitted neutrons. Well established techniques exist to utilise each of these signatures in isolation as a means of materials analysis, and each technique will be more, or less sensitive to a different subset of elements. The combination of multiple neutron-based techniques are being explored in this work, namely fast neutron transmission analysis (FNTA) and prompt gamma-ray neutron activation analysis (PGNAA) at the fast neutron facility (n-lab) within the Metrological and Applied Sciences University Research Unit (MeASURe) in the Department of Physics at the University of Cape Town. The FNTA and PGNAA techniques exploit transmitted neutrons and de-excitation gamma rays, respectively, as elemental signatures, and ideally require fast neutrons. In this work, the FNTA and PGNAA neutron techniques are being explored using neutrons from a compact accelerator-based neutron generator with the aim of developing standardised neutron-based measurement procedures for elemental analysis of materials in bulk.

The n-lab houses a well-characterised accelerator-based neutron source, a Thermo MP-320 deuterium-tritium (DT)-based sealed neutron tube generator (STNG) capable of producing 14.1 MeV neutrons at rates of up to 1 x 108 neutrons s−1 into $4\pi$ steradians when operated at optimum settings. Standard samples (single and multi-elemental) have been analysed using FNTA and PGNAA techniques. The transmitted neutron energy spectra were measured utilising a 2″ x 2″ EJ-301 organic liquid scintillation detector while de-excitation gamma-ray energy spectra were measured utilising a pair of 3″ x 3″ NaI detectors. The elemental signature extracted from the FNTA measurements was the removal cross section, and for PGNAA the background subtracted gamma ray spectra. The measured elemental signatures were used to form a library of standardised elemental responses, which were then used to deconvolve mass ratios of elements using an unfolding analysis software (MAXED) based on the maximum entropy principle. Presented in this work are experimental results from the analysis of eight elements of interest, including carbon, aluminium and iron, and the unfolding of elemental composition for simple mixtures of these eight elements.

Abstract # 142

## Unravelling hair forensics: Multidimensional profiling by marrying accelerator-based and benchtop techniques for molecular and ionome imaging

Karen Cloete[1], Alessandra Gianoncelli[2], Ziga Smit[3]

*[1] University of South Africa, [2] Elettra Sincrotrone Trieste, Italy, [3] University of Ljubljana, Slovenia*

Hair remains an invaluable biological screening material due to its numerous advantages over urine, blood, and other biological screening materials. Its intricate physico-chemical properties provide a wealth of insights into a person's diet, origin, and even health. Its ability to store chronological exposure to xenobiotics for application in forensic toxicology and drug abuse studies, its resistance to environmental degradation, and ease of sampling and transport further amplifies its potential as a powerful forensic screening tool. Considering the burgeoning potential of hair in forensic analysis, this talk will aim to answer the following: What role can accelerator-based techniques play to advance hair forensic analysis? Hair morphology for example curliness affects the incorporation of xenobiotics such as toxic metals and drugs into its chemical makeup – how can accelerator-based techniques unravel the hair ionome and differentiate between the external and internal hair region ionome more reflective of ingestion and less affected by surface contaminants that may not be removed with washing? Why is multidimensional hair analysis using accelerator-based and benchtop techniques crucial to amplify the full potential of hair physico-chemical screening to robustly answer intricate forensic questions? If scalp hair may not be available for sampling due to alopecia, could body hair serve as an alternative screening tool based on multidimensional physico-chemical analysis with synchrotron and benchtop techniques? In addition, the presentation will highlight studies focused on the use of advanced techniques including accelerator-based for wildlife hair forensics, the effect of hair treatments on the hair ionome, and hair molecular analysis.

# Compact Accelerators

Abstract # 242

## New applications of compact accelerators in security and non-proliferation

Igor Jovanovic

*University of Michigan USA*

Radiation sources based on compact accelerators hold significant promise for detecting illicit transport of nuclear materials and contraband, and for advancing global nonproliferation objectives, including nuclear safeguards and treaty verification. This talk will discuss several recent developments that exemplify how the characteristics of compact accelerator-driven radiation sources, including their energy spectrum, pulsed nature, and directionality can be combined with modern nuclear instrumentation and nuclear analytical techniques to benefit those applications. Specific examples include the use of neutron generators, bremsstrahlung, and quasi-monoenergetic sources in cargo security and safeguards of current and future nuclear fuel cycles.

Abstract # 92

## Recent advancements in compact accelerator and gamma source technologies

Marcos Ruelas, Ronald Agustsson, Robert Berry, Amirari Diego Lopez, Sergey Kutsaev, Alex Murokh

*RadiaBeam Technologies, LLC, USA*

Recent advancements in accelerator design, manufacturing technology, and supporting subsystems have ushered in a renaissance in compact accelerator-based electron, X-ray, and gamma sources. These sources have reduced size, weight, and power requirements with negligible or otherwise acceptable reduction in output performance. The use of frequencies above 9 GHz, and even >100 GHz, have allowed for miniaturization of the accelerating structure, but reduction in the size and weight of subsystems have allowed further improvements to the system footprints. Recently, these improvements have culminated in a new generation of portable electron and X-ray sources. In addition, these same manufacturing and design improvements have recently been applied to higher-energy (circa 30 -- 100 MeV) accelerators serving as drivers for gamma sources. Here, we report on these recent subsystem advancements, illustrative examples of compact accelerators, and the new applications they facilitate. Electron, X-ray, and gamma sources are covered.

Abstract # 73

# Compact industrial traveling wave x-band linac with pulse-to-pulse tunable output energy

Valery Dolgashev[1], Philipp Borchard[2], William Graves[3], Mark Holl[3], Roman Kostin[4], Anatoly Krasnykh[4], Sergey Kutsaev[5], Sergey Kuzikov[4], Drew Packard[6]

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We will present the design of a compact, highly efficient 9.3 GHz linac with pulse-to-pulse tunable output energy. This linac will produce of up to 500 W of 10 MeV electron beam power for medical and security applications. The novel feature of this linac is its patented traveling wave accelerating structure. This structure combines the benefits of high efficiency with the ability to vary the energy by changing the beam loading specific to the traveling wave cavities. One advantage of this accelerating structure over standing wave structures is that it is broadband and therefore has little power reflected back to the RF source, eliminating the need for a heavy, lossy waveguide insulator. The high shunt impedance will allow the linac to achieve an output energy of up to 10 MeV when powered by a compact commercial 9.3 GHz 1.7 MW magnetron. For pulse-to-pulse tuning of the beam output energy we will change the beam-loaded gradient by varying the linac's triode gun current. In this talk, we will discuss the physics design, engineering and mechanical design of the linac, and prototype measurements.

Abstract # 140

## Low energy linac for electronic brachytherapy

Ben Freemire, Chunguang Jing, Edgar Gomez, Pavel Avrakhov, Roman Kostin, Sean Miller, Wade Rush, Yubin Zhao

*Euclid Techlabs LLC, USA*

The use of electronic brachytherapy (EB) has grown rapidly over the past decade. It is gaining significant interest from the global medical community as an improved user-friendly technology to reduce the usage of Ir-192. However, the present EB machines all use electron beams at energies of 100 kV or less to generate the X-ray photons, which limits their use to low dose-rate brachytherapy. We focus on the development of a compact and light weight 1-MeV linac to generate and deliver >250 kV X-ray photons to the patient. The device is intended to retrofit to existing brachytherapy applicators. In this paper we will report progress on this project

Abstract # 106

## Madison Accelerator Laboratory: a unique nuclear research user facility at James Madison University

Tilda Pendleton, Adriana Banu

*JMU, USA*

Madison Accelerator Laboratory (MAL) is a unique electron/bremsstrahlung facility on the campus of James Madison University. The facility features a medical electron linear accelerator (linac), an X-ray imaging system, and a suite of particle detection instrumentation. The Siemens Mevatron linac produces electron beams with energies from 6-15 MeV and bremsstrahlung photon beams with endpoint energies from 6-15 MeV. Since its operation in 2017, MAL has produced results for both applied and basic nuclear physics research, but challenges remain in repurposing and transforming a clinical linac into a multidisciplinary user-research facility. This presentation will provide an overview of current research projects and collaborations ongoing at MAL as well as potential future additional research directions. Challenges of MAL's operation include measuring bremsstrahlung endpoint energies and photon flux; these will be discussed, and results and progress will be presented. The ultimate goal of MAL is to become a user facility that enables research in a wide range of nuclear science applications. This presentation seeks to disseminate the progress towards that end.

Abstract # 75

# Compact stand-alone superconducting RF accelerators

Thomas Kroc

*FNAL, USA*

Now that superconducting RF accelerators have become the standard for discovery science facilities, it is time for them to be applied to applications in the industrial sector. As part of its REDUCE objective, the Office of Radiological Security of the National Nuclear Security Administration (NNSA) supports efforts to reduce reliance on radioisotopes through the development of alternative sources of radiation for applications such as the sterilization of medical devices. X-ray sources with dose rates comparable to large panoramic gamma irradiators using cobalt-60 require electron beams of 100s of kilowatts. Other applications including environmental remediation, sewage and wastewater treatment also require large amounts of beam power. Accelerator systems for these industrial applications must be compact, reliable, and simple to operate.

A key element for compact systems is the elimination of liquid cryogens and the related liquification infrastructure. This requires careful management of the heat budget of the accelerator system so that cryocoolers, which are available commercially, can be used to maintain superconducting temperatures. Fermilab is developing a compact SRF electron accelerator utilizing four enabling technologies (in bold, below) to allow the use of superconducting accelerators in industrial applications. A 1.6 MeV, 20-40 kW prototype is currently being assembled. We will present the results of acceptance testing of the various components of the system. These include: a 50 kW RF power coupler with very low heat conduction from the ambient to the cryogenic area; an integrated electron RF gun; conduction cooling and commercial cryocoolers. The most critical technology we will report is the niobium tin coating of the inner surface of the accelerating cavity to allow operation at a temperature within the capacity of the cryocoolers.

Other compact, stand-alone efforts are underway at Jefferson Lab and at SLAC to address various areas of the industrial application space. These will also be summarized.

Successful operation of these prototype systems will validate the compact SRF concept that will be able to provide the 100s of kilowatts necessary for the applications noted above.

Abstract # 107

# A compact normal-conducting CW accelerator for industrial applications

Robert Rimmer[1], Fay Hannon[2], Shaoheng Wang[1]

*[1]Jefferson Lab, USA, [2]Phasespacetech, USA*

We will present a concept for a compact and efficient room temperature CW accelerator for industrial applications using a copper linac, magnetron RF and a thermionic electron source. These technologies have been proven reliable in field applications and major components can be sourced commercially. Thermionic cathodes have been shown to have very long operational lifetimes and can be replaced in-situ. Magnetrons are the lowest cost, highest efficiency RF sources available in this frequency range. Leveraging the significant accelerator expertise at JLab, these technologies will be combined to deliver high-power electron beams (up to 100 kW), with energies of 1-5 MeV that are cost-effective to produce and operate.

Abstract # 128

## Advanced compact radiation sources: free electron lasers and Compton sources

Jeroen van Tilborg[1], Sam Barber[1], Curtis Berger[1], Qiang Chen[1], Chris Doss[1], Eric Esarey[1], Robert Ettelbrick[1], Cameron Geddes[1], Anthony Gonsalves[1], Benjamin Greenwood[1], Robert Jacob[1], Finn Kohrell[1], Stephen Milton[2], Kei Nakamura[1], Guillaume Plateau[2], Carl Schroeder[1], Sarah Schroeder[1], Hai-En Tsai[1], Anthony Vazquez[1], Peter Walter[2], Reinier van Mourik[2],

*[1]LBNL, USA, [2]Tau Systems, USA*

Brilliant x-ray sources including coherent free electron lasers at energies up to keVs, and incoherent monoenergetic Compton scattering sources at MeV energies and beyond have revolutionized a broad range of science from materials to nuclear signatures. Such sources require linacs at GeV to tens of GeV energies, and technologies to make such accelerators smaller have the potential to both greatly broaden the science accessible and to enable field applications ranging from industry to medicine and security. Ultrashort pulse lasers enable resonant excitation of plasma waves, efficiently driving structures that can accelerate particles at rates of in the range of a GeV per centimeter. Such compact electron beams are being used to develop novel compact photon sources including free electron lasers and MeV photons from Compton and Thomson scattering. Work on such sources and highlights from across the community will be discussed. The same laser pulses enable diverse other applications including ion sources and future colliders. While these experiments are proving the building blocks, laser development holds the key to scaling to the repetition rate and precision required for applications. Related areas of accelerator science and technology will also be described.

Abstract # 164

## SRF cavity and microwave source development at General Atomics

Drew Packard[1], James Anderson[1], Gary Cheng[2], Gianluigi Ciovati[2], Edward Daly[2], Keith Harding[2], Leo Holland[1], Alex Laut[1], Charles Moeller[1], Nikolai Norausky[1], Uttar Pudasaini[2], John Rathke[3], Robert Rimmer[2], Tom Schultheiss[4], Kyle Thackston[1], John Vennekate[2], Devin Vollmer[1], Haipeng Wang[2]

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Superconducting radiofrequency (SRF) accelerators are critical to scientific facilities across the world. These accelerators require large liquid helium cooling plants to maintain the extremely low temperatures necessary for their operation, resulting in high capital and operating expenses. Recently, researchers at Thomas Jefferson National Accelerator Facility (TJNAF) and General Atomics (GA) demonstrated the SRF performance of a 952 MHz Nb3Sn/Nb, copper coated single-cell accelerating cavity using Sumitomo RDE-418D4 conduction cryocoolers. The cavity exhibited gradients up to 12.4 MV/m, equivalent to 1 MeV energy gain. The advent of the conduction-cooled cryomodule is a significant advancement for SRF accelerator systems that improves compactness and reduces cost. The TJNAF-GA collaboration is now focused on demonstrating the SRF performance of a cryomodule leveraging a multi-cell cavity that can achieve up to 10 MeV energy gain. This advancement will make environmental remediation and directed energy applications more feasible, such as waste processing and free electron laser systems, respectively. In parallel to the compact cryomodule development, TJNAF and GA are collaborating in the development of an efficient and scalable magnetron combination system. The coherent combination of compact and efficient magnetron technology can achieve powers on the order of megawatts at continuous-wave operation. Industrial applications of SRF accelerators, such as remediation of forever chemicals and bulk material processing, can achieve advanced efficiencies and decreased operating costs being driven by banks of magnetrons. The ongoing developments between GA and TJNAF and future directions will be discussed.

Abstract # 123

## Compact RF linac design for an accelerator driven system

Brahim Mustapha, Jerry Nolen, Taek K. Kim,

*ANL, USA*

A compact RF linac design has been developed for an Accelerator Driven System (ADS). The linac is about 150 meters long and comprises a radio-frequency quadrupole (RFQ) and 20 superconducting RF cryomodules. Three types of half-wave cavities and two types of elliptical cavities have been designed and optimized for high performance at the frequencies of 162.5, 325 and 650 MHz. The lattice was designed and optimized for operation with a peak power of 25 MW for a 25 mA – 1 GeV proton beam. The cavities RF design as well as the linac lattice will be presented along with end-to-end beam dynamics simulations for beam currents ranging from 0 to 25 mA. We conclude with a discussion of the ADS reliability requirements, and the balance between compactness and redundancy of the RF linac.

# Accelerator Design and Technologies

Abstract # 113

# $H^-$, $D^-$ and Alpha source developments for medical isotope production cyclotrons

Morgan Dehnel[1], Anand George[1], Cornelia Hoehr, Stephane Melanson, Nicolas Savard[1]

*[1] D-Pace, Inc., Canada, [2] TRIUMF, Canada*

The negative hydrogen ion is the work horse ion in terms of medical radioisotope production worldwide. This paper shall discuss latest developments in Penning ion source developments for cyclotrons utilizing internally produced $H^-$, largely for Positron Emission Tomography (PET) radioisotopes. In addition, evolution of the volume-cusp type ion source designs for $H^-$ production external to cyclotrons for high current Single Photon Emission Computed Tomography (SPECT) radioisotopes shall be described. Radioisotopes are increasingly being used for therapy as well as diagnostic imaging, and this is also creating interest in ion sources for alpha production for injection into cyclotrons and other accelerators. Latest progress in alpha source development for this purpose shall, therefore, be described.

Abstract # 112

# Development of Charge Stripper Ring at the RIKEN RI Beam Factory

Hiroshi Imao

*RIKEN, Japan*

The RIKEN RI Beam Factory (RIBF) is working on the future upgrade project to increase the intensity of heavy ion beams, especially for the heaviest uranium beams which are particularly important in unstable nuclear physics research in the midst of global research competition. The charge conversion efficiency of the two charge strippers (He gas and rotating graphite sheet disk strippers) in accelerating the uranium beams at RIBF is only 5%, which is a serious bottleneck for the intensity upgrade.

We have proposed the use of a new device called Charge Stripper Rings (CSRs) as an effective way to dramatically increase charge conversion efficiency. The overall charge conversion efficiency will be increased to 50% (10 times of the current level) with the CSRs. The design and development status of CSRs will be discussed.

Abstract # 110

# Advances in the Laser Ion Source development at BNL

Takeshi Kanesue[1], Antonino Cannavo[1], Giovanni Ceccio[2], Shunsuke Ikeda[1], Masahiro Okamura[1], Sergey Kondrashev[1], Kazumasa Takahashi[3]

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A laser ion source is well-known as a high current and high charge state heavy ion source using laser ablation of solid materials. This is the only type of an ion source capable of producing ampere-class heavy ion beam using compact and simple ion source structure. However, it is difficult to transport and inject such a high current beam into the first stage accelerator, typically a radio frequency quadrupole linear accelerator (RFQ linac) due to space charge effect. BNL is a pioneering laboratory for the laser ion source development. We have studied the Direct Plasma Injection Scheme (DPIS) to accelerate high current heavy ion beams by an RFQ linac. For example, we achieved 35 mA of Li3+ beam after an RFQ linac with laser power density on a target about 10^12 W/cm^2. A laser ion source can also generate a pulsed singly charged heavy ions by reducing laser power density just above threshold of plasma generation (~10^8 W/cm^2). At BNL, a laser ion source (LION) has been providing multiple species of heavy ions to an electron beam ion source for further ionization. The resulting highly charged ion beams have been used by NASA Space Radiation Laboratory (NSRL) and Relativistic Heavy Ion Collider (RHIC). The LION is a key device to realize a galactic cosmic ray study at NSRL and quasi-simultaneous operation of these two user facilities. An overview of the technology and recent developments of the laser ion source development at BNL will be presented.

Abstract # 132

# A novel method for $H^-$ beam energy measurement with doppler-shifted Lyman lines

Charles Taylor, En-Chuan Huang, Heather Andrews

*LANL, USA*

At LANSCE, we are developing a new technique for measuring our H- beam energy by examining the decay photon spectrum distribution following neutralization. The photons emitted during the decay have well-known discrete energies. Therefore, the Doppler shift of their wavelength reveals the speed of the particles they came from, which allows for the precise calculation of beam energy. This method will improve the energy accuracy by two orders of magnitude, greatly enhancing studies dependent on particle time-of-flight and medical treatments dependent on precise energy disposition. Many DOE-supported and international facilities use H- beams, including LANSCE, Spallation Neutron Source (SNS) at ORNL, TRIUMF Cyclotron, ISIS Neutron Source, and Linac4 at CERN. LANSCE currently uses H- beam for four of its five experimental areas. Additionally, the Isotope Production Facility at LANSCE is considering switching from H+ to H- beam with the upcoming front-end upgrade for various reasons, including the possible use of this improved energy diagnostic.

Abstract # 98

# U4: RF linac driver for timely Inertial Fusion Energy (IFE)

Alexander Burke[1], Robert Burke[2]

[1] *Elve Inc., USA,* [2] *Arcata Systems, USA*

The recently evolved U4 upgrade of the single-pass RF linac driver for IFE is based on Basko's assessments of the requirements for stable compression, fast ignition, and high-gain fusion burn of large cylindrical fuel pellets. Basko's simulations use the beams of Koshkarev's driver: 100 GeV Bi for compression and eight, telescoping Pt beams for fast ignition: four Pt isotopes in either charge state. U4's multiple, charge-balanced beams drive both compression and fast ignition. U4's 10 single-isotopic linacs are duplexed for + and - beams in separate bores of integrated RF structures. Large unit-cost reductions are presumed from new designs innovated to be mass manufactured to meet the large energy demands of the future.

A linac for each species led to the concept of a beam-transformer switch-network (Kvetchnet) that converts incoming parallel beams of single isotopes to multiple-isotope outgoing beams set to telescope longitudinally during ~3 km identical-length drifts to pellets in multiple chambers. Multiple chambers are an essential foundation for the U4 energy facility's attractive economics. At the intersections between incoming lines of isotopes (10, duplexed) and the outgoing beamlines (8, duplexed) are a pair of kicker magnet switches (50 nsec rise. 500 ns flattop) connected by a d.c. beamline ~16 m long (5o intersection Kvetchnet). 160 identical transformer kits: 320 switches and 160 connector beamlines.

U4's vitality derives from combined technical feasibility and the outlook for low-cost energy due to the large economies of scale of many chambers with one driver igniting high yield fusion pulses round-robin. Chambers are free from the neutron-damage materials problem that is MFE's nemesis. LLNL's exhaustive (1977-85) and highly favorable assessment of the HYLIFE (High Yield Lithium Injected Fusion Energy) chamber for IFE assumed ~1 pps energy yields ≥ 1 ton TNT/MWh/BOE—substantial economic value per pulse. Neutronically thick injected lithium eliminates the neutron-materials problem while containing the blasts. HYLIFE's advantages depend on large pulses to make lithium protection work, as does U4's further improved chamber. U4's combined advantages enable IFE to achieve major acceleration of fusion energy. ~ 2 BOE per second in ~10 chambers is the output of a supergiant oil field.

Abstract # 103

## Overview of Inverse Compton Scattering (ICS) Sources

Alex Murokh

*RadiaBeam, USA*

There is a growing demand in industrial and research communities for a laboratory-scale high-brightness light sources, in a wide range of applications. At high average powers such sources are needed for industrial processing, at moderate powers – mostly for metrology, and at a lower power for qualification, inspection, testing, and R&D. Inverse Compton Scattering (ICS) is one very promising technology on the lower end of the power spectrum, with the promise of a compact and energy tunable hard X-ray light source of a nearly synchrotron beam quality, and with excellent potential scalability into gamma ray spectral range. In this paper, the authors review a considerable volume of the experimental work performed to date on the ICS sources and discuss the recent and ongoing accelerator industry efforts to commercialize the technology. In addition, an overview of the RadiaBeam internal ICS demonstrator program is presented, including its status and outlook.

Abstract # 163

# Radiation shielding design analysis for the ring to Second Target Beam Transport at the spallation neutron source Second Target Station

Wouter de Wet, Kumar Mohindroo, Thomas Miller,

*ORNL, USA*

The Second Target Station (STS) facility at Oak Ridge National Laboratory's Spallation Neutron Source will receive a 700 kW, 1.3 GeV proton beam with a pulse frequency of 15 Hz, delivered by the Ring to Second Target Beam Transport (RTST). Spanning approximately 220 meters, the RTST includes 56 quadrupole magnets and 15 dipole magnets. According to the STS Project Radiation Safety Policy and Plan, radiation exposures in generally accessible areas must not exceed 0.25 mrem/hr during normal facility operations.

The radiation transport model geometry, created using constructive solid geometry (CSG), includes the entire beamline downstream of the accumulator ring to the STS target building. This encompasses the beam vacuum tubing, magnets, tunnel structure, and surrounding components like the soil berm, truck access tunnel, shield walls, and labyrinths. The MCNP6 general-purpose Monte Carlo radiation transport code was utilized to estimate dose rates in accessible regions, accounting for contributions from 1 W/m beam losses and backscatter from the beam striking the rotating STS tungsten target. Custom MCNP6 subroutines were developed to represent the beam losses along the RTST and the primary beam on the target. The ADVANTG code facilitated the generation of optimized weight windows to converge dose rates in areas of interest.

This work offers an overview of the passive radiation shielding design for the RTST facility. It encompasses methodologies for calculating expected dose rates in generally accessible regions and discusses technical design challenges along with their respective solutions.

Abstract # 192

## Upgrades to the photoinjector and ICS interaction point chamber of CXLS

Taryn Brown[1], Gregory Babic[2], Alan Dupre[1], Alex Gardeck[1], William Graves[1], Mark Holl[1], Antonella Semaan[1], Dean Smith[1], Samuel Teitelbaum[1], Sean Tilton[1]

*[1]Arizona State University, USA, [2]University of Maryland, USA*

Details and engineering challenges of the Compact X-Ray Light Source (CXLS) at ASU are described. The CXLS achieves x-ray photons with energies in the range of 6-20 keV by using Inverse Compton Scattering (ICS) where the electron beam interacts with a powerful laser instead of the traditional magnetic undulator. The short wavelength of the laser relative to a magnetic undulator reduces the electron beam energy required to produce hard x-rays. Since magnets are not used for undulation, as in traditional large light sources, the accelerator vault of the CXLS is only 10 m long. This extremely compact size allows the entire facility to fit into a university building and to be built at a fraction of the cost of other bright sources of femtosecond x-ray pulses. We review CXLS design elements and then describe operations experience and equipment upgrades with a focus on the photoinjector laser and the ICS interaction point chamber and its associated controls and beam diagnostics.

Abstract # 159

## Laser-Ion acceleration in plasmas and short bunch applications

Jörg Schreiber, Sonja Gerlach

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Chirped pulse amplification (CPA) laser systems, exemplified by the Advanced Titanium-Sapphire Laser (ATLAS) operated in the Centre for Advanced Laser Applications (CALA) at the Ludwig-Maximilians-University (LMU) Munich, are capable of generating laser pulses with Petawatt peak power and ~30 fs duration. When focused tightly onto targets, typically (sub-)micrometer thin foils, these pulses ionize and subsequently induce relativistic electron motion which separates electrons from ions. The emerging rectified fields of order ~MV/µm results in rapid acceleration of dense ion bunches.

This presentation will explain the physical processes involved and elucidate the characteristics of ion sources, in particular the accessible energy distributions using current technology. The ultrashort pulse enables acceleration within less than one picosecond, ensuring a similar precise synchronization of the bunch with the laser – a pivotal aspect for new application possibilities. Notably, this synchronization allows for time-resolved investigations of post-proton energy deposition processes within targets such as water. The intense plasma fields also facilitate ionization of heavy ions into high charge states. Recent observations include the acceleration of Neon-like gold to MeV/u kinetic energies, along with initial indications of fission within the microscopic plasma.

At CALA, our active focus lies in pushing the boundaries of technology to leverage the potential applications of laser-plasma acceleration. Our efforts encompass the development of instrumentation capable of characterizing the spatial and energy distributions of individual, intense ion bunches using ultrasound pulses. We are now working on providing fresh laser-ion converters, known as targets, with the repetition rate of 1 Hz dictated by the PW-laser. These advancements mark a significant step towards practical implementation, aiming to spark curiosity and stimulate engaging discussions.

Abstract # 109

## The ARIEL-e-Linac and its technical development for user operation

*Stephanie Diana Rädel*

*TRIUMF, Canada*

TRIUMF’s 30 MeV electron linac is transitioning from a commissioning operation to a user operation. The machine’s main user is ARIEL, which will be ready to take beam in 2026. But as of today, more users are upcoming, giving the machine the possibility to support scientific and medical experiments. Those upcoming users require modifications to the existing machine in order to support the change in the operational paradigm. For FLASH we needed technical development to shorten the access timeframe to the machine as well as small adaptions to the beamline. The optics adaptions we are putting forward to host the DarkLight experiment are more severe to handle the electron foil interaction. Terahertz is another upcoming user for the e-Linac, bringing high bunch charges, which are a challenge for our optics. All these changes will be presented.

Abstract # 119

## A CANS for Canada: a future neutron source for the North

Dalini Maharaj[1], Mina Abbaslou[2], Marco Marchetto[3], Robert Laxdal[3], Alexander Gottberg[3], Oliver Kester[3], Drew Marquardt[4]

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Neutron scattering has proven to be one of the most powerful methods for the investigation of structure and dynamics of condensed matter on atomic length and time scales. Neutron techniques have a broad range of applications in physics, chemistry, magnetism and superconductivity, material sciences, cultural heritage, biology, soft matter, health, and environmental and climate science. With the relatively recent closure of the National Research Universal reactor, Canada has lost its primary source of neutron for neutron scattering. With a globally shrinking supply of neutrons and the NIMBY perception that research reactors face, compact accelerator-driven neutron sources (CANS) are on the rise. CANS have potential produce an intense source of pulsed neutrons, with a capital cost significantly lower than spallation sources and reactor sources along with much less public stigma. A prototype Canadian CANS (PC-CANS) is proposed as the first step towards rebuilding Canadian neutron capabilities. This new source would be the first of its kind in Canada and provide neutrons for two neutron science instruments, a boron neutron capture therapy (BNCT) end-station. The accelerator designed for the PC-CANS would also facilitate a beamline for fluorine-18 radioisotope production for positive emission tomography (PET). Here, we outline the details of the PC-CANS and key design features that will all for such a diverse range of applications.

Abstract # 91

# Compact, energy efficient neutron source: enabling technology for thorium breeder and accelerator transmutation of waste

Ady Hershcovitch

*BNL, USA*

A novel neutron source concept, in which a deuterium beam (energy of about 100 keV) is to be injected into a tube filled with tritium gas or tritium plasma to generate D-T fusion reactions whose products are 14.06 MeV neutrons and 3.52 MeV alpha particles, is described. At the opposite end of the tube, the energy of deuterium ions that did not interact is recovered. Be walls of proper thickness will absorb 14 MeV neutrons and release 2 – 3 lower energy neutrons. Each ion source and tube form a module. Larger systems can be formed from multiple units. Beam propagation can be further enhanced with vortex-stabilized discharges, electron beams in opposite direction (with energy recovery) or magnetic fields where possible. Deuterium ions propagating through tritium plasma are slowed down and deposit significant energy in the tritium target. Plasma heating results in high temperature electron, thus reducing deuterium ion energy loss. Equilibrium electron temperature exceeding 200 eV can be achieved. Unlike current methods, where accelerator-based neutron sources require large amounts of power for operation, this neutron source is compact and can generate neutrons at higher power efficiency. Being modular, the concept can be tested in tabletop experiments. Concept description and basic calculation will be presented. Among possible applications for this neutron source concept are sub-critical nuclear breeder reactors and accelerator transmutation of radioactive waste.

Abstract # 121

## Niobium-tin as a transformative technology for low-beta linacs

Troy Petersen

*ANL, USA*

Niobium-tin has been identified as the most promising next-generation superconducting material for accelerator cavities. This is due to the higher critical temperature (Tc = 18 K) of $Nb_3Sn$ compared to niobium (TC = 9.2 K), which leads to greatly reduced RF losses in the cavity during 4.5 K operation. This allows two important changes during cavity and cryomodule design. First, the higher Tc leads to negligible BCS losses when operated at 4.5 K, which allows for a higher frequency to be used, translating to significantly smaller cavities and cryomodules. Second, the reduced dissipated power lowers the required cryogenic cooling capacity, meaning that cavities can feasibly be operated on 5-10 W cryocoolers instead of a centralized helium refrigeration plant. These plants and distribution systems are costly and complex, requiring skilled technicians for operation and maintenance. These fundamental changes present an opportunity for a paradigm shift in how low-beta linacs are designed and operated.

Abstract # 99

## Compact superconducting RF accelerators for water treatment

John Vennekate[1], Charles Bott[2], Alejandro Castilla[1], Gary Cheng[1], Gianluigi Ciovati[1], Jiquan Guo[1], Keith Harding[1], James Henry[1], Xi Li, Drew Packard[3], Mack Pearce[2], Uttar Pudasaini[1], John Rathke[4], Robert Rimmer[1], Tom Schultheiss[5]

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*[5]TJS Technologies LLC, USA*

Jefferson Lab is actively exploring the environmental applications of compact irradiation facilities utilizing Superconducting Radio Frequency (SRF) accelerator technology – a well-established technology primarily used in large research machines. Recent advancements, such as the application of thin films of superconducting alloys in radio frequency (RF) resonators and the development of high-capacity cryocoolers, have made it feasible to employ this key technology in compact, standalone irradiation facilities. The main advantage over conventional systems based on normal conducting technology is the significantly enhanced efficiency in beam power generation, enabling exposure to substantially higher radiation doses.

In the realm of addressing contaminants in wastewater treatment, particularly concerning persistent substances known as "forever chemicals," this technology presents an attractive solution, given the required considerable effort, i.e., dose to break them down.

In collaboration with the Hampton Roads Sanitation District, Jefferson Lab has established a test beamline to examine the impact of electron beams on substances like 1,4-dioxane and other contaminants. This study's findings, alongside the ongoing endeavors to design and construct a compact 10MeV, 1MW accelerator, will be discussed.

Abstract # 182

# Design of a compact accelerator-driven neutron source at the HZDR ion beam center

Reuven Rachamin, Shavkat Akhmadaliev, Claudia Bischoff, Ulrich Kentsch, Stefan Facsko

*HZDR, Dresden, Germany*

The Ion Beam Center (IBC) at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) is a unique user facility with decades of experience in materials research using ion beams of nearly all stable elements in a wide energy range from some eV up to 60 MeV. The IBC operates several electrostatic ion accelerators, ion implanters, low energy, highly charged, and fine-focused ion beam systems. The IBC provides experimental equipment for materials modification via ion implantation and irradiation, all types of ion beam analysis of materials, surface processing by low-energy, highly-charged, and focused ion beams, as well as for accelerator mass spectrometry (AMS).

Neutron beamlines are currently planned to be constructed at the 6 MV Tandetron of the IBC. Neutrons provide information that cannot be obtained with other methods and open new opportunities for material analysis at IBC, such as imaging and 3D tomography with fast and thermal neutrons, prompt and delayed gamma neutron activation analysis (PGNAA & DGNAA), and investigations of radionuclides production for radiopharmacology. The concept of the neutron source for the planned beamlines is based on the production of neutrons from the interaction of a proton beam with a beryllium target. A Monte Carlo (MC) simulation study was performed to design and evaluate the neutron beamlines using the FLUKA MC code (version 2023.3.1). In addition to the proton-beryllium interaction for neutron production, the study evaluates the possibility of using heavier ions, such as lithium, as a driver beam and hydrogen-rich material as a target. An overview of the planned neutron beamlines and the results of the neutronic and radiation protection parameters associated with the beamline design will be presented and discussed.

# High Power Accelerator Components and Targets

Abstract # 150

# The IFMIF-DONES Accelerator: Target & Irradiation Challenges and Future Research Opportunities

Claudio Torregrosa-Martin[1], Angel Ibarra[1], Concepción Oliver[2], Cristina de la Morena[2], Daniel Sánchez-Herranz[1], David Jiménez-Rey[2], David Regidor[2], Davide Bernardi[3], Francesco Saverio Nitti[3], Francisco Martín-Fuertes[2], Frederik Arbeiter[4], Iván Podadera[1], Javier Gutiérrez[5], Jesus Castellanos[6], Jorge Maestre[1], Juan Carlos Marugán[5], Mario García[1], María Luque[1], Moisés Weber[1], Philippe Cara[7], Santiago Becerril[1], Tamas Dézsi[8], Tonci Tadić[9], Urszula Wiacek[10], Wojciech Królas[10], Yuefeng Qiu[4]

*[1] IFMIF-DONES, Spain, [2] CIEMAT, Spain, [3] ENEA, Italy, [4] KIT, Germany, [5] Empresarios Agrupados, Spain, [6] UCM, Spain, [7] F4E, [8] C3D, [9] RBI, Croatia, [10] IFJ, Poland*

The IFMIF-DONES Facility will be a first-class scientific infrastructure situated in Granada, Spain. It will comprise an accelerator-driven neutron source capable of delivering ~1e17 n/s with a broad peak at 14 MeV. The neutron source will be generated by impinging a continuous wave 125 mA, 40 MeV deuteron beam into a liquid Li jet target, circulating at 15 m/s and evacuating the 5 MW power of the beam. The primary scientific objective of IFMIF-DONES is the irradiation of specimens in a fusion-like neutron environment, essential for the material qualification of future fusion reactors like DEMO. Positioned a few millimeters downstream from the target, the material specimens will undergo irradiation under controlled temperatures ranging from 250 to 550 °C, with continuous monitoring of the radiation field (although other irradiation modules which could reach temperatures up to 1000 °C are also foreseen). The anticipated damage rate is within 20 dpa in 2.5 full power years for an irradiation volume of 300 $cm^3$, and up to 50 dpa in 3 years for an irradiation volume of 100 $cm^3$. Beyond its core mission of fusion materials qualifications, IFMIF-DONES will provide facilities for a diverse set of other experiments, making it a multidisciplinary neutron facility. These experiments span a wide spectrum of research fields, including, among others, medium flux fusion-related experiments (such as tritium breeders or fusion components validation), as well as many others non-fusion related, such as fast-neutron imaging, neutron time-of-flight, radioisotope production, or fundamental neutron physics research. This contribution will provide an overview of the project, highlighting its main requirements and technological challenges concerning the high-power target and irradiation modules operation and monitoring. Furthermore, it will provide a glimpse into the potential future nuclear research opportunities that extend beyond the fusion energy field.

Abstract # 169

## High power targetry for Accelerator Driven Systems: challenges and perspectives

Massimo Barbagallo

*Transmutex SA, USA*

Accelerator-driven subcritical systems (ADS) represent an advantageous option for the transmutation, volume reduction, and safe disposal of nuclear waste. Neutron spallation sources for Accelerator Driven Systems, commonly known as ADS Targets, must at the same time feature high performances from a neutronics point of view and function reliably and safely, especially in the current scenario where the ADS concept takes hold as a viable option in the commercial sector.

Most of the ADS facilities currently being designed or constructed are meant to be operated in the next decade. All the concerned projects highlight the challenges associated with the usage of spallation targets as interfaces between multi-megawatt charged particle beams and subcritical cores operating at significant thermal power.

A review of different options for ADS targetry is presented in this talk, with particular emphasis on requirements, perspectives, and needed R&D programs.

Abstract # ???

# Status of the Second Target Station Project with Target Systems Highlight

Peter Rosenblad, Ken Herwig, Michael Allit, Steven Hartman, Gary Bloom, Leighton Coates
*ORNL, USA*

The Second Target Station (STS) project is an expansion to the existing Spallation Neutron Source (SNS) in Oak Ridge, TN. The project is currently in the preliminary design phase. STS seeks to provide world leading peak cold neutron brightness to a suite of new instruments, eight of which are included in the project scope. SNS is currently in the final stages of the Proton Power Upgrade Project (PPU), which will leave the linear accelerator and accumulator ring capable of providing 2.8 MW delivered in micro-second long pulses at 60 hz. The First Target Station (FTS) will accept a maximum of 2 MW, leaving power available for STS. Every 4th pulse from the accumulator ring will be directed to STS via a new beam transport line. Thus, STS will receive 700 kW at 15 hz and the FTS will operate at 2 MW with an irregular 45 pulses per second. STS will achieve world leading peak brightness using the following ingredients: 1) compact, short, high net energy (46.7 KJ) pulses, 2) a compact rotating tungsten target with a low coolant volume fraction, and 3) closely coupled compact hydrogen moderators surrounded by water pre-moderator and beryllium reflector.

This presentation will provide an overall technical description of the project and its status. Current design and major evolutions across all systems will be presented. Subsequently, a more detailed, but still high-level description of the evolution and status of the Target Systems will be provided.

Abstract # 127

## High-Fidelity Neutronics Simulation Aided Target Study for the SNS Proton Power Upgrade Project

Wei Lu, Franz Gallmeier, Kevin Johns

*ORNL, USA*

The Proton Power Upgrade (PPU) project at Spallation Neutron Source (SNS) is progressing well towards completion in 2024, when it is to deliver a 2MW 1.3 GeV proton beam at 60 Hz repetition rate to the SNS first target station (FTS). It thus imposes a further challenge to the engineering design of the mercury target to mitigate increased cavitation and high-cycle fatigue damage from ~45% more energy deposited into the system, which is mostly met by gas injection into the mercury flow. However, at the same time the target designs must maintain the moderator performance at a high level to serve the core mission of SNS of producing high-intensity neutron beams for material science. Taking advantage of an automated high fidelity modelling method with the coupling of DAGMC to MCNP6, at SNS we are able to directly track particle transport in CAD models generated from engineering designs for the Monte Carlo simulations of the SNS Target-Moderator-Reflector system. Thus, detailed energy deposition analyses in the target were able to be performed for various target designs under different incident beam conditions, revealing subtle but destructive flaws and improving design efficiency. An original tapered-node design of the target front, which improved the mercury flow but impacted the moderator performance by > 5% loss, had to be revised to reduce the performance losses to ~2%. On the other hand, the more energetic proton beam shifts the peak neutron production zone slightly further into the target and a study of the optimized target length was thus performed to find out whether a more desirable position of the target could be achieved. While a slightly shorter target showed performance benefits averaged over moderators, such a gain was washed down if averaged over instruments since the upstream moderators host two times more instruments than the downstream ones.

Abstract # 171

# High-Power Beam Intercepting Devices in Particle Accelerators

Antonio Perillo Marcone

*CERN, Switzerland*

Several beam intercepting devices (BID) are used in particle accelerators for different functions: machine protection (stopping the beam in accidental scenarios), human safety, beam conditioning (e.g. collimators, scrapers, slits), secondary beam production (targets) and absorbers (beam dumps).

Since these devices are found in accelerators with a broad range of beam energies and particle types, a large diversity of requirements, materials and designs are observed.

Typical considerations are physical and structural properties of materials. Hence, the full palette of materials is used in BID across the different accelerators, from ceramics and carbon-based materials (graphite and CfC) to virtually all metals.

In addition, some devices need to absorb and manage significant power (heat) deposited by the beam, which imposes other constraints in the design, such as cooling requirements and service temperature of the employed materials.

Irradiation damage is also accounted for in the design of some devices.

An overview of the main considerations for components that need to absorb and dissipate significant beam power and particle accelerators will be presented here, including their main functionalities, requirements and design features.

Abstract # 195

## FRIB challenges and beam power ramp-up

Qiang Zhao

*FRIB/MSU, USA*

Since May 2022, the Facility for Rare Isotope Beams (FRIB) has been delivering various heavy ions ranging from oxygen to uranium on target with energy up to 300 MeV/u for user operation. The primary beam power has been steadily raised from 1 to 10 kW with a successful demonstration of multi-charge simultaneous acceleration after a stripper. Over the next five years, an incremental ramp-up to the ultimate design beam power of 400 kW is planned. It is more challenging to operate high-power heavy-ion facilities than those of electron and proton due to higher power deposition density and higher radiation damage, as well as the necessity for the frequent switches of beam species. Both carbon foil and liquid lithium film strippers are currently used to boost ion charge states around 20 MeV/u. Although multi-charge states are selected for further acceleration simultaneously, for some ions, up to 10 kW undesired charge states will dissipate on the charge state selector. Regulation of low-level RF is being developed to stabilize beam energy due to the instability of lithium film. Beam collimators in the front-end and stripper area have been implemented. Adding more refined collimation along the linac to reduce uncontrolled losses is being investigated. Besides the traditional beam loss monitors, halo monitor rings and thermal sensors at both cryogenic and room temperatures are used to detect low beam losses. We will share our operational experience and discuss the challenges of beam power ramp-up.

Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0023633, the State of Michigan, and Michigan State University.

Abstract # 141

# Development of a novel conductive ceramic based RF window

Alexei Kanareykin, Ben Freemire, Chunguang Jing, Roman Kostin

*Euclid Techlabs LLC, USA*

We have developed a novel Magnesium Oxide based ceramic material which embraces a small amount of conductivity to prevent charging while maintaining extremely low loss tangent over a large frequency range. Both waveguide and coaxial types of CW RF windows using this conductive ceramic material were developed and tested. We will report technical details.

Abstract # 93

## CPI Developments in High Efficiency Klystrons

Peter Kolda, Takuji Kimura, Steve Lenci

*Communications & Power Industries LLC, USA*

Since the invention of the klystron over 75 years ago, the demand for new high-power devices has persisted. What has changed is the importance of the efficiency of the products as laboratories strive for environmentally considerate operation. CPI has collaborated with scientific institutions around the globe to address this demand. Based in Palo Alto California, the CPI Microwave Power Products Division's engineering team has recently produced new klystrons at 402.5 MHz, 704 MHz, 2.998 GHz, 9.3 GHz, and 12 GHz.

Recent requirements for Inverse Compton Scattering systems in a compact format have been a driving force in improving the efficiency of klystrons. The engineering team has endeavored to improve the efficiency of the klystrons and has focused on 12 GHz as the test item. The efficiency of the SLAC XL4 and XL5 klystrons that CPI is licensed to build are approximately 40%. These 50 MW peak power devices operate with a beam power of 120-130 MW. The average power is 18-20 kW. Working with partners at CERN CPI has considered the Bunch Align Compress (BAC), Core Oscillation Method (COM), and Core Stabilization Method (CSM) as techniques to boost efficiency and is pursuing an improved design targeting an efficiency above 55%. CPI has used particle in cell codes to craft a design that achieves this efficiency goal and is in the process of manufacturing a prototype for use at INFN, Frascati, Italy. CPI is also working on a 25 MW high efficiency klystron at 12 GHz that is anticipated to achieve similar high efficiency. Results for both new designs are expected in 2024.

Abstract # 102

# Novel Materials R&D for Next-Generation Accelerator Target Facilities

Abe Burleigh[1], Kavin Ammigan[1], Gaurav Arora[1], Sujit Bidhar[1], Adrien Couet[2], Nicholas Crnkovich[1], Frederique Pellemoine[1], Izabela Szlufarska[2]

*[1]FNAL, USA, [2]University of Wisconsin, USA*

High-Entropy Alloys and Electrospun Nanofiber materials are two classes of novel materials that can offer improved resistance to beam-induced radiation damage and thermal shock. Research to develop these new materials specifically for multi-megawatt accelerator target applications, such as beam windows and particle-production targets, are ongoing at Fermilab within the scope of a DOE Early Career Research Program. The research program combines in-beam experiments with complementary simulations to tailor the microstructures of these novel materials for use in next-generation accelerator target facilities. Iterative simulations to optimize the material composition, physics performance, and beam-induced thermomechanical response will guide the material design and fabrication processes based on established figures of merit. This will be followed by material irradiation experiments using low-energy ions and prototypic high-energy protons with extensive post-irradiation material characterization to assess and qualify the selected novel materials. This talk will describe the alloy design and synthesis, microstructural pre-characterization of the alloys, and plans for the eventual down selection following low-energy ion irradiation studies.

Abstract # 130

## Upgrades at the WNR Facility

Josef Svoboda, David Broughton, Andrew Leland Cooper, Sean Kuvin, Hye Young Lee, Michael Mocko

*LANL, USA*

The Weapons Neutron Research (WNR) facility at the Los Alamos Neutron Science Center (LANSCE) has set a long-term objective to enhance Target 4. This target facilitates six distinct flight paths (FP), each with specific beam delivery requirements. Historically, the as-designed MCNP geometry model has been employed. However, to guarantee precise beam delivery to all FPs, there is an emerging need to utilize a detailed as-built MCNP model. A novel approach has been introduced that employs the Laser Tracker System. This system accurately determines the position of the target, shutters, and flight paths. These data subsequently inform MCNP geometry and provide as-built MCNP geometry model. The beam spot quality is further assessed using a time-gated neutron imaging system.

Abstract # 147

## Automating the coupled neutronics-structural stress optimization at ORNL's Second Target Station

Lukas Zavorka, Kristel Ghoos, Joseph Tipton, Igor Remec

*ORNL, USA*

Oak Ridge National Laboratory's (ORNL) Second Target Station (STS) is designed to become the world's highest peak-brightness spallation source of cold neutrons. Exceptionally bright cold neutron beams will provide transformative capabilities to examine novel materials for advanced technologies in the decades to come. Bright beams will enable new neutron scattering experiments using innovative instruments under more extreme conditions, using smaller samples and shorter irradiation time. A comprehensive optimization study of neutron production is necessary to generate such bright beams. This work presents an automated optimization workflow that combines high-fidelity neutronics modeling with structural stress analyses and modern optimization algorithms. The coupled multi-physics, multi-parameter optimization workflow is essential to completing the STS project successfully. The workflow can be applied in the design process at other neutron, experimental, and accelerator facilities.

The current design of the STS consists of a 700-kW water-cooled rotating tungsten target and two compact pure para-hydrogen neutron moderators at 20 K. The target will be driven by a short-pulsed (<1 us) 1.3 GeV proton beam at 15 Hz from the Spallation Neutron Source's (SNS) linear accelerator. Neutrons with a broad energy spectrum will be generated in the target via spallation reactions. Some neutrons will enter hydrogen moderators surrounded by a light water premoderator and a beryllium reflector. After their moderation, cold neutrons will exit through small 3x3 cm emission windows and travel towards one of the eventually 18 modern instruments.

A compact arrangement of the target and moderators is key to generating bright neutron beams. However, arrangements that improve neutronics output typically reduce the structural integrity and thus increase the probability of failure. The goal of the coupled neutronics and structural optimization is to maximize neutron production while maintaining high factor of safety. In the past, one iteration through neutronics and structural analysis took several weeks to months. With the new automated workflow, the duration has been reduced to hours, which allows us to find the optimal solution much faster.

The optimization workflow uses parametrized solid CAD engineering models of the key STS components, such as the target and moderators. The detailed models are converted with Attila4MC into Unstructured Mesh (UM) models for neutronics calculations with MCNP6.2. The automated CAD to MCNP conversion improves the fidelity of the models and minimizes the time necessary for their generation. The high-fidelity energy deposition data from neutronics calculations are extracted together with neutron brightness. Energy deposition serves as input for the calculation of the factor of safety, which automatically evaluates both mean and peak amplitude stress with Sierra [4]. Neutron brightness and factor of safety are passed to the Dakota optimization toolkit, which analyzes the results and proposes a new set of design parameters using one of the state-of-the-art optimization algorithms. This cycle repeats until the optimization workflow converges and the optimal design is found.

This talk reviews the current STS design and the optimization workflow. We will describe individual steps of the workflow, share some practical information about its implementation, and discuss recent results.

Abstract # 129

# Automated Thermo-structural Analyses and Optimization of an Edge-cooled Spallation Target

Joseph Tipton, Kristel Ghoos, Aaron Jacques, Justin Mach, Joel Montross, Lukas Zavorka

*ORNL, USA*

The Second Target Station (STS) project is progressing through the preliminary design phase with a driving goal of creating the world's brightest neutron source. To achieve this, the spallation target must accept focused proton pulses with high energy (1.3 GeV/proton), high power (700 kW), and high rate (15 Hz) over a design life of 10 years with high availability. Testing resources are quite limited in this design space, and engineers must instead rely heavily upon detailed analysis and simulations to inform design decisions.

This presentation will describe the suite of tools used and developed at STS to simulate target structural lifetime performance. This analysis workflow leverages codes developed at US national labs (i.e. CUBIT meshing, SIERRA multiphysics, ParaView postprocessing, DAKOTA optimization) along with custom Python modules (i.e. neutronics interpolation, critical plane fatigue analysis) to create a highly automated and scalable simulation tool. Material static structural and fatigue properties are key inputs and are derived from best available data under representative conditions (e.g., solution annealed Inconel 718 at beginning of service life, tungsten and tantalum in irradiated condition, copper with radiation swelling). The tool is then used to guide design optimization of the selected edge-cooled target design under a variety of representative load scenarios.

Abstract # 151

## Affordable, Efficient Injection Injection-Locked Magnetrons for Superconducting Cavities

Milorad Popovic[1], Thomas Blassick[2], Mary Anne Cummings[3], Rolland Johnson[3], Stephen Kahn[3], Ronald Lentz[3], Michael Neubauer[3], Jerry Wessel[2], Tony Wynn

*[1]FNAL, USA, [2]Richardson Electronics, LLC, USA, [3] Muons Inc., USA*

Existing magnetrons, primarily employed for investigating control methods and lifespan enhancements in superconducting radiofrequency (SRF) accelerators, were originally designed for diverse applications such as kitchen microwave ovens (1kW, 2.45 GHz) or industrial heating (100 kW, 915 MHz). Our paper describes our collaboration with Richardson Electronics LLC (RELL), focusing on the development of rapid and adaptable manufacturing techniques.
These techniques include enabling innovative phase and amplitude injection locking control methods, extending the magnetron's lifespan and enabling cost-effective refurbishing, ultimately aiming for the lowest possible life-cycle costs.

Our objective is to test modified magnetron sources to power SRF cavities to accelerate an electron beam. We plan to construct and evaluate a magnetron operating with our patented subcritical voltage operation methods specifically tailored for driving an SRF cavity.

Our focus in this endeavor is identifying and addressing critical areas in magnetron manufacturing and design that significantly influence life-cycle costs. These areas encompass optimizing Qext (external quality factor), improving filament design, fine-tuning the magnetic field, enhancing vane design, and introducing innovative strategies for controlling outgassing.

Our ultimate goal is to transform these devices, originally intended for disparate applications, into highly efficient components for driving SRF cavities. Through these advancements, we aim to achieve superior performance, prolonged durability, and significantly reduced life-cycle costs for magnetrons utilized in SRF accelerators.

# Industrial Applications of Accelerators

Abstract # 95

## Multi-cell X-ray target with energy recuperation

Aurora Cecilia Araujo Martinez[1], Sergey Kutsaev[1], Alex Murokh[1], Stephen Coleman[2], Jonathan Edelen[2], Suresh D. Pillai[3]

*[1]RadiaBeam Technologies, LLC, USA, [2] RadiaSoft LLC, USA, [3] TAMU, USA*

X-ray irradiation offers several advantages compared to other irradiation technologies including superior penetrating quality compared to electron beams. These advantages make X-ray targets key components in a broad range of industrial applications including food irradiation, sterilization of medical devices, and non-destructive testing, among others. However, the low electron to X-ray conversion efficiency (<~10%) is a major drawback. In this talk, we will present a novel design of an X-ray conversion target based on a multicell RF structure with energy recuperation approach, promising to improve the photon yield compared to conventional X-ray targets for industrial applications. The system consists of a special RF driven target, formed by a series of accelerating cells with closed irises operating on the S-band frequency at 2856 MHz. The design incorporates a high atomic number material within the irises to generate the X-rays. We will present the rf design of the multi-cell X-ray target, Monte Carlo and beam dynamic simulation results performed to maximize the electron-to-X-ray conversion efficiency.

Abstract # 148

## An accelerator-driven green power plant

Rolland Johnson[1], Mary Anne Cummings[1], J. D. Lobo, Milorad Popovic[2], Tom Roberts[1]

[1]*Muons, Inc., USA,* [2]*FNAL, USA*

The long, prohibitively expensive procedures for licensing a nuclear fission-based power plant can be replaced by 1) using accelerator-driven subcritical modular reactors that never contain a critical mass and 2) continuously removing volatile fission products from the molten salt reactors so that any accidental releases are insignificant. Mu*STAR Nuclear Power plants, composed of upgradable modular accelerators and reactors, can then be continuously improved using Deming's principles of Total Quality Management.

Abstract # 233

# Estimating the socio-economic benefits of accelerator-based techniques

Sara Nienow, Marwa Salem, Claire Strack, Amanda Walsh

*RTI International, USA*

Accelerator applications generate substantial socio-economic impact across a broad range of topics and challenges of global importance. However, while accelerator investments require direct monetary contributions from a discrete number of investors, resulting socio-economic benefits are often broadly distributed and not naturally monetized. Hence, the return on investment in accelerators is not always clear or straightforward to communicate.

Varied and innovative approaches are needed to assess the economic returns to accelerator-based techniques since applications can cover almost any area of life. Applicable economic impact estimation methods include market analysis, benefits transfers, and stated or revealed preference methods. A mixed-methods approach fills quantitative data gaps with qualitative inputs, while threshold assessments and impact scenarios clarify the influence of modelling assumptions on study results.

Under a cooperative agreement from NIST, RTI conducted an economic impact assessment of U.S. federal neutron scattering research facilities, including both reactors and accelerators. Here, we present the results of four case studies of technologies influenced by neutron scattering research: hard drives, aircraft, weight loss medications, and electric vehicles. The studies demonstrate innovative approaches to estimating the benefits of complex research with cross-cutting applications. Standardized impact case studies of accelerator-based techniques can communicate the socio-economic benefits of accelerators worldwide.

Abstract # 131

# Stronger and durable pavement infrastructure using accelerator technology

Jayakar Thangaraj

*FNAL, USA*

This talk introduces a new class of simple, turn-key superconducting radio frequency (SRF) accelerators for broad use in industrial applications. Leveraging recent R&D breakthroughs in high-temperature SRF cavities, cost-effective radio-frequency sources, modern cryo-coolers, and high average current electron guns, Fermilab is building an accelerator based on the Nb3Sn coated 1.3 GHz TESLA style cavity design for pavement construction. We will show the experimental results of this novel concept on conduction cooling of SRF cavities, which removes the need for liquid Helium, thus making SRF technology accessible to industrial applications. We will also describe our linac design that generates electron beam energies up to 10 MeV in continuous-wave operation and the development status. We show that a single accelerator module can deliver average beam power as high as 250 kW and above through thermal, RF, and particle simulation. Compact and light enough to mount on mobile platforms, our machine will enable novel applications for in-situ crosslinking of materials, making more robust, durable, and efficient pavement infrastructure. In-situ crosslinking of bituminous materials at the point of use would eliminate the finite lifetimes in hot mixes and reduce the energy and pollution associated with heating the hot-mix asphalt.

Abstract # 193

# Evaluating ebeam as a means of sterilizing screwworms for sterile insect technique

Aaron Tarone[1], Ashleigh Haughey[1], Cameron Bright[1], John Welch[2], Keyan Zhu-Salzman[1], Pamela Phillips[2], Sunil Chirayath[1], Suresh Pillai[1], V. Renee Holmes[1], Dany Mulyana[1]

*[1]TAMU, USA, [2]USDA-APHIS*

The screwworm eradication program is the first example of using ionizing radiation to sterilize insects for pest control. This USDA program resulted in the elimination of the primary screwworm from North America. The program was executed using Cs 137 or Co 60 to sterilize flies. However, there is considerable interest in moving toward eBeam or Xray based methods for sterilizing flies, due to economic and security reasons. We are evaluating the feasibility of eBeam as a replacement for the Co 60 source currently used in Panama to maintain the eradication zone. We will report on similarities and differences in LEEB and HEEB for these purposes, based on gonad development, retrospective biological dosimetry, and life history performance after treatment. We have also simulated the ideal source of eBeam to treat screwworms with the lowest achievable DUR. Results are promising and suggest that eBeam is likely a viable alternative to gamma radiation sources, which can accommodate factory-scale production (i.e., 20 to 100 million a week) of irradiated insects for eradication efforts.

Abstract # 238

# IAEA activities to support development of radiation treatment of polymers

Valeriia Starovoitova, Melissa Denecke, Celina Horak

*NAPC, IAEA*

Promotion of industrial uses of radiation technologies and related capacity building is one of the main programmes of the IAEA. To support its Member States in strengthening their capabilities the IAEA Radiochemistry and Radiation Technology Section (RCRTS) promotes utilization of both source-based and accelerator-based radiation technology in fields with high societal and economic impact. While some applications of radiation technology use almost exclusively high activity sources (i.e. non-destructive testing and well logging), many others rely on accelerators (i.e. irradiation of polymers and films or food irradiation). Our section helps all the Member States develop both source-based and accelerator-based radiation technologies, depending on the application.

This presentation will discuss the status of the accelerator-based technologies, including development of radiation generators. It will also describe the IAEA tools through which the IAEA activities in support of such technologies are implemented.

Abstract # 149

# Status of the new PUFFIn dose distribution software tool

Randolph Schwarz, Mark Murphy, Mie Azuma

*Pacific Northwest National Laboratory, USA*

Staff at Pacific Northwest National Laboratory (PNNL), at the request of the Office of Radiological Security (ORS) within the U.S. National Nuclear Security Administration (NNSA), identified impediments for those companies desiring to transition from cobalt-60 to an accelerator technology for processing product. One of those impediments identified was a dose simulation software tool that was much more simplified, was faster than existing commercial software, and could be run on a regular laptop. This would allow nonexperts to quickly and easily learn the basics in dose distribution in materials and the influences of gamma-rays versus electron beam and X-ray. PNNL's answer to this tool gap was to develop PUFFIn, which stands for Penelope User Friendly Fast Interface. Unlike most other commercial dose simulation tools, PUFFIn utilize the PENELOPE radiation transport code instead of MCNP. PUFFIn was developed primarily as an educational tool, and healthcare product manufacturers and the associated sterilizer facilities were expected to be examples of the main benefactors.

The PUFFIN software package was initially released to the sterilization community in April of 2023. Workshops were held at Texas A&M University in the USA and at the Aerial CRT facility in Strasbourg France. The initial release of the code showed that with a few days training users were able to use PUFFIn to predict expected dose distribution in materials, including the minimum and maximum dose locations (i.e., dose uniformity ratio, DUR) within several polymer healthcare products.

This presentation will review the progress made in 2023 and the upgrades that were made to the PUFFIn code for the 2024 release of the software. A discussion of the comparison with experimental data will be presented, along with a discussion on improvements made to the code.

Significant upgrades that were made to the code that will be discussed include the ability to import complex 3D data sets from both CAD and X-Ray Tomography, the expansion of the number of materials supported, and the ability to run on multiple processors.

Abstract # 118

## Radiation-induced modification of LDPE: effects of electron beam accelerator exposure

Zaouak Amira, Chaouki Belgacem, Jelassi Haikel, Meriam Khemiri

*CNNST, Tunisia*

Radiation is currently being exploited to modify polymers in order to improve properties for various applications. This study thoroughly examines the effects of high energy electron beam irradiation (10 MeV) on low density polyethylene (LDPE) material. LDPE was subjected to a broad range of doses ranging between 10 and 300 kGy at room temperature under different conditions. Extensive characterization techniques such as the Fourier transform infrared spectroscopy (FTIR) and differential scanning calorimetry (DSC) were conducted on the non-irradiated and irradiated samples. Our findings revealed significant changes in LDPE's chemical structure after irradiation under air atmosphere by the formation of carbonyl groups located at 1715 $cm^{-1}$ proving its oxidation degradation. The determination of carbonyl index showed that the irradiation effect was more noticeable when higher levels of irradiation were applied. In addition, the evaluation of the mechanical properties of LDPE in terms of tensile strength and elongation at break showed that these properties were significantly affected independently of the irradiation conditions. Finally, this research sheds light on the complex interplay between irradiation conditions and LDPE's structural properties, offering valuable insights for applications in polymer materials and radiation-induced modifications.

Abstract # 230

## ABS and PP assessment and response to gamma ray vs electron beam exposure

Nazarena Ciávaro, Verónica Vogt, Brian Borda, Fátima Arano, Mariela del Grosso

*National Atomic Energy Commission, Argentina*

Although medical devices are sterilized in Argentina using ionizing radiation, electrons beam sterilization is of great interest. This is partly due to the lack of knowledge regarding their comparative effects on materials (primarily polymers). Thus, the objective of this work is to study the effect of both radiation sources: gamma rays (60Co) and electrons beams on the polymers acrylonitrile-butadiene-styrene (ABS) and polypropylene (PP) irradiated under different atmospheric conditions.

ABS and PP were irradiated at 60 kGy using a 10 MeV electron accelerator (Aerial CRT, France) and a 60Co source at the Semi Industrial Irradiation Plant (CNEA, Argentina). Polymer test specimens were cut according to the ASTM D 638 standard and packaged in polyethylene bags in the presence of air and vacuum. The polymers were characterized using differential scanning calorimetry (DSC), Fourier transform infrared spectroscopy (FTIR) and mechanical tests. Additionally, simulation of the dose uniform distribution (DUR) using PUFFIn software was studied. The utilized variables were beam energy, width and height 10 MeV, 10 cm and 10 cm, respectively; number of particles 1e7; and irradiation distance to the source 100 cm.

The results obtained showed a 90 % reduction of the PP strain irradiated with gamma rays under atmospheric and vacuum conditions and a 70% reduction with electrons beams for both conditions. The elastic modulus of the gamma irradiated samples decreased by 9% and 4% and the electrons beam treated samples showed a decrease of 17 % and 18% when irradiated under air and vacuum conditions, respectively. The yield stress remained at 21 MPa for all conditions analysed. The FTIR assay showed a change in the PP at the 1745 $cm^{-1}$ wavenumber, associated with the appearance of C=O groups in aldehydes, ketones or carboxylic acids due to oxidation of the polymers after irradiation. There were no significant differences in the melting temperature of the polymer after irradiation.

In ABS irradiated under vacuum and atmospheric conditions, there were no significant changes in the elastic limit, yield stress and deformation. The FTIR technique did not show any notable change in the ABS chemical structure. The glass transition temperatures of the ABS were around 104ºC and 201ºC in all cases for the conditions analysed.

The simulated DUR of the PP and ABS samples irradiated with electrons beams using PUFFIn was 1.13, more studies must be carried out on biomedical products and their packaging conditions. In conclusion, in PP some modifications on the chemical and physical properties are observed at 60 kGy with both: gamma rays and electron beams. On the other hand, ABS seems to be a radio-resistant polymer that can be treated with both irradiation technologies without major modification at 60 kGy.

Abstract # 203

# Effect of radiation on the commonly used natural rubber and silicone rubber in medical applications and devices

Tonguç Özdemir, Ceren Kurtuluş, Ahmet Güngör

*Mersin University, Turkey*

Polymers are inevitably used for many medical applications and devices. Development of the polymeric materials over the recent decades provided valuable commodity materials to be used in different medical applications such as single-use medical devices, implants, drug delivery and packaging systems because of their versatility and economic advantages and their ability to withstand sterilization processes. Irradiation is a widely used technology for sterilizing medical products. Gamma irradiation is one of the most common sterilization techniques which has controlled doses penetrating deeply into many materials. Although its widespread usage, it has some drawbacks due to the safety and security considerations.

Rubbers are widely used in medical applications due to their unique physical and mechanical properties. This study focuses on to investigate the radiation effects on natural rubber (NR) and silicone rubber (SR) by comparing the results obtained from gamma and e-beam irradiations. Rheological analyses were carried out to determine appropriate vulcanization parameters. The prepared NR and SR test samples were subjected to gamma irradiation at 2 different dose rates (High-dose: 213 kGy/h and Low-dose: 10 kGy/day) and 6 different doses of 10, 20, 30, 40, 60 and 80 kGy., and to e-beam irradiation at a single dose rate (1 kGy/sec) and 7 different doses of 10, 20, 30,40, 60, 80 and 120 kGy.

Mechanical tests were carried out for non-irradiated and irradiated test samples for both irradiation modalities. Swelling ratios were determined and crosslink densities were calculated by Flory-Rehner equation. Gel content of the samples was tested by Soxhlet extraction. TGA, DSC, DMA, FTIR and SEM analysis were carried out to investigate the changes in thermal, dynamic-mechanical and morphological properties. The degree of change of samples with e-beam and gamma irradiation were compared to determine the degradation and modification pathways.

This study is a Coordination Research Project (CRP) supported by International Atomic Energy Agency (IAEA) (Project # F24701).

# Medical Applications of Accelerators

Abstract # 168

## The status and future plans of the SPES project

Faical Azaiez

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The SPES project (Selective Production of Exotic Species) at LNL (Laboratori Nazionali di Legnaro) aims at the realization of an accelerator facility for research in the fields of Fundamental Physics and Interdisciplinary Physics with a major part dedicated to Research and Development of innovative radioisotopes for medical diagnostics and therapies. The status of the project will be given with emphasis on the production of radionuclides of medical interest.

Abstract # 68

# Optical fibers for medical accelerators

Cornelia Hoehr

*TRIUMF, Canada*

In nuclear medicine and targeted radiation therapy, the production of isotopes vital for these applications is often contingent upon targets mounted on particle accelerators, which may exist in solid, liquid, or gaseous states. In these harsh environments – high temperature and pressure in the case of liquid and gas targets, high radiation fields, spatially restricted, and potentially corrosive materials - the utilization of optical fibers (OFs) is emerging as a pivotal technology for the monitoring of these targets, ensuring their efficient and secure operation. The advantages of OFs, including radiation and corrosion resistance, compact dimensions, electromagnetic independence, and linear responsiveness across extensive measurement ranges, underscore their increasing importance in such critical applications.

In this presentation, we will introduce systems of OFs along with operational insights to measure diverse parameters crucial for ensuring the optimal operation of targets. These include monitoring beam alignment and current, ensuring the correct target material and target fill levels, and precisely gauging temperature and pressure within the targets.

Abstract # 172

# Isotope Harvesting from FRIB

Greg Severin, Chirag Vyas

*MSU, USA*

Many interesting radionuclides are produced as byproducts of routine operations at the Facility for Rare Isotope Beams. In the coming years, the facility will install a water filled beam dump that will accumulate many of the byproduct radionuclides in a form that can be readily "harvested" for use in other applications. In preparation, a direct connection between the beam dump and a new bank of hot cells has been established, and processes for extracting the radionuclides are being developed. So far it has been shown that, through simple trapping purifying techniques, radionuclides like 47Ca, 76Kr, and 62Zn can be obtained readily. As new beams are developed at FRIB, the spectrum of harvestable isotopes will widen, allowing access to otherwise difficult to create radionuclides for basic and applied science.

Abstract # 97

# Design Details of a Radioisotope Separator Facility at the University of Missouri

Peter Norgard

*University of Missouri Research Reactor, USA*

A production-scale radioisotope separator line based on a prototype design is under development at the University of Missouri Research Reactor (MURR). Several years back, the separator line was contemplated and built to enhance the specific activity of a radiopharmaceutical compound involving Sm-153. The purpose remains to improve the specific activity of particular radioisotopes, especially lanthanides, where real benefits may be wrought. Further, with the recent announcement that the University of Missouri is embarking upon a new research reactor to replace MURR, there is a renewed sense of purpose in developing ancillary facilities that will take advantage of the production stream from a new reactor, and to expand and enhance our research and education mission. The initial separator line was designed and built around a 1.3 T sector magnet to define a waypoint intended to guide future development, and to develop a working knowledge of the capital equipment. That knowledge was then put to use in designing the next generation, so-called “production-scale” separator line. The design goal of the production system is to separate useful quantities of a radioisotope produced in the reactor in a time frame that is meaningful based on the isotope decay rate. This discussion will focus on the combined modeling of the electromagnetic transport system, including a simplified model of the ion source, extraction and focusing optics, and the momentum separator. Particular modeling assumptions and design choices will be identified, and modeling results will be reviewed. Models were performed in COMSOL or using numerical modeling in R.

Abstract # 234

## A Systematic Study of Photonuclear Reactions for Isotope Production

Edna Cardenas[1], Daniel Dale[2], Tony Forest[2], Michael Reichenberger[1], Van Romero[2], Douglas Wells

*[1]INL, USA, [2]ISU, USA, [3]New Mexico Tech, USA*

New Mexico Institute of Mining and Technology (NMT), Idaho National Laboratory (INL) and Idaho State University (ISU) have launched a collaboration that is focused on research and education in isotope production and related science and technology of measurements, simulations, separations and applications, with an emphasis on the education of undergraduate and graduate students in this area. The research emphasis is focused on a systematic study of promising photonuclear reactions for many radioisotopes listed in the 2015 DOE/NIH National Nuclear Science Advisory Committee (NSAC) Isotope Subcommittee report "Meeting Isotope Needs and Capturing Opportunities for the Future: The 2015 Long Range Plan for the DOE-NP Isotope Program". We are measuring bremsstrahlung-weighted excitation functions and inferring the photonuclear cross sections to fill in some of the many gaps in the world's photonuclear data, as documented in the International Atomic Energy Agency (IAEA) "Handbook on Photonuclear Data for Applications". Photonuclear excitation function measurements will include (γ, α), (γ, p), (γ, n), (γ, np), and possibly other reaction channels. This program provides support and education each year for roughly 14 students and will provide critical talent in support of domestic efforts in isotope science.

Abstract # 228

# Accelerator based production of Mo-99: target thermal performance

Sergey Chemerisov, Peter Tkac, Phil Strons, Roman Gromov, Andrei Patapenka, Ken Wesolowski, Charles Jonah, David Mullins, Josh Hlavenka, Ron Kmak

*ANL, USA*

The National Nuclear Security Administration's (NNSA), in partnership with commercial entities and the US national laboratories, is working to accelerate the establishment of a reliable domestic supply of Mo-99 for nuclear medicine while also minimizing the civilian use of HEU. One of the potential technologies is utilizing the photonuclear reaction in an enriched Mo-100 target to produce Mo-99. In this approach a high-power electron accelerator is used to produce the required flux of high energy photons through the bremsstrahlung process. Due to the small photon cross section for the reaction and high cost of the enriched Mo-100 material, one would want to use the highest photon flux available. That leads to a high thermal load on the target. The ability to remove heat from the target is a limiting factor in the production of Mo-99. A pressurized gaseous-He cooling system was installed and tested at Argonne to allow study of the thermal performance of the target and production of Mo-99. Multiple irradiations of the natural and enriched Mo-100 targets were conducted at different beam energies to study the thermal performance of the target. In the latest experiments production scale target performance was investigated by varying beam size and helium cooling flow to benchmark the CFD simulations. A comparison of the computer simulations and experimentally measured target system parameters will be presented.

Abstract # 224

## Isotope production in the mid-mass region with photonuclear reactions

Robert Bentley[1], Geno Santistevan[1], Douglas Wells[1], Dan Dale[2], Kean Martinic[2], Alan Hunt[3], Joe Fischer[3], Andrew Hutton[4], Adam Stavola[4], Stephen Benson[4], Kevin Jordan[4], Joseph Gubeli[4], Pavel Degtiarenko[4], Lila Dabill[5]

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Measurements and analysis of photonuclear cross sections are essential to a more fundamental understanding of nuclear-electromagnetic interactions and structure. Such research also contributes to the fields of radioisotope production, forensics, astrophysics, and medical imaging and therapy. To investigate this, bremsstrahlung photons are produced via an electron linear accelerator and impinge on a tungsten radiator. In this work, these photons are the source of activation for several natural targets, namely molybdenum, ruthenium oxide hydrate, and nickel. By a series of irradiations at integral end-point energies, cross sections may be extracted, along with corresponding activity and excitation functions (yield curves). Methods and results from past and planned experiments for various photonuclear reaction channels are reported for these isotopes.

Abstract # 183

# Comparative evaluation of electron beam vaccine development strategies using High (HEEB), Medium (MEEB), and Low-energy Electron Beam (LEEB) with Gamma Irradiation

Chandni Praveen, Sathvik Patchametla, Jennifer Elster, Suresh Pillai

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Globally, there is an urgent need to develop effective vaccine technologies to address the ever-increasing problems of emerging, multi-drug-resistant pathogens. Identifying vaccine development technologies that are rapid, cost effective, environmentally friendly, and able to impart broad-spectrum protection, and lasting immunity is a great challenge. Ionizing radiation is a versatile technology that has demonstrated encouraging outcomes in development of whole-cell inactivated vaccines that are metabolically active but replication-deficient. Damage to genetic material (DNA/RNA) both directly and indirectly renders the pathogen inactive and safe. The irradiated cells are effective in inducing an effective immune response and providing protection owing to intact structural proteins and other antigenic epitopes on their cell surface. Conventionally, radio vaccines are developed using legacy nuclear technologies based on radioactive isotopes such as Cobalt-60 which requires stringent safeguarding and disposal requirements making it commercial unsustainable. Transitioning to environment friendly and sustainable alternative radio vaccine technology such as machine source-based electron beam (eBeam) technology can be an effective solution. Current study focusses on comparatively evaluating inactivation kinetics of target vaccine candidates, antigenicity and in vitro efficacy of eBeam radio vaccines to Co-60 based vaccines. The key vaccine candidates are Human rotavirus, Influenza A virus, Human Respiratory Syncytial Virus, Acinetobacter baumannii, Streptococcus pneumoniae, and Listeria monocytogenes. Our previous studies using HEEB and Salmonella sp. have shown demonstrated antigenic properties in eBeam inactivated cells stimulating innate pro-inflammatory response and maturation of Dendritic cells. The eBeam irradiated cells also retained stable immunogenic properties over longer period at wider storage temperatures ranging from -20ºC to room temperature indicative of their sustainability. Comparative studies such as these will demonstrate the availability of vaccine technologies to replace cobalt-60 based isotope technologies.

Abstract # 229

# Transformative accelerator technologies for FLASH radiotherapy

Carol Johnstone[1], Reinhard Schulte[2]

*[1] FNAL, USA, [2] Loma Linda University, USA*

Conventional therapy to treat cancer is through surgery, chemotherapy, radiation therapy and immunotherapy with 2/3 of cancer patients receiving radiation therapy during the course of their treatment. Conventional radiation therapy with X-ray, protons and ions increases the therapeutic index by creating a physical dose differential between tumors and normal tissues through precision dose targeting, image guidance, and radiation beams that deliver a radiation dose with conformality with the highest conformality produced by pencil proton and ion beams. However, the treatment and cure are still limited by normal tissue radiation toxicity, primarily necrotic side effects. Recently a new paradigm for increasing the therapeutic index of radiation therapy has emerged based on the FLASH radiation effect. FLASH radiation therapy (FLASHRT) is an ultra-high-dose-rate delivery of a therapeutic radiation dose within a fraction of a second. Experimental studies and preclinical research have shown that normal tissues are universally spared at these high dose rates, whereas tumors respond “normally” to the delivered dose. Dose delivery conditions to achieve a FLASH effect are not yet fully characterized and evidence for FLASH varies with radiation type and delivery in terms of beam macro and micro-structure. Current estimates are that doses delivered in less than 200 ms at high instantaneous dose rates (~105 Gy/sec or higher) produce normal-tissue-sparing effects yet kill tumor cells at a level corresponding to the dose delivered. At these high instantaneous dose rates and short integrated dose timescales, the accelerator community faces many technical challenges to create the high dose and intensity rates with compact accelerators and ensure safe delivery of FLASH-level radiation beams. The subject of this presentation will be a review of accelerator intensity and structure requirements and advances in novel accelerator technologies towards a practical realization of FLASH-RT.

This work is supported by Fermi Research Alliance, LLC under contract no. DE-AC02-07CH11359.

Abstract # 122

# A compact medical cyclotron for research into medical and multi-disciplinary applications

Saverio Braccini

*AEC-LHEP, University of Bern, Switzerland*

The Bern medical cyclotron laboratory is based on an 18 MeV proton cyclotron equipped with a specifically conceived 6 m long research beam line, terminated in a separate bunker. This particular configuration is designed for industrial Positron Emission Tomography (PET) radioisotope production as well as for multi-disciplinary scientific activities. A research program is ongoing encompassing novel radionuclides for theragnostics, targets, particle detectors, radiation biophysics, proton induced neutron fields, radiation protection, and materials science. In particular, novel methodologies for the optimized production of radionuclides for theragnostics in nuclear medicine (Sc-43, Sc-44, Sc-47, Cu-61, Cu-64, Cu-67, Ga-68, Er-165, Tm-165, Tm-167 and Tb-155) with solid targets are developed. The beam line has been recently adapted for performing irradiations of cells in both conventional and FLASH regime. Along this line, scintillators are studied to face the challenge of dosimetry in the FLASH radiation therapy. The scientific results of the first ten years of operation of the Bern cyclotron laboratory will be presented.

Abstract # 231

# A New US Center for Heavy Ion Therapy and Research

Carol Johnstone

*FNAL, USA*

Progress in cancer therapy with ions heavier than protons, i.e., notably helium and carbon, but also as heavy as oxygen and neon, requires research and development capability preferably in a broad user environment. Heavy ion therapy offers significant advantages in the treatment of many types of cancer compared to protons and, even more so, to conventional radiotherapy with high energy x-rays (photons). Ion research activity however is currently limited in the US from the absence of accelerator facilities offering ion beams for therapy and research – placing the U.S. significantly behind Europe and Asia. With dramatic advances in beam delivery technologies and next generation compact accelerators and gantries, the potential exists to not just match existing facilities which use conventional accelerator technologies but to create a unique facility that will play a leadership role in ion research, particle therapy, and technical innovation. A new, funded center for ion therapy research is under construction in Waco, TX, in collaboration with recognized accelerator entities both academic and industrial with medical partnerships. The advanced accelerator technologies, which are entering the engineering phase, will produce beams for both clinical and research applications, offering a complete range of ions, intensities and energies required by the medical community, including the capability to perform ultra-high dose irradiation (FLASH) research. FLASH, a recent research initiative, which has the potential to reduce cancer treatment toxicities and improve cure outcomes, is now considered a critical capability for a competitive research center. The beam intensities for FLASH using ions are well beyond those provided by current medical ion accelerators which are primarily synchrotrons. The work reported here describes an innovative staging approach for the Center's accelerator complex with low and high energy cyclotrons which inject into a high-energy, 250-MeV/nucleon Fixed Field Gradient therapy accelerator which is also capable of variable energy extraction. This state-of-the-art cancer research center housed within a comprehensive cancer facility will provide the resources to promote ion therapy in the U.S, including preclinical/clinical trials and protocols between modalities, and also support broad ion beam accelerator and delivery R&D.

Abstract # 167

# Facility design for the FLASH proton therapy

Trbojevic Dejan

*BNL, USA*

We present a design of the complete proton FLASH radiation therapy facility using the Brag peak. It includes commercially available injector cyclotron (10-30 MeV) with the fixed field alternating (FFA) gradient beam lines, permanent magnet fast-cycling synchrotron accelerator, and a delivery system- an FFA gantry. This facility removes limitations of the present proton cancer therapy facilities allowing FLASH radiation to be performed with 40 Gy/s in 100 ms. This is an extraordinary way to allow FLASH therapy as no magnet adjustments are needed for any proton kinetic energy between 70-250 MeV. The proposal is based on already experimentally proven FFA concept at the Energy Recovery linac 'CBETA' built and commissioned at Cornell University.

Abstract # 83

# Detailed Transfer Line Beam Characteristics at an Operational Proton Therapy Center

George Gillespie[1], Joshua Konzer[2]

*[1]G. H. Gillespie Associates, Inc., USA, [2]McLaren Health Proton Center, USA*

The McLaren Proton Therapy Center functions as a clinically active, multi-room cancer treatment center. Beam size, position, and current measurements along the transfer lines are being utilized together with simulations to validate computer models for the Center's transfer lines and associated beam parameters. BPM data collected along the beam lines provide detailed beam measurements. A computer tool, utilizing nonlinear constrained optimization programs that are integrated with a beam envelope code, is used to find detailed beam phase space parameters (sigma matrices, centroids) that reproduced the measured data. Quadrupole scan and steerer scan experiments are used to validate the calibration and alignment of these devices, as well as to independently confirm beam parameters at selected locations. Beam current measurements along the beamlines are used to infer transmission efficiencies and are compared to multi-particle simulations in order to identify beam loss locations. The goal of the work is to develop an improved understanding of the beams and beam transfer lines to support further beamline optimization and design activities. An overview of the combined experimental and simulation methodology will be described and selected results presented. The methods and tools described should be applicable to many types of operating accelerator facilities.

# Nuclear Data

Abstract # 69

# The Proton Activation Data File PADF-2

Alexander Konobeev and Dieter Leichtle

*Karlsruhe Institute of Technology, Karlruhe, Germany*

The cross-sections for the interaction of protons with isotopes of elements from C to Cu were obtained at energies from the reaction threshold to 200 MeV. The work included calculations using different models and computer codes, ALICE, CEM, PHITS, and TAYLS, analysis of experimental data, and evaluation of cross sections.

All types of experimental data were applied to correct calculated curves, independent and cumulative data for specific target isotopes, and independent and cumulative data for natural mixtures of isotopes.

For reactions for which no experimental data are available, the cross-sections were estimated by analyzing the calculated data, taking into account the quality and predictive power of various models in different energy ranges.

The resulting files can be downloaded from the https://t1p.de/3vzun website.

Abstract # 120

# Exploring the Origin of the Rarest Stable Isotopes via Photon-Induced Activation Studies at the Madison Accelerator Laboratory

Adriana Banu

*James Madison University, USA*

The focus of this research work is to determine experimentally the ground state reaction rates for eight photoneutron reactions proposed to be investigated via photon-induced activation at the Madison Accelerator Laboratory (MAL), a unique bremsstrahlung facility on the campus of James Madison University, in Harrisonburg, Virginia. The eight photoneutron reactions are – 64Zn(γ,n), 70Ge(γ,n), 74Se(γ,n), 78,80Kr(γ,n), 84,86Sr(γ,n), 90Zr(γ,n). The corresponding proton-rich stable nuclei of interest belong to the region $A < 124$ that is notoriously underproduced by the current stellar evolution models for the astrophysical p-process. Because in the laboratory one only has access to target nuclei in the ground state, the stellar photodisintegration reaction rates, dominated by excited state contributions at the high temperature regime of the p-process, cannot be directly constrained experimentally. With the measurements at MAL, we can provide instead nuclear input to constrain crucial parameters of the statistical nuclear reaction models, i.e., γ-ray strength function, especially relevant for photoneutron reactions, which is the overarching goal of this research project at MAL. This presentation seeks to disseminate the progress made at MAL towards that end, highlighting the current R&D challenges encountered when trying to implement the so-called superposition technique at an unconventional bremsstrahlung facility that features a repurposed medical electron linear accelerator.

Abstract # 173

# Validating Thermal Neutron Capture γ-Ray Data using the RPI Gaerttner LINAC Center

Katelyn Cook[1], Yaron Danon[1], Devin Barry[2], Amanda Lewis[3], Michael Rapp[2], Adam Daskalakis[2], Peter Brain[4], Dominik Fritz, Alec Golas[1], Adam Ney[2], Gregory Siemers[1], Benjamin Wang[1], Sukhjinder Singh[1]

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Accurate modelling of neutron induced capture γ-ray production is essential for many applications such as understanding γ-ray heating in critical systems, shielding calculations, nuclear medicine, particle physics experiments and active neutron interrogation. To determine the accuracy of nuclear data evaluations and simulation tools used to transport thermal neutron capture γ-ray cascades, the 16-segment NaI(Tl) detector array at the Rensselaer Polytechnic Institute (RPI) Gaerttner Linear Accelerator (LINAC) Center has been upgraded. The updated system is capable of measuring neutron capture γ-ray spectra and multiplicity as a function of incident neutron energy by using the time-of-flight (TOF) method and detecting prompt γ rays emitted via capture reactions. A new simulation method has also been developed to model the event-by-event capture γ-ray cascade energy deposition in the detector array using DICEBOX and a modified version of MCNP-6.2 (mod-MCNP-6.2/DICEBOX). The updated modeling capabilities have been tested using the well-studied thermal $^{56}$Fe(n,γ) γ-ray intensities. Validation of the system has been extended with $^{55}$Mn and $^{59}$Co thermal neutron capture measurements. The experimental capture γ-ray spectra results agree with mod-MCNP-6.2/DICEBOX calculations using evaluated nuclear data from the ENSDF and RIPL-3 databases.

Abstract # 218

# Photonuclear Yields, Cross Sections, and Isotope Production of $^{nat}Ga(\gamma,x)$ and $^{nat}V(\gamma,x)$ Reactions

Geno Santistevan[1], Adam Stavola[2], Douglas Wells[1], Joseph Gubeli[2], Kevin Jordan[2], Stephen Benson[2]

*[1] New Mexico Tech, [2]JLAB*

Photonuclear reaction data are important for a variety of applications, from isotope production for medicine to radiation shielding to understanding astrophysical nucleosynthesis. Yet cross sections of photonuclear reactions for many species are not well known. Of the 286 combined stable and primordially stable ($t_{1/2} > 7 \times 10^8$ yr) isotopes that exist, only a small fraction (approx. 10%) of the $(\gamma,n)$, $(\gamma,p)$, $(\gamma,np)$, and $(\gamma,\alpha)$ reactions involving these isotopes have been experimentally measured. The research here fills at least two of the experimental photonuclear cross section data gaps, specifically the $^{71}Ga(\gamma,\alpha)$ and $^{51}V(\gamma,\alpha)$ cross sections which, respectively, lead to the production of $^{67}Cu$ and $^{47}Sc$ medical radioisotopes. Both are identified as high priority isotopes of interest by the US Department of Energy and are deemed to be in short supply. These two reaction channels are both novel production methods for these radioisotopes. Presented here are methods and results, target design and simulation data, as well as preliminary gamma spectroscopy measurements that are being used to determine radioactivity for the subsequent calculations of cross sections and excitation functions.

# POSTERS

Abstract # 58

# Switching irradiation facility in Jordan from Co-60 to E-beam and X-ray

Moh'd Amer Etoom

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Jordan Atomic Energy Commission (JAEC) intends to switch the existing Co-60 irradiation facility to an e-beam X-ray 5-7Mev machine, due to security of Co-60 supply as well as increasing prices and the complexity of transportation to the unstable region (Middle East), which has been an issue in recent years. several national stakeholders are generally financially supportive to the switching from Co-60 to e-beam/X-ray in order to sustain this technology.

The existing facility will be used as e-beam/X-ray facility with some modifications for the existing concrete biological shield, which thickness must be increased to suit X-Ray applications, the personal maze will be filled with concrete, the other two sides can be easily thickened, and the side of product maze should be modified to suit the new product handling system. The ceiling thickness depends on the machine orientation; for side orientation the ceiling will be thickened. The shield may also be combinations of steel and/or lead in addition to concrete. The power consumption for both e-beam/X-ray applications will be covered by the existing solar system of 50kW generation capacity to be increased to about 200kW. Also new warehouse will be constructed.

Even though the capital cost of the e-beam/X-ray machine is high, it is more reliable than Co-60 for the sustainability of work, reducing security threats, and providing a wide range of applications that will be supportive for the industry in Jordan.

Abstract # 70

# The effect of electron beam irradiation on bio-threatened organic artefacts

Hassan Abdelrehim

*NCRRT, Egypt*

With the development of radiation techniques, attempts were made to use both gamma radiation and electron beam radiation for the disinfection of various types of historical objects that were inhabited by microorganisms or insects, which ended up causing the objects' destruction. . However, these technologies suffer from some limits as total dose and dose rate can influence the efficient elimination of bio-burden, with an increase in deterioration and changes in the material during radiation treatments.

In this work cotton and jute fabrics were s used as simulated ancient shrouds. The fabrics were aged by heating at 100 ◦C for 72 h. The textile fabrics was cut into 10 × 3 cm (length × width). The experimental samples were infected with the selected species within the used media through a direct incubation period for 20 days in order to be infected with the species that may affect the ancient shroud. The influence of electron beam irradiation on cotton and jute -based objects was evaluated in order to determine safe effective dose for cellulosic materials. To avoid over-exposure, a wide range of doses from 3 kGy up to 20 kGy were studied and many analytical techniques were used to determine possible changes of mechanical, chemical and physical properties of treated cotton and jute -based objects. Infrared spectra of irradiated samples before and after ageing by heat method were recorded. The effect of irradiation on post-irradiation effects and appropriate irradiation procedures for wider use of the technique was evaluated. The results showed that there were slightly changes in the IR spectra of all irradiated samples compared with spectra of untreated sample. ESR studies showed that the amount of radical formed increased, by radiation and decayed by time. In conclusion it is possible to use the electron beam for disinfection and preservation of cotton and jute textile used as funeral shroud in ancient Egypt with insignificant effects on their properties.

Abstract # 105

## Advanced Monte Carlo simulations and benchmark of residual dose rate assessments in the ATLAS detector at CERN LHC

Thomasso Lorenzon[1], Daniel Björkman[2], Davide Bozzato[1], Anna Cimmino[1], Robert Froeschl[1], Vasiliki Kouskoura

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At the European Organization for Nuclear Research (CERN), the Large Hadron Collider (LHC) pursues an unprecedented effort to push further the frontiers of physics. Both the accelerator and its four detectors (ALICE, ATLAS, CMS, LHCb) collectively form a one-of-a-kind advanced technological system capable of producing and recording the most energetic particle collisions ever achieved under laboratory conditions. The CERN Radiation Protection group supports the machine's operational programme by ensuring the highest safety standards in terms of radiological control and dose optimization procedures throughout the entire LHC lifecycle. In particular, a significant effort is put in place for the essential task of assessing residual dose rates for planned exposure situations, such as maintenance and upgrade projects that are recurrently scheduled during shutdown periods of the LHC.

This paper focuses on the advanced Monte Carlo techniques developed at CERN for predicting residual dose rates in the LHC experimental caverns during machine shutdowns, when the detectors change configuration to allow for maintenance, substitution, and subsystems upgrades. The method is applied to the ATLAS detector at LHC, for which residual dose rates for two different shutdown periods (including the upcoming Long Shutdown 3) are evaluated with the FLUKA Monte Carlo code distributed by CERN and compared to experimental measurements already performed in the ATLAS cavern.

Abstract # 115

# Radiation as sterilization modality of intravenous fluid delivery system device and its effects on the physicochemical and functional properties

Jeric Flores, Charito Tranquilan-Aranilla, Alvin Kier Gallardo,
Bin Jeremiah Barba, Rafael Kyle Bitangcor, Lorna Relleve, Gilbert Diano, Haydee Solomon

*Philippine Nuclear Research Institute, Philippines*

Due to the growing demands for medical device supplies in the world today, more effective, and efficient techniques for sterilization are currently being evaluated. Sterilization based on ionizing radiation is a widely used method globally for reducing disease-causing microorganisms in healthcare products. Currently, the Philippines is entering the market for radiation sterilization as the upgrading of its irradiation facilities to cater to commercial-scale demands is coming to completion. To aid in this endeavor, a case study on a locally produced intravenous fluid delivery system made up of distinct polymers (polyvinyl chloride, polypropylene, acrylonitrile butadiene styrene, polycarbonate) was conducted. The impact of ionizing radiations, gamma and electron beam, on the physicochemical (FT-IR, TGA, Tensile) and functional properties (JIS T 3211-2011) of the medical device at different absorbed doses were assessed. The result of the characterizations was used for the establishment of radiation sterilization dose (RSD) according to the ISO 11137-2:2013. Result indicated that at an absorbed dose of 15 kGy and 25 kGy, most properties were unaffected, except for the discoloration of some parts. Bioburden analyses showed an average of 0 colonies forming unit per gram; thus, 0 kGy verification dose was used for confirmation. Subsequent sterility tests were conducted to substantiate absorbed doses in the range of 15-25 kGy, which have the potential to serve as the RSD for the infusion set device.

Abstract # 116

## Shielding properties of lead-free tellurite glasses against photons, neutrons, and ions

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The shielding capabilities of five different glass systems, namely 60TeO2–(30-x)ZnO–5Bi2O3–5TiO2-xB2O3, where x varies from 0 to 10 mol\%, against photons, protons, alpha particles, neutrons, and carbon ions were investigated. The study involved the theoretical analysis and Monte Carlo simulations of various shielding parameters such as attenuation coefficients, mean free path, value layers, effective atomic number, effective electron density, and build-up factors, spanning an energy range from 1 keV to 1 GeV. Additionally, rapid neutron removal cross-sections and effective conductivity for the transport properties of the glass compositions were examined. The simulation utilized the glass samples as shielding materials and subjected them to bombardment by photons emitted from Cs-137 and Co-60 sources. Stopping potentials and projected range of photons, alpha particles, and ions were also analyzed using the Stopping and Range of Ions in Matter (SRIM) software. The results indicated that the glass composition 60TeO2–30ZnO–5Bi2O3–5TiO2 exhibited superior attenuation capabilities against gamma rays, protons, alpha particles, and carbon ions in comparison to other samples. Conversely, the glass composition 60TeO2–20ZnO–5Bi2O3–5TiO2-10B2O3 displayed excellent neutron shielding behavior owing to its higher boron atom concentration. By comparing the calculated attenuation parameters, potentials, and ranges with previously reported data and recommended glass systems for nuclear applications, it is concluded that the selected glass sample demonstrated effective and comparable shielding properties. This study provides valuable insights into the shielding properties of different glass compositions against diverse radiation types. These findings are crucial for the development of shielding materials for nuclear applications and environments with potential radiation exposure.

Abstract # 117

## Upgrading and development of the Lebanese accelerator setup for IBA applications in environment and archaeology

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A 5SDH Tandem Pelletron accelerator was commissioned at the Lebanese Atomic Energy Commission in 1999. It was to promote the use of ion beam analysis techniques (IBA) among the local scientific community for their research studies, as well as to perform collaborative projects with different potential users and collaborators from abroad. Many IBA applications have been done in cultural heritage, environment and materials science, using mainly PIXE (proton induced x-ray emission), RBS (Rutherford backscattering spectroscopy) and PIGE (proton induced gamma ray emission). Meanwhile, the accelerator facility was in a continuous process of upgrading over the years, for a better use of IBA techniques capabilities. The latest developments of the accelerator concern the use of SDD detectors, the installation of a new external micro-beam-line and recently the modification of the ion injector by adding a dual ion source, comprising a new alphatross radio frequency and a duoplasmatron. Thus, it will be shown the improvement in the performance and the new capabilities of the modified setup, also highlighting some significant case studies.

Abstract # 126

# HIF IFE industry for industry

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There's no industry without energy. There's no environment without clean energy. Renewables are too little too late--and they are much less than fully green. Moreover, renewable energy is not cheap—merely competitive amid high energy prices. HIF-IFE will do it all: stabilizing energy prices at earlier levels with the greenest of all energy sources.

Size is the key. The world energy system is immense. It needs a makeover within 50 years. This will be accomplished by comprehensively green HIF-IFE plants that produce cheap heat therefore cheap electricity therefore cheap hydrogen to make carbon neutral hydrocarbons and hydro nitrogens, plus major flows of potable water. Output as large as a supergiant oilfield, built with common materials and sited underground, global buildout of the fusion energy system will be in time, on time, and producing not only affordable green energy but a financial bonanza.

HIF-IFE uses the single pass rf driver (SPRFD), conceived in 2004 to drive the large yield fusion pulses that LLNL overwhelmingly concluded to be the key to the green HYLIFE (High Yield Lithium Injected Fusion Energy) power chambers: fusion energy yield ≥ a ton of TNT/ MWh/ BOE—substantial economic value per pulse. Neutronically thick injected lithium eliminates the neutron-materials problem that is the nemesis of MFE. Like HYLIFE, stable deployment of neutronically thick injected lithium in the SPRFD's chambers depends on BOEs of high value energy per neutron-protected pulse and a full second to restore the configuration of injected lithium.

Based on Basko's assessments of the requirements for stable compression, fast ignition, and high-gain fusion burn of large cylindrical fuel pellets, SPRFD's recently evolved U4 version extends Koshkarev's use of + and - charged beams for fast ignition to beams for compression and fast ignition. U4 uses multiple parallel linacs for isotopes with masses from cadmium to thorium. Each of the 10 linacs is duplexed for + and - beams, in separate but integrated RF structures. Large unit-cost reductions are presumed with designs innovated for mass manufacturing to make HIF-IFE the reliable base-load supplier for the large energy demand that will continue into the long future.

Energy must again become cheap as well as comprehensively green to realize desirable aspirations such as those expressed for the Green New Deal. HIF-IFE plants are big, but the financial proposition is impressive. A 50 billion plant will produce 25 billion worth of electricity annually at 5¢/kWh, with negligible fuel costs and typical accelerator and power plant O&M cost.

Abstract # 137

## Coupled target-beam-moderator optimization for the Second Target Station

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*ORNL, USA*

The Spallation Neutron Source at the Oak Ridge National Laboratory is driven by a linear accelerator that is currently undergoing an upgrade to 2.8 MW proton beam power with 1.3 GeV proton energy. Besides powering the First Target Station, which is in operation since 2006, the accelerator will provide 700 kW of proton beam power to the Second Target Station (STS), which is currently in the preliminary design phase. The STS will accommodate 18 to 20 neutron scattering instruments, the first three of which are expected to deliver early science in 2034.

The STS is being designed to become the world's highest peak brightness source of cold neutrons. To facilitate the design process of the STS target and moderators, we have developed a fully automated optimization workflow that enables efficient, high-fidelity modeling, simulation, and optimization of new designs. In this workflow, a parametrized solid geometry from SolidWorks and SpaceClaim is converted into unstructured mesh geometry with Attila4MC, a neutronics calculation is run with MCNP6.2, followed optionally by a mechanical analysis in Sierra. The optimization is managed by Dakota.

Previously, a detailed optimization of the moderator dimensions was performed while keeping the target and beam profile fixed. Additionally, the target and beam profile were optimized for a given moderator size. In this analysis, the optimization of the beam profile and the dimensions of the target and moderators are combined in a single analysis in which the peak and time-integrated brightness is maximized. We discuss the results of a detailed optimization of the two moderators with a fixed beam footprint. Afterwards, we discuss the effect of changing the beam footprint as well as the beam shape.
The presented optimization workflow can be used in the design of other high-power targets, neutron scattering facilities, nuclear or particle physics facilities, and radiotherapy systems.

Abstract # 143

# Towards cancer nanoradiopharmaceuticals – radioisotope nanocarrier system for prostate cancer theranostics based on radiation-synthesized polymer nanogels

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Despite the tremendous development of oncology, castration-resistant prostate cancer remains a debilitating malignancy. One of the most promising approaches to address this issue is to exploit the advancements of nanomedicine in combination with well-established nuclear medicine and radiotherapy. Following this idea, we have developed the radioisotope nanocarrier platform of electron-beam-synthesized nanogels based on poly(acrylic acid). This biocompatible polymer provides abundant carboxylic groups, which lead to excellent colloidal stability of developed nanoplatform and enable convenient bioconjugation. We have investigated various protocols for nanocarrier functionalization, based on distinct -COOH activating agents (EDC/NHS and DMTMM) for optimized conjugation yield of targeting ligand-bombesin derivative. This engineered peptide can bind gastrin-releasing peptide receptors overexpressed in prostate cancer, moreover, it bears radioisotope chelating moiety. We managed to demonstrate the very promising performance of our nanoplatform in-vitro - effective and specific uptake in PC-3 prostate cancer cells followed by significantly reduced cell viability as a consequence of delivered radiation. Even though our system requires further studies for more promising results in vivo, our study represents a vital advancement of radionanomedicine - a step, that will be one of many that will lead to effective therapy for castration-resistant prostate cancer.

Abstract # 145

## Status of accelerator facilities in Thailand: past, present, and future

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Since the introduction of particle accelerators in 1984, primarily employed in radiation therapy, industry, and security, Thailand has progressively utilized the advantages of accelerator technologies across various applications, expanding to agriculture, scientific research, and transportation. Notably, the “Siam Photon Source (SPS)”, a 1.2 GeV synchrotron light generator, was established in 1996 at the Synchrotron Light Research Institute (SLRI), Nakhon Ratchasima, with the main objectives including advancing scientific research, especially those related to industrial, agricultural, food, and medical applications. Furthermore, Thailand acquired a linear accelerator in 2014 and a cyclotron in 2017 at the Her Royal Highness Princess Maha Chakri Sirindhorn Proton Center (HPSP) and the Thailand Institute of Nuclear Technology (TINT), respectively, aiming to enhance precision radiation therapy and to facilitate the production of radiopharmaceuticals. As of the latest official report, Thailand currently possesses 164 linear accelerators, 15 electron beams, 7 cyclotrons, and 1 synchrotron, with 46.5% and 18.2% of all accelerators locating in the central and eastern regions, respectively. Despite the widespread use of accelerators in Thailand, plans for more advanced facilities are underway to further expand the technological capabilities. These initiatives encompass the establishment of an accelerator mass spectrometer (AMS), featuring a 1.7 MV tandem accelerator for carbon dating purposes, as well as a second synchrotron light source, with a higher energy of 3 GeV. The implementation of these facilities is expected to significantly enhance Thailand's knowledge and research capabilities, as well as increasing economic competitiveness of Thailand’s entrepreneurs.

Abstract # 153

# Design of the moderator reflector assembly for the Second Target Station

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Igor Remec, Lukas Zavorka

*ORNL, USA*

The Second Target Station (STS) at Oak Ridge National Laboratory will be a 700 kW, 15 Hz pulsed spallation neutron source designed to provide the world's highest brightness cold neutron beams to 18 beamlines. In order to produce the required neutron beam performance, two compact liquid hydrogen moderators are located above and below the tungsten spallation target within the Moderator Reflector Assembly (MRA). The lower tube moderator is a novel triangular 3 tube arrangement feeding 6 beamlines while the upper cylinder moderator feeds the remaining 12 beamlines. The characteristic moderator dimensions, the tube diameter and the cylinder height, were determined to be 30 mm in order to maximize neutron brightness while providing appropriate sample illumination. The hydrogen vessels are surrounded by an insulating vacuum layer to reduce the heat load to the cryogenic moderator system (CMS), which supplies the moderators with less than 20 K hydrogen. Except for the neutron extraction ports and hydrogen supply and return lines, the moderators are surrounded by a light water premoderator and then a beryllium reflector. The dimensions of the moderators, premoderators, and reflectors were determined by a parametric neutronics optimization which included engineering feedback to provide geometries with appropriate vessel wall thicknesses. The moderator and reflector vessel designs provide robust implementation of the neutronics optimization geometry which minimize aluminum welding, sometimes at the expense of complicated machining. The reflector vessels are held in place around the target by a water-cooled stainless-steel backbone. An upper shield block, water piping, and hydrogen transfer lines are added to the backbone to complete the MRA. The neutronic performance is dependent on the alignment of the moderators to the neutron guide entrances, thus the MRA is designed to be remotely replaced in a precise location using kinematic mounts. Prototypes of the most critical MRA hardware, the upper and lower hydrogen vessels and vacuum vessels, have been manufactured successfully, demonstrating feasibility and providing opportunities for design improvement.

Abstract # 155

# ORNL Second Target Station vessel systems preliminary design update

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The Second Target Station (STS) is currently under preliminary design at Oak Ridge National Laboratory (ORNL). STS will significantly expand the existing capabilities of the Spallation Neutron Source (SNS) at ORNL by constructing a second target station that utilizes the existing SNS accelerator and provides a world leading source of cold (long wavelength) neutrons. The Target System design of STS differs significantly from the SNS First Target Station design due to the use of a rotating Tungsten target wheel. In order to accommodate the target wheel design, a unique vessel and shielding system is being developed. I will present an overview of the STS target monolith, followed by the preliminary design and analysis of the Vessel Systems components, and share several trade studies that have been undertaken to make critical design choices.

The Vessel Systems scope within STS consists primarily of the Core Vessel, Core Vessel Shielding and Core Vessel Nozzle Extensions. The Core Vessel surrounds the STS Target and Moderator Reflector Assembly (MRA) and provides an optimal environment for Neutron production and transport. Core Vessel shielding is comprised of an assembly of liquid cooled and uncooled shield blocks contained within the Core Vessel that absorb radiation from the spallation process and cool the areas surrounding the Target and MRA. Core Vessel Nozzle Extensions extend radially from the outside diameter of the Core Vessel to the outside diameter of the target monolith in the instrument bunker. Each nozzle extension houses a monolith insert that makes up the first section of optical guide between the MRA and the neutron instruments.
An overview of the STS monolith will be presented as an introduction to our overall target systems design. The fabrication approach of the Core Vessel will then be presented, with a focus of Core Vessel simplification to reduce manufacturing complexity and cost. The results from preliminary thermal and structural analyses will also be presented. Finally, the results of a Nozzle Extension trade study will be presented that highlights the design, construction approach and connection method to the Core Vessel.

Abstract # 161

# Radiation induced recycling of polycarbonate and acrylonitrile butadiene styrene plastics by gamma radiation and electron beam

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Global concerns over plastic waste management have grown due to its negative impacts on aquatic and terrestrial environments. Despite their wide use, conventional plastic waste recycling methods such as chemical and mechanical recycling have limited efficiency. Radiation technologies, particularly gamma irradiation and Electron Beam (EB), offer promising plastic waste recycling alternatives by enhancing the mechanical properties of plastic polymers through processes like crosslinking and radiation-induced degradation. The main aim of this PhD thesis research is to comprehensively investigate the mechanisms of gamma and EB recycling as an efficient and sustainable technique for transforming plastic waste into useful resources. In the initial phase of this study, we aim to present preliminary Monte Carlo (MC) results for simulating gamma radiation and EB interactions with Polycarbonate (PC) and Acrylonitrile Butadiene Styrene (ABS) plastics, with the objective to recycle them for sustainable applications.

Abstract # 174

## Contribution of PM2.5 organic and inorganic components to air pollution in Lebanon

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Nowadays, air-pollution-derived fine particulate matter (PM2.5) is fully acknowledged to be a major public health problem. PM2.5 generally corresponds to a very complex and heterogeneous mixture of both inorganic (e.g. metals, ions) and organic (e.g. polycyclic aromatic hydrocarbons: PAH) chemicals, and biological components (e.g. pollen, fungi). Beirut city is characterized by high transport density and high electricity production by diesel-powered private generators, resulting in high levels of air pollution. These two factors favor in particular the emission of fine particles, which increases the environmental toxicological risks associated with particulate pollution. This study aims to determine the chemical characteristics of PM2.5, collected in in the southern suburb of Beirut city.

The sampling of PM2.5 was done twice a week for 24 hours, collected on Teflon filters. Beside the gravimetric measurements, the consequent samples were analyzed by proton induced X-ray emission technique PIXE at the Lebanese 1.7 MV Tandem-Pelletron accelerator of Beirut. The temporal variation of the mass of PM2.5 as well as their elemental concentration is shown to be dependent on the pollution sources and weather conditions. On the other hand, the organic chemical characterization of PM2.5 has revealed the presence of wide chemicals notably PAH. The influence of anthropogenic sources was confirmed by the chemical characterization.

Abstract # 184

# Electron beam decomposition of losartan and methocarbamol two emerging pollutants from aqueous solutions

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Losartan (LOS) is among the most widely prescribed antihypertensive drugs worldwide, and methocarbamol (MET) is a commonly utilized analgesic in recent years. These pharmaceuticals are considered emerging contaminants, posing risks to the environment and aquatic ecosystems. Traditional wastewater treatment technologies currently face challenges in adequately eliminating these substances. In this study, we describe the successful degradation and mineralization of both losartan and methocarbamol in aqueous solution using Electron beam irradiation. Aqueous solutions of MET and LOS were subjected to irradiation at doses ranging from 1 to 4 kGy. The results obtained demonstrated a removal efficiency of 98%. Investigations into the changes in absorption spectra, pH impact, Chemical Oxygen Demand (COD), and Total Organic Carbon (TOC) were conducted. The findings revealed a decrease in all absorption bands with an increase in irradiation dose, eventually disappearing entirely after a 4 kGy dose. The radiolytic degradation of MET and LOS under three different pH conditions (pH = 10, 6.2, and 3) highlighted that the highest removal efficiency was achieved at a neutral pH. Remarkably, % TOC removal reached 98% at 4 kGy for both compounds, indicating quasi-total mineralization. Furthermore, the results of spectrophotometric analyses provided evidence in favor of a pseudo-first-order degradation kinetic for LOS and MET. Finally, by identifying by-products through liquid chromatography–mass spectrometry (LC/MS), proposed degradation mechanistic pathways for LOS and MET were elucidated, indicating that the irradiation process initiates with the fragmentation of the starting molecule involving hydroxyl radicals generated by water radiolysis.

Abstract # 187

# Physicochemical properties of e-beam irradiated honey

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Sterilization by electron beam irradiation offers significant advantages. In the present work, the effect of e-beam on the physicochemical properties of honey was studied. Four commercially available honey samples were irradiated with the beams of 3.5MeV electrons at dose rate 10, 20, 30, and 40 kGy using the linear pulse accelerator Board of Radiation and Isotope Technology (BRIT), India. The specifications of the E-beam set-up are: 250mA pulse current, 1mA average current, 10Hz pulse repetition rate, 3cm per second conveyer speed, and 5kGy dose per pass. Prior to irradiation, radiometric B3 films were appropriately placed onto the glass plates for dose monitoring. There was a total of sixteen samples which were sealed in glass bottles and subjected after irradiation to various physicochemical tests pertaining to their color, pH, refractive index, free radical scavenging activity, sugar analysis, and total phenolic counts (TPC), and compared with pristine honey samples.

The refractive index of honey (measure of the quantity of reducing sugars) was examined by a BRIX refractometer, and values were compared with the results of analysis of reducing sugars done by RP-HPLC with RI detector, to get the Fructose/Glucose (F/G) ratio. It was seen that the ratio of reducing sugars was not affected significantly by the higher doses of irradiation, and the F/G ratio remained higher than 1, which ensured that honey did not crystallize at room temperature. The pH measurements revealed a slight decrease from 10 to 40kGy, which could be attributed to radiolysis-induced increase of free amino acids. The lower pH is also expected to improve the anti-bacterial activity of honey.

The color intensity of honey is due to polyphenols and could thus be related to the antioxidant activity. The DPPH radical scavenging assay and Folin-Ciocalteau method were carried out for the antioxidant activity and total phenolic content, respectively. It was observed that these parameters varied with dose of irradiation. Thus, the color of all honey samples darkened post irradiation and a corresponding increase was noted in the antioxidant activity and total phenolic content. In conclusion, the irradiation dose of 30kGy sufficiently improved the antioxidant activity for all samples without significantly affecting other properties. Thus, E-beam irradiation is not only useful for sterilization but also for enhancing its quality parameters.

Abstract # 188

# Simulation of dose distribution with PUFFIn® software on hydrogels for environmental applications

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The use of absorbent materials such as hydrogels is of interest to reduce the environmental impact of dyes in industry. These can be polymerized with ionizing radiation and functionalized with materials such as clays with the ability to bind organic and inorganic molecules. Our work group develops hydrogels polymerized with Gamma radiation (60Co), and, as the objective of this study, it was proposed to perform dose distribution simulations using electron beams (E-Beam) in hydrogels. For this, the Dose Uniformity Ratio (DUR) was studied using the PUFFIn® software in hydrogels composed of 5% w/v polyvinyl alcohol, 4% w/v clay, 1% w/v agar, and dimensions (X,Y,Z):(4 cm,4.5 cm,1 cm). The variables set in the software were particle number 1*10+6, beam width and height 10 cm, source distance from product 100 cm. In the simulations E-Beams of different energies (2 MeV, 5 MeV, 7 MeV and 10 MeV), and different source locations (from Y and Z axis) were evaluated. The simulations showed that as energy increases, the penetration of electrons increases. When the source was applied along the Z axis with energy of 5 MeV to 10 MeV the results showed good homogeneity in the dose dispersion, with a low DUR (1.06-1.25). While with 2 MeV+E-Beam from Z, and with hydrogels treated from the Y axis, the DUR was higher, with a range of 4.7-33.12. In these cases, a large dose dispersion is observed, so the cross-linking of the polymers would not be homogeneous and a modification of the dimension, or the rotation of the sample during the irradiation process, should be considered.

In conclusion, in irradiation with E-Beam it is important to consider the geometry of the product, and the location and energy to obtain good dose homogeneity. Also, the PUFFIn® software proved to be a versatile tool that can be used to analyze dose distribution with different irradiation parameters and product geometries useful in industry and research, however, the studies must be confirmed with laboratory tests.

Abstract # 189

# Electron beam technology for enhanced methane generation in resource recovery facilities

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The term "resource recovery facility" has replaced traditional wastewater treatment plants, reflecting the contemporary emphasis on circular economies where the recovery and recycling of water, nutrients, and energy take precedence. Anaerobic digestion (AD) is commonly employed in these facilities to manage wastewater solids or sludges. This process relies on anaerobic microorganisms to convert organic substances in sewage sludges into methane and carbon dioxide, collectively known as biogas. The AD process offers several advantages, including the stabilization of organic matter in wastewater solids, the reduction of pathogens and odors, and a decrease in the overall quantity of solids/sludge by transforming a portion of the volatile solids fraction into biogas. Ideally, the products of anaerobic digestion should yield abundant biogas, stabilized solids, and nutrients like ammonia-nitrogen and phosphorus, which can be utilized in agricultural lands. The AD process comprises hydrolysis, acidogenesis, and methanogenesis, with hydrolysis considered the rate-limiting step dictating the duration of the process and methane production. The hypothesis is that electron beam (eBeam) technology, when used as a pre-treatment for sewage sludge, can eliminate microbial pathogens, reduce sludge viscosity (improving hydrolysis), enhance biogas production (by improving acidogenesis and methanogenesis), and improve overall process efficiency by reducing digester residence times. Demonstrating the effectiveness of eBeam in enhancing methane generation can replace the use of cobalt-60 for such applications. Laboratory studies, utilizing respirometers, were conducted on 10 kGy eBeam-treated primary sludge samples from a local wastewater treatment plant to test experimental hypotheses. Optimization studies revealed that a digester seed to sludge ratio of 1:6 produced the maximum amount of methane. Sludge viscosity was reduced by up to 70%, and that digester residence time can be reduced when eBeam is used to pre-treat the sludge. Preliminary experiments with eBeam pre-treated sludge yielded 92 mL methane/gm dry sludge compared to 60 mL of methane/gm dry sludge from the untreated sample. Comparison studies with cobalt-60 are planned. Preliminary economic analyses indicate that eBeam pre-treatment of sewage sludges will be significantly more cost-effective than cobalt-60 pre-treatment without any associated security risks.

Abstract # 190

# Comparison of computational codes for the accelerator-based and reactor-based production of Cooper-67

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Cooper-67 (67Cu) is becoming a trend radioisotope due to its theranostic applications. 67Cu has a half-life of around 2.58 days and a simultaneous emission of β− radiation and γ-rays. That trait makes this radionuclide useful for therapy and for diagnostic imaging through the SPECT-CT technique. As the scientific community look for adequate and efficient production routes, the necessity for precise calculations concerning the final activity is of paramount importance. This work seeks to employ computational codes such as PHITS, FLUKA, TALYS, TopMC in order to benchmark previous experimental results with the default physical models and the nuclear database of these software. The main goal of this project is to realize which Monte Carlo codes or deterministic calculators better estimates the production yield of this radioisotope when a target is irradiated either with charged particles or with neutrons. Desirable nuclear reactions to be analysed include, but are not limited to: $^{70}$Zn(p,α)$^{67}$Cu, $^{67}$Zn(n,p)$^{67}$Cu, $^{68}$Zn(p,2p)$^{67}$Cu, $^{68}$Zn(γ,p)$^{67}$Cu.

Two previous experimental results performed by other institutions are used as reference. We duplicate their targets employing CAD-based software such as AutoCAD and Inventor. Then the geometry is exported to the other software for executing the irradiation routine following as much as possible their experimental conditions. The sought production yield is found as soon as the simulation has finished. We conclude which code, which physical model, and which nuclear database better resembles the real scenario. So further experimental studies can predict confidently the production yield beforehand.

Abstract # 194

## Study of neutron production in accelerator-driven spallation targets

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This work investigates the characteristics and properties of spallation targets in ADS (Accelerator Driven System). The aim is to obtain a high neutron flux with a hardened neutron spectrum for transuranic transmutation in a hybrid fission ADS system. The proposed system uses a proton source (a particle accelerator) with energies between 0.3 and 1.6 GeV, focusing on different high-density material targets: three in liquid state, mercury, natural lead, a lead-bismuth eutectic alloy (LBE) and two solid states, tungsten (W) and natural uranium (U). The geometry of the spallation target (radius R and height H) is varied to understand these variables' role in the neutron yield. The neutron flux on the target surface is evaluated for the different energies of the incident protons and different geometries of the targets, considering the results of simulations in MCNPX (Monte Carlo N-Particle Transport Code). The results show a neutron multiplicity saturation limit for incident beam energy at 1 GeV. It is verified that there are optimal dimension values for the target radius and length, respectively, at R close to 15 cm and L close to 50 cm for incident proton energies of 1 GeV. The neutron flux distribution of the study targets presents a hardened spectrum suitable for using ADS for nuclear waste transmutation. A subcritical reactor with different neutron sources provided by some targets has been tested to evaluate the neutronic parameters of the hybrid system.

Abstract # 199

# Multi-technique hair analysis to determine occupational metal exposure in Sudanese gold artisanal miners

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Artisanal mining is a growing segment of the mining industry in certain parts of the world. Workers are often not equipped with protective safety gear and are exposed to mining pollutants that can hurt the health and well-being of workers. As occupational biomonitoring studies within the mining industry of countries such as Sudan are limited, this study aimed to explore the utility of a multi-technique approach to biomonitor human tissue retrieved from artisanal gold miners, i.e., hair, for the presence of toxic metals. Gold artisanal miners from the region in Sudan voluntarily submitted hair samples for the study that were screened using different elemental screening techniques including PIGE, PIXE, RBS using a tandetron accelerator.

Abstract # 200

## Electro-mechanical behavior of irradiated nano-filled polyvinyl alcohol

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Polymers are extensively used in medical devices. Polyvinyl alcohol (PVA), a hydrophilic polymer, is one of the polymers used for various biomedical applications. The simple chemical structure and high hydroxyl group contents provide PVA-based materials with many desired properties. Various factors control the mechanical and electrical properties of PVA to produce a PVA-based material with consistent, repeatable properties for medical device applications. They can be sensitive to ionizing radiations. In this work, nanopolymer film samples were prepared from PVA and Titanium oxide (TiO2) nanoparticles. The samples were subjected to neutron irradiation in the Nigeria Research Reactor (NIRR-1) at different doses. The mechanical and electrical properties of the irradiated nanocomposite were studied. The result revealed that the nanoparticles enhanced the mechanical strength of the polymer. Neutron irradiation also caused a significant increase in the mechanical strength due to cross-linking. The aging due to neutron irradiation, however, produces ionic radicals in the nanopolymer. The ionic radicals lead to an increase in electrical conductivity. There was also an observed increase in the charge storage capability of the samples. A PVA with improved mechanical, charge storage, and electrical conductivity will find use as an electroactive polymer and other applications.

Abstract # 201

## Challenges and considerations in transitioning from cobalt-60 to linear accelerators for radiotherapy in LMICs healthcare settings: a case study of Nepal

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Nepal is a landlocked country around thirty million inhabitants. For decades, Cobalt-60 machines have been the workhorses of radiotherapy in low- and middle-income countries (LMICs) like Nepal. Their affordability, relative ease of use, and lower maintenance needs made them the go-to technology for providing essential cancer treatment. In recent years, the field of medical physics has witnessed significant advancements in radiation therapy technology, with linear accelerators (linacs) emerging as a preferred choice for delivering precise and targeted radiation doses. However, the transition from traditional cobalt-60 machines to linacs poses unique challenges, especially in underdeveloped healthcare settings like Nepal. This article delves into the issues, challenges and considerations surrounding this transition and explores potential solutions for a successful integration.

The transition from Cobalt-60 to linear accelerator in LMICs is undeniably a formidable challenge, but it also signifies an unparalleled opportunity to enhance cancer care for millions of patients. Meticulously addressing these challenges through a strategic and multidimensional approach empowers LMICs to overcome hurdles and capitalize on the clinical advantages of linac, ultimately delivering improved radiotherapy services to their citizens. Crucially, the decision to transition should be tailored to the unique needs and resources of each healthcare setting, emphasizing a case-by-case basis. A well-planned and coordinated approach is instrumental in ensuring a successful transition that not only benefits patients directly but also strengthen the overall cancer care infrastructure in LMICs. Experience has underscored the paramount importance of vigilant monitoring, anticipated challenges, and adopting a strategic and adaptable approach as circumstances evolve. This underscores the necessity of developing sustainable financing models for the long-term operation and maintenance of linac, acknowledging the potential for unforeseen circumstances that demand adaptability and resilience in the implementation of advanced medical technologies. Nepal, by addressing infrastructure limitations, financial constraints, workforce training, regulatory compliance, and community engagement, can pave the way for a successful integration of modern radiation therapy technology. International collaborations, knowledge-sharing initiatives, and a steadfast commitment to improving healthcare infrastructure will play pivotal roles in ensuring equitable access to advanced cancer treatment in the region.

Abstract # 225

# High yield muon catalyzed fusion & muonium

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Fusion holds great promise as a clean and abundant energy source. However, traditional thermonuclear fusion encounters significant challenges due to the extreme temperatures required to overcome the coulomb barrier for two nuclei to fuse. In contrast, muon-catalyzed fusion presents an alternative approach that can surmount this barrier at significantly lower temperatures. Muons, with properties resembling those of electrons but 200 times heavier, can effectively reduce the atomic orbital radius, enabling central nuclei to overcome the coulomb force through the strong force. By introducing muons into a mixture of deuterium and tritium (two hydrogen isotopes), fusion is facilitated, releasing a 3.5MeV alpha particle and a 14.1MeV neutron. In the majority of cases, the muon is liberated and can initiate further fusions. However, approximately 0.8% of the time, it adheres to the alpha particle and remains bound until it either decays or undergoes reactivation through collisional ionization. To maximize the number of fusions per muon, it is crucial to enhance the cycling rate and reactivation fraction. Theoretical predictions and experimental data both suggest that the sticking rate decreases with increasing density. However, there exists a discrepancy between experimental observations and theoretical estimations regarding the extent of this decrease. To address these disparities, this experiment aims to investigate the cycling rate and sticking fraction under higher temperatures and pressures than previously explored.

Additionally, search for Muonium ($M \equiv \mu^+ e^-$, chemically a light isotope of hydrogen) to Antimonium conversions, antimatter gravity, and M atomic spectrum measurements are in need of a reliable high-efficiency source of Muonium.

Both experiments can be supported at the MeV Test Area (MTA) experimental hall using a recently installed secondary production beamline. This beamline uses the 400 MeV Fermilab proton Linac beam and a tungsten target to produce low energy secondary muons which are then captured in the secondary beamline. This work will present the details and methodology used to design and realize an optimized, low-cost production, capture, and transport system for low energy muons, forming a beam for fusion and muonium research.

Abstract # 226

# Muography in the context of general relativity and extremely massive objects

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Muography has been an interesting experimental detection method for thick and dense materials, which typically eluded other forms of radiation detection, such as electron and gamma radiography. The applications of Muography ranges from observations of volcanic and pyramid structures to underground GPS function, border security control, cybersecurity of cosmic transmissions, etc. It can be seen that the use of Muography has been extensively broadened beyond its initial purpose of dense material detections. However, there is a caveat that muons just happen to have the right amount of mass and lifetime on Earth, enabling them to be the appropriate detection particle in thick and dense environments. From a theoretical standpoint, when heavy stars or planets are involved, muon detection mechanism would need to take not only special but general relativity into account; the lifetime dilation would be affected not just by velocity, but the local gravitational field and metric. I then proceeded to consider the possibility of employing tau particles in heavy environments and discuss the criterion for choosing between Muography and "Tauography". Furthermore, magnetic fields are known to yield noises in Muography pictures, and the effects on Muography in conjunction with gravity will also be discussed.

Abstract # 227

# Regulatory Control at Class I Accelerator facilities in Argentina: Present and Future

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The Nuclear Regulatory Authority of Argentina (ARN), through the ‘Class I Particle Accelerators Control Department’, develops the regulatory tasks associated to the radiation protection of Class I Accelerator facilities. The group of facilities under control includes from R&D linear accelerator facilities to radiopharmaceutical production facilities with cyclotron. Furthermore, the Department is part of the ‘Licensing Project of the Argentine Center of Proton Therapy’ that has been formed ad hoc to face this challenging regulatory endeavor.

Due to the radiological risk and technological complexity, the regulatory framework established by the ARN determines four stages for the authorization process of a Class I facility: construction, commissioning, operation and decommissioning. Regulatory processes are implemented applying a graded approach and considering the particularities of each stage of the life of a facility. Safety requirements are verified through documentation review and safety assessments, as well as regulatory inspections that are carried out for all the operating conditions throughout the entire country.

Another relevant aspect is the authorization of the personnel of the facilities, which is addressed by the assessment of the training programs and the accreditation of the qualification, among others.
The paper summarizes the activities conducted by the ARN during the Class I Accelerator facilities licensing and inspection processes, describes the regulatory approach adopted and the implemented steps to strengthen its capacities: highlighting the importance and role of the regulatory process in guaranteeing the safety operation of these facilities. Finally, the milestones achieved so far, the lessons learned, and future plans are presented in the paper.

Abstract # 232

# A novel low-energy muon production beamline at Fermilab

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The MeV Test Area (MTA) secondary beamline at Fermilab has been designed to efficiently generate and capture a high-emittance, low-energy pion beam using the 400 MeV primary proton Linac beam on a tungsten target, leading to a tertiary muon beam from decay along its secondary path. The beamline can also capture surface muons ($\mu$+) produced at the target. However, a key challenge lies in the significant muon decay angles emitted relative to the transported phase space of the pion beam – which is a result of the very low muon momentum from decays of 50-100 MeV/c pions. This, coupled with an almost constant pion production beam profile as a function of production angle, compromises the efficiency of the beamline elements to effectively capture muons outside the limited angular acceptance of the secondary beamline. To address this limitation, a low-energy MTA muon beam collaboration group is actively engaged in research and development for incorporating newly acquired, stronger-gradient quadrupoles to enlarge the capture solid angle of the secondary beamline compared with the current and conventional solenoidal capture approach. The work presented here is the plan to upgrade and optimize the lattice structure of the MTA's secondary beamline, in initial pion capture efficiency and enhancement of the muon flux delivered to experiments beyond the current conventional solenoidal capture configuration.

Abstract # 235

# Alpha track detection from industrial effluents on polymeric CR-39 solid state nuclear track detector

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Natural radioactivity is extensively existing in the earth's natural environment because it is composed of the cosmogonic and primordial radionuclides, hence it is commonly occurring in different ecological, geological as well as environmental formations like, rocks, soils, sand, plants, water, and air. There are several other industries such as Coal fired power plants, Phosphate fertilizer production plants and Granite cutting & polishing Industries etc. which release alpha emitting natural radionuclides like 238U, 232Th and 222Rn into the environment during production, manufacturing and discharge processes which has been steadily increased therefore, it is of vital interest to monitor the alpha radioactivity in the air, solid and liquid waste emanating from these industries.

Solid State Nuclear Track Detection (SSNTD) is one of the most convenient analytical techniques to measure low level alpha radioactivity due to its numerous advantages such as simplicity, high sensitivity, and capacity to store permanent records. In the present investigation we have standersized CR-39 detector using thorium nitrate and uranyl nitrate salt solution and we have optimesed different parameters like Concentration range (5- 1000μg/L) Etching time (1-8 H) Exposure time (1-24 H) Normality of etchant (2-6M) Temperature (50-75˚C) and Amount of TEAB added to NaOH (1-10%). Differnet effluent samples were collected from the discharge point source of selected industries. An advanced functional material such as organic polymeric chemically known as Allyl Diglycol polyarbonate CR-39 detector pieces of thickness 700 micron and size of (1.5 cm × 1.5 cm) were then immersed into effluents for a different period to study alpha track detection. Therefore, these tracks have been extensively investigated applying new chemical etching method of comprising a mixture of 5% Tetraethyl ammonium bromide (TEAB) with 6M NaOH (w/w) at optimized temperature of 60˚C.

The observations of these detector pieces were done under optical microscope attached with digital camera in addition of Magvision software at the higher magnification, spinning disc confocal microscope Scanning electron microscopy & Atomic Force Microscopy to study the morphology of alpha tracks in CR-39 detector. The total number of tracks were counted, and highest track density and average track diameter at different exposure times for all samples was measured. Low level concentrations of 238U & 232Th (μg/L) from these effluent samples taken along from these industries were measured by Inductively Coupled Plasma Mass Spectrometer. The introduction of Tetraethyl ammonium bromide with NaOH as a new chemical etchant has provided better enhancement in formation and revelation of alpha tracks in very less etching time. The output of the developed etching technique appears extremely better for the usual track appearance, track density, and track diameter profile. The present work offers a novel approach to detect alpha track detection on CR-39 and low-level environmental alpha radioactivity from industrial effluent samples.

Abstract # 176

# Production and spectroscopic investigation of Mercury and Radon isotopes produced in complete fusion reaction and multi-nucleon transfer reaction at MASHA facility

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In this work, the production and spectroscopic investigation of Mercury and Radon isotopes was performed using complete fusion reactions neutron evaporation residues and multi-nucleon transfer reaction at the mass separator MASHA. The MASHA setup is installed on the beam line of Cyclotron U-400M at Flerov Laboratory of Nuclear Reactions (FLNR) in Joint Institute for Nuclear Research (JINR), Dubna, Russia.

The isotopes produced in complete fusion reactions and multi-nucleon transfer reaction were passed through the magneto-optical system of MASHA setup with charge state Q=+1 and were separated on the basis of their mass to charge ratio. For the detection of these isotopes, a position sensitive Si detector was used. Further, the experimental data obtained were analysed and spectroscopic investigations were carried out.

Abstract # 245

## DYNAMITRON® DC 1500/25/4 type electron beam accelerator scan system update

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The proposed theme of this research focuses on studying, developing and nationalizing an automated system scanning the Dynamtron ® DC1500/25/4 electron beam accelerator with energy of 1.5 MeV , beam current of 25 mA and beam scanning of 60 to 120 cm , with a total power of 150 kW, installed at Ipen-CNEN /SP in 1978 and since then used in radiosterilization, disinfestation , treatment of industrial and domestic effluents, modification and cross-linking of polymeric materials, curing of composite materials among other applications . The scanning system of the electron beam accelerator aims to control the length of the electron beam from 60 to 120 cm with a thickness of 25.4 mm, in which the magnet and electronic coils are controlled for scanning control. This entire system is in the original configuration of the accelerator manufacturer, RDI Radiation Dynamics, Inc, installed at IPEN in 1978, however, since 1987, it no longer provides spare parts for this type of accelerator. Next, a new control system was developed, where the scanning system with control signal is composed of a Siemens S7-1200 programmable logic controller, an arbitrary function generator and other components. This updated system allowed greater agility in routine operations, continuing the work using this electron accelerator, which serves research improvements in different areas such as human tissues, precious stones, new composites and polymers, food and medical products and health, in addition to demands services for external companies.