The 4th International Forum on Advances in Radiation Physics
(IFARP-4)
Riyadh – Saudi Arabia
27 – 31 March 2022

Contents

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Dosimetric Needs in Support of Flash Radiotherapy

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Abstract

FLASH RT, the focus of much research, has been motivated by the potential to deliver quality prescribed doses with minimal effects on healthy tissues. One perceived need in delivery of the prescribed dose is an ability to carry out time-resolved radiation dosimetry, the desire being to obtain this with minimal saturation. Concerning earlier reports on the use of silica optical fibres scintillators for real-time radiotherapy dosimetry accessing radioluminescence (RL) indicates merits, especially minimal saturation, versatility, wide dynamic range, and high spatial resolution. Topping the list for such radiotherapy dosimetry is the ability to potentially provide for time-resolved dosimetry, alluding to pulse-by-pulse dosimetry with minimal saturation. In this work, we elucidate the potential of pure silica optical fibre scintillators used for RL based time-resolved dosimetry characterized in an industrial radiation facility electron beam with ultra high dose rates (up to 7 kGy/s), resembling a FLASH RT source. The RL yield indicates low saturation with linear response to absorbed dose (up to 70 kGy). In another development, Ge-doped silica optical fibre were characterized for time-resolved dosimetry properties. The characterization was carried out in a high-energy clinical X-ray beam (6 MV), in particular a Varian 2100 C/D linear accelerator. Responses were recorded for six dose-rates (between 100 MU/min and 600 MU/min), using a PMT setup with the photon-counting circuit gating time set at its shortest capability of 1 μs. The Ge-doped optical-fibre scintillator showed linear RL response, with minimal observable memory and afterglow and plateau effects. The fluorescence lifetime analysis demonstrates a calculated rise time of 590.1 ns and a decay time of 0.423 μs, indicating good potential for FLASH RT that may have a pulse repetition frequency as high as 400 Hz. Such time-resolved dosimetry and minimal saturation performance alludes to the potential for silica optical-fibre scintillators to be used for FLASH RT dosimetry.

IO-001

An iterative position reconstruction method for gamma cameras

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Abstract

The gamma camera is a widely used molecular imaging tool in nuclear medicine. In the last decades, we have observed a growing interest in compact gamma cameras with high spatial resolution and sensitivity. In gamma cameras, event position reconstruction is usually performed with the traditional centroid method, or, alternatively, using statistical reconstruction methods. The second approach can provide better spatial resolution, potentially smaller distortions, larger useful field of view, and better filtering of noise events. However, it requires the knowledge of the response of each individual photosensor as a function of the event position (so-called light response function, LRF). Here we describe an iterative method, which allows to obtain the LRFs from flood irradiation data without imposing strict requirements on the spatial uniformity of the event distribution. We used an open-source package ANTS2, developed for simulation and experimental data processing for broad range of Anger-camera-type detectors and optimized for the iterative LRF reconstruction. The successful implementation of this method was demonstrated for a traditional commercial gamma camera with a circular crystal and cylindrical photomultipliers and a compact gamma camera with square-shaped photosensors and a square-shaped monolithic scintillator. In each case, the method was validated with simulated and experimental data.

Recent Advances in Compton camera detector development for medical imaging

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Abstract

Photon-detecting imaging technologies play a crucial role both in diagnostics for nuclear medicine as well as for different tumour therapy modalities. Advanced techniques aim at exploiting the kinematical constraints of Compton scattering in a so-called Compton camera. In particle therapy there is a strong need for an in-vivo beam range verification in order to allow for reducing presently applied safety margins around the tumor volume, compromising the potential high precision of the treatment modality. Compton cameras aim at tracking the origin of (multi-MeV) prompt photons generated in the interaction of the therapeutic particle beam with tissue. In nuclear medicine, PET-based diagnostics could be enhanced in sensitivity by widening the scope of applicable radioisotopes to β^+ emitters which emit a third, prompt photon from an excited state of the β^+-decay daughter nucleus. Registering the trajectory of this third photon with, e.g., a Compton camera in coincidence to the 511 keV annihilation photons leads to what is called 'Whole Gamma Imaging (WGI)' or 'γ-PET'. Also, hybrid detector systems could be designed, e.g., to combine (γ-)PET with Compton imaging for range verification during hadron therapy. The presentation will describe recent results obtained in characterizing Compton camera detector components in various configurations at LMU Munich: comparative performance studies (spatial resolution, energy-dependent and position-dependent energy resolution, CRT) will be presented for monolithic as well as pixelated scintillation detectors ($LaBr_3$:Ce, $CeBr_3$, GAGG, including a 3-layer, segmented LYSO DOI detector block) acting as scatterer or absorber for a Compton camera. Different types of SiPM arrays were used as photosensor in different couplings to the crystals, together with an ASIC-based signal processing. Offline (laboratory) and online (proton beam) data will be presented and a Compton-camera prototype as well as a γ-PET detector configuration were studied. Results of systematic studies over a wide photon energy range will be presented.

The Importance of Nuclear Data for Production of Diagnostic and Theranostic Radionuclides via Accelerator Route

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Abstract

Accurate knowledge of nuclear nuclear data are important for production of a radionuclide via charged particle-induced reactions. This study outlined the availability and scarcity of standardized nuclear data for production of promising medical radionuclides via accelerator-route. The data are considered for the radionuclides that have potentials to be used in theranostic/therapeutic applications. The current trends in nuclear data production and evaluation activities using accelerators are discussed in detail. This work is expected to provide a direction on the accelerator based production of promising radionuclides in no carrier added form for various medical applications.

Keywords: Nuclear data, Production routes, No carrier added production, Theranostic applications

A cause of neurodegeneration? Structural interpretation of Cu binding in N-Truncated Amyloid-β Peptides from X-ray Absorption Spectroscopy

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Abstract

Alzheimer's disease (AD) is a progressive neurodegenerative disorder characterized by the presence of amyloid plaques composed mainly of amyloid-β peptides (Aβ). Soluble, diffusible Aβ oligomers of unknown structures may be involved in extensive redox chemical reactions possibly causing cellular toxicity. The first protein sequencing studies of the Aβ plaque core (APC) of AD patients identified NH_2-terminal heterogeneity; the majority (64%) of the APC-AD Aβ peptides begin with a F_4 residue. Novel X- ray Absorption Spectroscopy (XAS) of Cu-Aβ under *in situ* electrochemical control (XAS-SEC) with propagation of uncertainty for hypothesis testing has allowed elucidation of the relationship between the truncated peptide structures and the redox properties of the Cu^{II} bound. XAS of Cu^{II}:$Aß_{1-16}$ and Cu^{II}:$Aß_{4-y}$ (y=9,12,16) frozen solutions (10 K) and XAS-SEC at room temperature under potentiostatic control have been measured. In two experiments at the Australian Synchrotron XAS beamline, the excellent performance is demonstrated by the structural uncertainty of the final results. Derivation of new structural models for binding of Cu I and Cu II with N-truncated Aβ peptides helps to explore the reduction properties in the peptide. We explain how this can be an explanation of the cause of neurodegeneration.

Spectra and Gamma Factors for X-rays for Diagnosis

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Abstract

X-ray spectra depend on the current, voltage, target and filter in an X-ray generator (X-ray tube) on the other hand, the dose depends on the spectrum. For diagnosis are used 30 to 120 keV X-rays whose features are important for patient and staff radiation protection, for the design of working protocols as well as for shielding barriers design and evaluation. In this work the 70 to 120 keV X-rays spectra were estimated using Monte Carlo methods for X-ray units having Rh and Mo targets, and Al filter. The spectra were estimated along the useful beam and for X-rays that leak-out from the X-ray unit. With the spectra, the total photon fluence and the Gamma factors (Γ-factors) were calculated. Using the MCNP5 code a model of an X-ray unit was designed. The model includes the target, the glass and the shielding enclosures as well as the filter. It was simulated the transport of 70 to 120 keV monoenergetic electrons and the X-ray production when electrons collide with the target. Spectra were estimated in several points along the useful beam, as well as to 100 cm from the focal point to 90º and 180º from the useful beam to evaluate the X-rays leaking from the unit. X-ray spectra and the fluence-to-H*(10) and fluence-to-Ka conversion coefficients were used to calculate the Ambient dose equivalent and the air-Kerma. Glass enclosure and filter eliminates the low-energy photons that are useless to produce the image reducing the dose at the entrance surface on the patient. The spectra is the contribution of continuous and the discrete spectra due to Bremsstrahlung and characteristic photons ruled by the target material. The spectra end-point depend on the voltage. The X-ray spectra, Ka and H*(10) are larger in the useful beam in comparison with spectra of leaking-out photons.

Pregnancy and medical radiation

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Abstract

Thousands of pregnant patients and medical radiation workers are exposed to radiation each year. Lack of knowledge is responsible for great anxiety and probably unnecessary termination of many pregnancies. The consequence of radiation exposure in foetuses is mostly based on observations rather than based on scientific research. Ethical issues prohibit researching on the foetus. Therefore, most of the data on the impact of radiation on the foetus derives from observations of patients who suffered Japan's Hiroshima bombing and the Chernobyl nuclear power plant disaster. Based on the observations made from the victims of the high level of radiation exposure, the consequences of radiation exposure can categorize into four broad groups, including pregnancy loss, malformation, developmental delay or retardation, and carcinogenesis. For many patients, the exposure is appropriate, while for others the exposure may be inappropriate, placing the unborn child at increased risk. ICRP Publication 84 concerns the management of pregnant patients as well as pregnant workers in medical establishments where ionising radiation is used. Based on the above report, this presentation discusses how to deal with these matters and problems, which are: Medically necessary radiation exposure of a pregnant woman, Radiation-induced malformations, Pre-conception radiation, Handling of Pregnant or Probably Pregnant Patient in the Hospital, Absorbed Doses, Absorbed dose to the fetus in Conventional Radiology, Nuclear Medicine and Radiation Therapy, Dose Limits for Pregnant Workers, Research involving pregnant women, Termination of pregnancy.

IO-007

Concept for a real-time distributed optical fiber radiation sensing system

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Abstract

Ionizing radiation in medical, industrial, reactors and high energy accelerator facilities have adverse effects on installed electronics. Such effects will eventually limit equipment lifetimes. Monitoring radiation levels across a facility requires an accurate radiation dosimetry which is distributed in nature. Specialty optical fiber has demonstrated its potential as both passive and active radiation dosimetry in such facilities. The coupled ability of specialty optical fiber as a sensor and as a waveguide opens a new dimension of distributed radiation sensing that is both in-situ, real-time and high-resolution. In this paper, a review is presented on suitable materials used in a specialty optical fiber that would provide suitable techniques to real-time and distributed radiation sensing based on Radiation Induced Attenuation (RIA) and distributed measurement techniques in the Rayleigh based reflectometry. The discussion poses challenges that face distributed radiation sensing systems such as the ability to measure distributed radiation dynamically over time. The concept of a real-time distributed optical fiber radiation dosimetry sensing system is introduced, focusing on the use of photobleaching in low-OH pure silica optical fiber and RIA based measurements using the phase sensitive optical time domain reflectometry (POTDR) technique. Preliminary results for RIA and photobleaching assisted RIA recovery for low and high OH pure silica optical fiber is discussed. The results are in support for the inception of a real-time distributed optical fiber radiation sensing system.

IO-008

Radiation physics programmes at the University of Surrey

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Abstract

The University of Surrey has a large radiation physics portfolio. It is based on a large number of academics active in the fields of experimental nuclear physics, theoretical nuclear physics, radiation detector science and medical physics. The presentation will discuss some recent works, such as (i) retrofitting environmental monitors with SiPM-s, (ii) measurement of lifetimes of excited nuclear states using the FATIMA $LaBr_3$(Ce) scintillation array and applying the fast-timing method and (iii) the principle and use of the AGATA HPGe gamma-ray tracking array.

X-ray Phase-Contrast Imaging: Principles and Applications

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Abstract

Although X-ray's production, interaction and detection are generally described using particle models, wave-particle duality calls for considering diagnostic X-rays also as electromagnetic waves, with a wavelength in the range of 0.1-0.01 nm. Novel imaging techniques, which take advantage of the wave nature of X-rays, have been recently introduced and developed, initially at synchrotron radiation facilities, and later also at more portable X-ray sources. These techniques are referred to as X-ray phase contrast imaging (XPCi), since they allow to highlight not only the traditional absorption contrast, but also the contrast due to the phase shift that the X-ray wave suffers in traversing the sample. This supplementary pool of contrast is often much larger than conventional attenuation and can allow the visualization of low-absorbing details embedded in a similar background, as is often the case in medical imaging. XPCi can be implemented via several techniques, including: Propagation-Based XPCi, Analyzer-Based XPCi, Edge Illumination, Interferometry, Grating Interferometry, and Speckle Imaging. Some of these techniques have proven considerable potential in different biomedical applications, highlighting features that have poor visibility in conventional imaging. Moreover, specific characteristics of XPCi can be exploited in particular applications. For instance, the edge-enhancement effect, typical of Propagation-Based XPCi, has been used in mammography to discriminate between benign and malignant lesions; the sensitivity to ultra-small angle scattering of Grating Interferometry (dark field imaging) has allowed unprecedented visualization of the airways and important insight in lung imaging; the possibility to obtain parametric images (such as in Analyzer-Based XPCi) has been used to simultaneously visualize the articular cartilage, the underlying subchondral bone and the trabecular bone, correlating features on the whole structure. Recent works pave the way for the design of versatile multi-resolution XPCi systems, that could span from low-dose imaging for patients' follow-up to high-resolution imaging for virtual histology.

Recent Research on Utilizing Artificial Intelligence in Radiation Therapy

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Abstract

In 2020, an estimated 19.3 million new cancer cases will be diagnosed worldwide, with cancer death accounting for nearly half of the incidence. Radiation therapy (external and internal beam) uses ionizing radiation to eradicate cancer cells or slows their growth (shrink tumors) by damaging their DNA. The challenge in radiation therapy is increasing tumour control probability while minimizing damage to surrounding normal tissue. Artificial intelligence (AI) is a branch of computer science that aims to create computer-based systems that replicate humans' decision-making and problem-solving abilities. In recent decades, artificial intelligence has been utilized to improve radiotherapy outcomes. In radiotherapy, AI allows for the processing and analysis of enormous datasets. AI enables the iterative implementation of complicated tasks in massive datasets (e.g., defining healthy tissue or determining optimal treatment planning) for image segmentation and outcome prediction, benefiting the entire radiation therapy community. Therefore, this presentation will review the recent research published on utilizing AI in the radiation therapy field.

IO-011

Radiation Protection in Medicine: Current Challenges and Future Prospective

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Abstract

Ionizing radiation from natural and artificial sources (induced radioactivity and X-ray and particle beams) in medicine has increased drastically since discovering X-rays in 1895 and radioactive in 1896. Radiation medicine is used for diagnostic, image-guided intervention, and therapy procedures. The dose per procedure increased significantly with the introduction of hybrid technology such as positron emission tomography (PET) associated with computed tomography (CT). On the other hand, radiation in medicine must be carefully balanced between the benefits of improving health and welfare and the hazards associated with radiation exposure. Recent reports showed that approximately 1.3% and 0.5% of patients received an adequate dose above 100 mSv from CT in the US and Europe. In the US, it was estimated that around 29 thousand new cancer cancers are expected annually due to medical radiation carried out in the past years. Vast differences were reported between radiology departments suggested that some patients still exposed to unnecessary radiation. Therefore, there is a significant and ongoing need to safeguard patients from avoidable and accidental radiation and medical professionals, specifically from large radiation doses. Medical examinations that are not justified for a specific goal and the doses that are not adequately optimized can result in unwarranted patient doses. Patients and medical personnel may be exposed unintentionally due to unsafe design or incorrect usage of medical equipment. The main challenges include the development of imaging technology with lower radiation dose and highest image quality, sensitive detectors, and the establishment of dose tracking systems in each country. The well-informed society, implementation of diagnostic reference levels, and availability of international guidelines for staff training and dose management are opportunities for patient dose reduction.

IO-012

Radiopharmaceuticals in the Era of Precision Medicine

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Abstract

Radiopharmaceuticals are a unique group of products that are labeled with radioisotopes of diverse diagnostic and/or therapeutic characteristics. Both sets of products are the most essential components of contemporary nuclear medicine practice. In particular, positron emission tomography (PET) radiopharmaceuticals are being increasingly utilized in nuclear medicine for a precise clinical diagnosis/therapy of many diseases and have become an integral part in the era of precision medicine. The development of [^{18}F]fluorodeoxyglucose ([^{18}F]FDG) in the seventies for studying glucose metabolism together with the establishment of reliable synthesis was a major breakthrough leading to the development of PET. Until now, [^{18}F]FDG is the most widely used radiopharmaceutical in PET imaging which is attributed to its biochemical and physical properties. However, [^{18}F]FDG is non-specific and many lesions and organs have been noted to show elevated [^{18}F]FDG uptake which interfere with image interpretation. It must be emphasized that advancement of precision medicine imaging by PET requires development of new and more precise radiopharmaceuticals for imaging and assessing specific molecular targets. The precision imaging of such targets will allow earlier detection of disease(s) onset, proper characterization and management of disease at various stages, earlier and direct assessment of treatment effects, thus enabling effective personalized patient management. Consequently, varieties of precision radiopharmaceuticals for clinical use beyond the measurement of glucose metabolism were developed and thoroughly investigated. Therefore, we here report the advances of current and future theranostic radiopharmaceuticals that encompass various radioisotopes such as Fluorine-18, Gallium-68, Lutetium-177, Iodine-124 and Copper-64.

IO-013

Determination of radioactivity concentration and hazards assessments near radioactive waste site in Saudi Arabia

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Abstract

Radioactive waste arises from the operation of nuclear power plants and research reactors, from nuclear fuel cycle operations and from various types of activities such as (activities in industry, mining, oil and gas production, research, and medicine) in which radioactive material is used. Petroleum and natural gas industry produce significant quantities of naturally occurring radioactive material (NORM) originating from the reservoir rock encountered during production, maintenance and decommissioning. As well as making large use of radiation generators, sealed and unsealed radioactive sources, some of them are potentially dangerous to human health and to the environment if not properly controlled. Radioactive waste presents a potential hazard to human health and the environment, and it must be managed properly to ensure that any associated risks do not exceed acceptable levels (IAEA, 2014). In this study, an investigation has been determined to estimate the radioactivity concentrations in soil samples around the area of radioactive waste site along with the radiological risk for public and environment. This is the first study to evaluate the radiological impacts in the area under investigation. Soil samples were collected from different locations near the radioactive waste site and the activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs were measured using gamma-ray spectrometer consisting of a high purity germanium detector. Radiation hazard indices were calculated to evaluate the radiological risk for the public and environment, i.e., the absorbed dose rate in air, radium equivalent activity, and annual effective dose rate which will be presented in the conference.

IO-014

Silica-based Passive dosimeters for Medical Radiation measurements

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Abstract

For several decades, glass thermoluminescent dosimeters (TLDs) have been used as effective tools for measuring doses in medical applications. To- date, there are several types of phosphor-based TLD that have been used for evaluation of wide range of doses (from relatively low levels of exposure that are used in diagnostic imaging radiology to high dose levels that are used in radiotherapy applications). Glass thermoluminescent dosimeters offer many advantages including their small physical size, good sensitivity, reusability, and their excellent reproducibility, also allowing a wide dynamic range unlike the conventional phosphor-types such as TLD-100 that are widely used in radiation-medicine analyses. Several studies have been previously conducted using various types of doped and undoped silica media to determine the characteristics of these TL materials in particular dosimetry applications. As examples, assessments have been made of the relatively low doses of dental radiography, chest x-rays, and mammography. In respect of the scattered radiation from Gamma-Knife Radiosurgery, *in vitro* measurements of the scattered doses absorbed by eye lens have been performed in an audit of 20 hospitals around the UK. In addition, *in vivo* measurements for doses received by radiosensitive organs including thyroid, chest, and pelvis have been made using various types of silica-based dosimeters.

IO-015

Radiological and nuclear emergencies: lessons learned

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Abstract

Radiation, both radiological and nuclear, emergencies are non-routine events that require a prompt action to mitigate a radiation hazard or its adverse consequences for human life, health, property or the environment. This lecture will define radiological and nuclear accidents. It will present case examples of radiation accidents, including major nuclear power plants accidents as well as radiotherapy accidents. The experiences of the Chernobyl and Fukushima nuclear accidents will be covered. These nuclear emergencies involved release of energy resulting from a nuclear chain reaction or from the decay of the products of chain reaction. On the other hand, radiological emergencies are situations involving an uncontrolled radiation exposure from a radioactive source or X ray equipment such as a linear accelerator. Several examples of such radiological accidents, including a series of devastating radiotherapy mistakes, will be shared with the audience. Some of the main lessons learnt are the necessity to provide accurate risk communication concerning radiation exposure. This is required in order to provide scientifically correct information on radiation to the authorities as well as to the public, placing it into perspective in terms of the health hazard. Other main learned lessons include building staff awareness and alertness as well as compiling and implementing documentation and procedures. Other lessons include equipping and training staff with the required competences, functions and responsibilities. Finally, the concerned institutions should be able to develop an effective mitigation plan for prevention of accidental exposures.

IO-016

Radioactive Waste Management- Nuclear Waste Disposal

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Abstract

The goals of this study were to analyze the radioactive waste stream for proposed nuclear power plants in Saudi Arabia by finding suitable methods for treating the radioactive waste, and assessing the radiation dose for each treatment method. The site proposed for a new nuclear power plant in Saudi Arabia is the city of Jeddah. For the near-surface disposal facility option, the direct dose rate to a member of the public starts to increase after the facility closure and reaches a maximum value of 1.4 mrem/y after 50,000 years. The radionuclides ^{99}Tc and ^{129}I contribute most of this dose rate because they each have a long half-life. For the deep disposal facility option, the Rub' al Khali region (the empty quarter) was the selected location, and the resultant direct dose rate to a member of the public from fission products is 0.12 mrem/y. Another option is to ship the spent fuel abroad for reprocessing which would reduce the amount of radioactive waste disposed of in Saudi Arabia. The proposed reprocessing facility for this option is the La Hague fuel reprocessing plant in northern France. The final option is to store the spent fuel in dry casks, and the site proposed for this option is the Bryman region. Dry casks often are used when there is no long-term disposal facility available. It is assumed, however, that there is no need to build a dry cask storage facility in Saudi Arabia due to the favorable characteristics of potential long-term disposal sites.

IO-017

Radiation detection and nuclear security

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Abstract

Global interest in strengthening nuclear security and combating nuclear terrorism has increased with the global increase in the peaceful applications of nuclear and radioactive materials. The increase in the use of nuclear and radiological materials requires strict security measures to prevent theft and illicit trafficking of these materials and to protect their facilities. Radiation detection techniques are considered one of the most important measures necessary to achieve nuclear security and confront nuclear terrorism. This presentation discusses the most important concepts of nuclear security and presents the most important radiological detection techniques used in this field.