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European Radiation Protection Week 2024

Aurelia Auditorium Congress Center
Rome, November 11-15, 2024

ABSTRACT BOOK

Edited by
C. De Angelis, S. Della Monaca, P. Fattibene,
S. Grande and A. Rosi

ISTITUTO SUPERIORE DI SANITÀ

Conference

European Radiation Protection Week 2024

Aurelia Auditorium Congress Center
Rome, November 11-15, 2024

ABSTRACT BOOK

Edited by
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European Radiation Protection Week (ERPW) is an annual event organized under the Consortium of European Radiation Research Platforms (MEENAS), bringing together experts to discuss various aspects of radiation protection. The conference aims to foster an environment for presenting scientific findings, promoting knowledge sharing and discussing current and emerging issues in radiation protection research. It also provides a platform for exchanging ideas and establishing connections. The ERPW meeting series is endorsed by several international organizations within the MEENAS Group, including MELODI (Multidisciplinary European Low Dose Initiative), EURADOS (European Radiation Dosimetry Group), EURAMED (European Alliance for Medical Radiation Protection Research), NERIS (European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery), ALLIANCE (European Radioecology Alliance) and SHARE (European Platform for Social Sciences and Humanities in Ionising Radiation Research). ERPW 2024 is organized by the Istituto Superiore di Sanità (ISS) in Rome, in collaboration with the Italian Association of Radiation Protection (AIRP).

Key words: Radiation protection; Ionizing radiation; Radiation dosimetry

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La European Radiation Protection Week (ERPW) è un evento annuale organizzato sotto il consorzio delle piattaforme europee di radioprotezione (MEENAS), che riunisce esperti per discutere vari aspetti della radioprotezione. La conferenza mira a creare un contesto favorevole per la presentazione di risultati scientifici, favorire la condivisione delle conoscenze e discutere le questioni attuali ed emergenti nella ricerca sulla radioprotezione. Costituisce inoltre una piattaforma per lo scambio di idee e la creazione di collaborazioni. La serie di incontri ERPW è supportata da diverse organizzazioni internazionali all'interno del Gruppo MEENAS, tra cui MELODI (Multidisciplinary European Low Dose Initiative), EURAD OS (European Radiation Dosimetry Group), EURAMED (European Alliance for Medical Radiation Protection Research), NERIS (European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery), ALLIANCE (European Radioecology Alliance) e SHARE (European Platform for Social Sciences and Humanities in Ionising Radiation Research). L'ERPW 2024 è organizzata dall'Istituto Superiore di Sanità (ISS) in collaborazione con l'Associazione Italiana di Protezione *Radiologica (AIRP).*

Parole chiave: Radioprotezione, Radiazioni ionizzanti, Dosimetria delle radiazioni

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PROGRAMME

Tuesday, 12 November 2024

8.30 Registration

9.30 Opening session

9.45 Plenary Lecture
Facing the Challenges of NORM: Strategies for Radiological Protection
Cristina Nuccetelli

Session 1
CURRENT SCIENTIFIC DEVELOPMENTS AND CHALLENGES FOR THE APPLICATION OF ENVIRONMENTAL RADIOLOGICAL PROTECTION

10.15 *Science-based evolution of the ICRP reference animals and plants approach*
Jacqueline Garnier-Laplace

10.35 *Current status of ICRP Task Group review of the potential role of ecosystem services in environmental radiological protection*
Marie Simon-Cornu

10.55 *Considering the environment when applying the system of radiological protection*
Christelle Adam-Guillermin

11.15 Coffee break

11.45 *Addressing environmental radiological protection in the framework of reasonableness and tolerability*
Thierry Schneider

12.05 *Atmospheric Be-7: its importance in radioprotection, environmental physics, and space weather. Data collected and preliminary analysis*
Alessandro Rizzo

12.17 *Analysis and prediction of radionuclides effects in ecosystems at multiple scales*
Frédéric Alonzo

12.29 *AOP in the context of radioecology: challenges and insights*
Sandrine Frelon

12.45 MELODI awards

13.15 Lunch

Session 2A
RADIATION PROTECTION IN MEDICAL APPLICATIONS (I)

14.15 *Streamlining the determination of Diagnostic Reference Levels per clinical indication (DRLsci) for computed tomography at hospital CUF Santarém, Portugal*
Diogo Madaleno

14.27 *Context-aware software for education and training*
Mahta Mazloumi

14.39 *Assessment of patient's awareness and knowledge of radiation dose and risks associated with dental radiography and computed tomography: a questionnaire based study*
Salome Kiparoidze

14.51 *A validated, vendor-independent, automatic tool for patient size-specific-dose-estimate calculation in adult abdomino-pelvic CT*
Eric Pace

15.03 *Automatic reconstruction of patient-specific whole-body CT*
Isidora Sofía Muñoz Hernández

15.15 *The IRIDE project for personalized retinoblastoma treatment with brachytherapy*
Micol De Simoni

15.27 *Virtual training helps radiation protection: a free tool for interventional staff*
Hugo de las Heras Gala

15.31 *Investigation and feasibility study of a new compact X-ray dark-field imaging setup and corresponding image analysis and optimization*
Xiaolei Yan

Session 2B
PLANNED AND EXISTING EXPOSURE OF WORKERS DUE TO ARTIFICIAL RADIATION IN NORMAL OPERATIONAL CONDITIONS

14.15 *What do we need to use the full range of ICRU Report 95?*
Rick Tanner

14.35 *An artificially intelligent system for defect detection in leaded personal protective equipment*
Niamh Belton

14.47 *Fitness-to-work and occupational exposure to ionizing radiation: Criteria for the evaluation in workers with neoplastic diseases*
Giulia Castellani

14.59 *A different method for assessing electric field exposure in hospital environments*
Riccardo Di Liberto

15.03 *Occupational radiation received by orthopaedic surgeons and risk to workers*
Stephen Barnard

15.07 *Design of environments dedicated to the handling of unsealed sources and the production od radiopharmaceuticals*
Gian Marco Contessa

15.19 *An estimation of the value of a man Sievert*
Andreas Engström

15.23 *Multifunction air-radiation monitoring system suited for early warning as well for environmental surveillance*
Maurizio Salmi

Session 2C
ADVANCES IN PREVENTING AND MANAGING EXPOSURETO RADON AND NORM

14.15 *Radon risk communication: lessons for radiation protection*
Tanja Perko – (Invited speaker)

14.35 *Comparative analysis of end-users' perceptions of the reuse of NORM-contained by-products in building materials*
Nazanin Love

14.47 *NORM database in the Regulatory Italian framework*
Sonia Fontani

14.59 *Considerations of necessary modification of existing waste disposal and recovery options when applied towards NORM*
Hubert Makuła

15.11 *Characterization of the FYCDY-P30 electrostatic collection chamber for measurements of Rn-220 and Rn-222 at ENEA INMRI laboratories*
Antonio De Donato

15.23 *Radon exhalation campaign to estimate greenhouse gas emissions using the "Radon Tracer Method" - JRC-Ispra*
Serena Mancini

15.35 *Evaluating the impact of citizen science projects in the field of radiation protection: the radon case*
Mabel Akosua Hoedoafia

15.47 *Perceptions, performances and presentations of radon in health spas*
Robbe Geysmans

15.40 Poster session P1 and Tech Sharing Corner

16.20 Coffee break

Session 3A
RADIATION PROTECTION IN MEDICAL APPLICATIONS (II)

16.50 *Foetal dose estimation in pregnant patients undergoing CT examinations using different dose calculators*
Eszter Kolozsi

17.02 *Therapeutic ^{131}I dose for hyperthyroidism treatment of unifocal autonomy in compliance with Council Directive 2013/59/Euratom optimization principle*
Cristina Canzi

17.14 *Development of an AI-powered virtual assistant for radiation dose management in pregnant patients undergoing CT and X-ray guided interventional procedures*
John Damilakis

17.26 *Main achievments of the HARMONIC Project - Health effects of cArdiac fluoRoscopy and MOderN radIotherapy in paediatriCs*
Isabelle Thierry-Chef

17.38 *Comparative analysis of effective doses for children undergoing chest CT examinations: photon-counting vs energy integrating detector CT*
Patrizia Kunert

17.50 *A national pilot project for the implementation of clinical audit indicators in interventional radiology*
Monica Cavallari

18.02 *Radiobiological kidney protection: assessing the effect of diffrent coadministration schedules with human recombinant antioxidant rA1M and ^{177}LU-octreotide*
Nishte Rassol

18:06 *Proposal of a new approach for molecular radiotherapy dosimetry*
Elena Solfaroli Camillocci

18:10 *Assessment of the current CT protocols in use for oncological imaging in Slovenian hospitals: iViolin project*
Nadin Abualroos

18.14 *Assessment of dental radiography quality assurance practices among dental offices equipped with intraoral X-ray devices in Georgia*
Davit Nadareishvili

18.18 *A free and open-source semi-automated quality control workflow for planar X-ray images designed for integration into QATRACK+*
Clarissa Attard

Session 3B

DOSIMETRY IN EXTREME SITUATIONS: HIGH DOSE RATES, MIXED FIELD, LOW DOSE RATES, UNKNOWN RADIATION FIELDS

16.50 *Dosimetry in extreme situations: radiological emergencies and armed conflicts*
Clemens Woda

17.10 *Radiation protection in the experimental hall of the Elettra storage ring*
Arianna D'Angelo

17.22 *RENEB Interlaboratory comparison - biological dosimetry for doses higher than 2.5 Gy*
Martin Bucher

17.34 *Radiation protection and safety for the EuPraxia@SPARC_LAB project*
Raffaella Donghia

17:46 *Calibration of dosimetric instruments in Poland*
Alicja Jakubowska

17.58 *Preliminary beam dump design related to the Frascati Laser for Acceleration and Multidisciplinary Experiments (FLAME) installation upgrade*
Federico Chiarelli

18.10 *Testing different luminescence measurement protocols for display glass as an accident dosimeter*
Michael Discher

18.14 *An interlaboratory comparison on EPR on tooth enamel within the EURADOS WG10*
Sara Della Monaca

Session 3C
DOSIMETRY OF MEDICAL OPERATORS

16.50 *Proton Therapy – Specific radiation protection issues*
Agnieszka Szumska

17.02 *Impact of clinical workloads on shielding evaluation in interventional radiology*
Michelangelo Biondi

17.14 *Development of a preadsheet for calculating barrier thickness for radiotherapy bunker*
Andrea Guasti

17.26 *Radiation dose monitoring data analysis to estimate radiological risk allowance for interventional radiology staff*
Eleonora Bortoli

17.38 *Exposure to activated air and walls of clinical staff in proton therapy centers*
Gonzalo García-Fernández

17.50 *Occupational Radiation Exposure of medical staff involved in ERCP*
Satoru Matsuzaki

Wednesday, 13 November 2024

9.00 Plenary Lecture
New insights in leukaemogenesis
Christophe Badie

Session 4
DEBATE: FUTURE APPROACHES FOR LOW DOSE RESEARCH

9.30 *Can sequencing technology lead us into a hidden garden of radiation research?*
Niwa Ohtsura

9.40 *Challenges in assessing transgenerational effects of low dose radiation exposure using whole genome sequencing*
Arikuni Uchimura

10.00 S*trategies and technologies for elucidating the biological effects of low-dose radiation*
Kensuke Otsuka

10.20 Round table and open discussion

11.00 Coffee break

Session 5A
BIOLOGICAL AND HEALTH EFFECTS OF LOW DOSE EXPOSURE (I)

11.30 *Investigating persistence of radiation damage in haematopoietic stem cell subpopulations induced by direct irradiation or by bystander signals*
Katalin Lumniczky

11.42 *Sex driven effects of osteoimmunogenic cells after low-dose irradiation*
Lena Winterling

11.54 *Biologically-based assessment of minimum latency time between radiation exposure and cancer*
Markus Eidemüller

12.06 *Effects of low-dose radiation on senescence in the context of aging and associated risks disease*
Dmitry Klokov

12.18 *PLEASE MIND THE GAPS! How AOP approach for radiation-induced CVD strengthen the role of biology in radiation protection?*
Omid Azimzadeh

Session 5B
EXPOSURE OF MEMBERS OF THE PUBLIC AND ENVIRONMENT WITH REGARDS TO LEGACY, WASTE MANAGEMENT AND DECOMMISSIONING ISSUES

11.30 *Estimation of nearfield inhalation doses from decommissioning of contaminated buildings*
Sreeyuth Lal

11.42 *Clearance levels bureaucracy and radiation protection*
Alfonso Maria Esposito

11.54 *Drone-gamma: unmanned airborne vehicle for remote detection of gamma-emitting radionuclides*
Javier Guillén

12.06 *Evidence of contamination of the Urdzhar district of Abai, Kazakhstan, from the Chinese nuclear weapons testing program at Lop Nor*
Richard Harbron

12.18 *Statistical analysis of the sampling grid for the radiological Characterization of a site*
Carlo Sabbarese

11.30 Tech Sharing Corner

12.30 Poster session P2

13.00 Lunch

Session 6A
BIOLOGICAL AND HEALTH EFFECTS OF LOW DOSE EXPOSURE (II)

14.00 *Exploring the systemic impact of ionizing radiation: miRNA changes in blood-derived extracellular vesicles and their cell-specific effects*
Simone Moertl

14.12 *Effects of acute and chronic irradiation on the hippocampus in apolipoprotein E deficient mice*
Francesca Antonelli

14.24 *Neutron biological effectiveness: tackling variations as a function of incident energy and depth in a human-sized phantom*
Giorgio Baiocco

14.36 *Transcriptional radiation response signature of human skin*
Lourdes Cruz-Garcia

14.48 *Implementation of the cytokinesis block micronucleus assay for biodosimetry purposes at NRPI*
Jakub Vávra

14.52 *Low dose radiation bystander effects through IGFBP5, a component of the senescent cell secretome*
Domenico Aprile

14.56 *Tritiated micro-particles: computational dosimetry and analysis of radiobiological* in vitro *data*
Alice Mentana

15.00 *Evaluation of DNA damage and genetic instability in interventional radiologists*
Dominika Kochanová

15.04 *Cytogenetic analysis in peripheral blood lymphocytes of patients exposed to low dose ionizing radiation in fluoroscopically guided interventional procedures*
Dimka Georgieva

15.08 *Radiation signature in plasma metabolome of total-body irradiated nonhuman primates and clinical patients*
Ales Tichý

15.12 *Dose-effect relationships of dicentric formation determined by fully- & semi-automated dicentric evaluation using different DCScore classifiers after 3 h or 24 h colcemid treatment*
Christina Beinke

Session 6B

EXPOSURE OF MEMBERS OF THE PUBLIC, WORKERS AND ENVIRONMENT FOLLOWING A MAJOR NUCLEAR OR RADIOLOGICAL ACCIDENT OR INCIDENT OR MALEVOLENT NUCLEAR OR RADIOLOGICAL ACT (I)

14.00 Strengthening Ukraine's health sector capacity to respond to nuclear emergencies
Kenbayeva Zhanat

14.20 *Balancing small modular reactor emergency preparedness with the importance of traditional food consumption in the Canadian north*
Luke Lebel

14.32 *Inter-comparison exercise within the NATO Project BIOPHYMETRE*
Antonella Testa

14.44 *Thyroid cancer incidence risk in the residents around the Semipalatinsk nuclear test site, Kazakhstan*
Evgenia Ostroumova

14.56 *Assessment of uncertainties and errors in post-Chernobyl dosimetry*
Vladimir Drozdovitch

15.08 *Risk of haematological malignancies in Gomel and Mogilev regions of Belarus after Chernobyl fallout*
Ljubica Zupunski

15.20 *Atmospheric transport and deposition of radon-222 and its progeny using flexpart*
Jens Peter Frankemölle

Session 6C

PATIENT MEDICAL DOSIMETRY

14.00 *Improving out-of-field dosimetry in modern radiotherapy: insights from EURADOS WG9*
Marie Davídková

14.20 *Feasibility of a novel video frame interpolation algorithm for radiation dose reduction in the catheterisation laboratory using AI-generated synthetic angiographic images*
Paddy Gilligan

14.32 *EURADOS roadmap for internal dosimetry in radiopharmaceutical therapy: vision towards dosimetry-based prescription*
Ramona Bouwman

14.44 *Assessment of effective dose conversion coefficients for categories of radiological and nuclear medicine examinations: an Italian MoH-ISS project*
Osvaldo Rampado

14.56 *Age and biological sex influences the biodistribution and dosimetry of ^{131}I in Sprague Dawley rats*
Anja Schroff

15.08 *A Monte Carlo calculation of cumulative radiation dose from multiple imaging modalities in paediatric interventional cardiology*
Angelo Giannone

15.12 *A dosimetric evaluation of gynaecological cancer patients undergoing HDR brachytherapy using a Cobalt-60 source*
Chris Doudoo

15.16 Poster session P3 and Tech Sharing Corner

16.00 Coffee break

Session 7A

PIANOFORTE - BUILDING A COLLABORATIVE FUTURE FOR RP: INTEGRATING COMMUNITY EFFORTS AND OPEN CALL SUCCESSES

16.30 *PIANOFORTE - Building a collaborative future for radiation protection integrating community efforts and open call successes*
Jean-Christoph Gariel

16.50 *How the processes of prioritisation, selection of call topics and review of proposals are developing and evolving*
Filip Vanhavere

17.10 *The SONORA Project: towards safe optimized and personalized radiology and radiotherapy procedures for pregnant patients (PIANOFORTE 2013-15)*
Francesca De Monte

17.18 *DISCOVER: Dissecting radIation effectS into the Cerebellum micrOenVironmEnt driving tumour pRomotion*
Simonetta Pazzaglia

17.26 *Synergy between IMMPRINT and IMAGEOMICS projects to improve breast cancer patient health and safety*
Géza Sáfrány

17.34 *ImPRovements in atmospheric dispErsion moDellIng and proteCTive action strategies in case of nuclear detonations – The PREDICT Project*
Clemens Woda

17.42 *LuTADose: Personalized dosimetry to improve the clinical outcome of prostate cancer patients treated with $^{177}Lu/^{225}Ac$-PSMA targeted therapies*
Michel Koole

17.50 *Preliminary results from the first year of the research project PIANOFORTE: CITISTRA*
Jan Helebrant

17.58 In vivo *patient-specific real-time dosimetry for adaptive radiotherapy (VERIFIED). WP1 - Development of Anthropomorphic Phantoms (PIANOFORTE)*
Luana de Freitas Nascimento

18.06 *A vision for "FAIR" data and infrastructures in radiation protection*
Liz Ainsbury

Session 7B

EXPOSURE OF MEMBERS OF THE PUBLIC, WORKERS AND ENVIRONMENT FOLLOWING A MAJOR NUCLEAR OR RADIOLOGICAL ACCIDENT OR INCIDENT OR MALEVOLENT NUCLEAR OR RADIOLOGICAL ACT (II)

16.30 *Evaluate the radiological dispersion devices consequences through numerical simulations*
Andrea Malizia

16.42 *Modelling the effect of counter-measures on radiological assessment*
Mario Gaspar Quarenta

16.54 *Framework for localization of atmospheric contamination source with neural networks*
Anna Wawrzyńczak-Szaban

17.06 *Characterization of using a portable OSL/IRSL reader for in situ dose assessments of NaCl pellets*
Maria Karampiperi

17.18 *Enhancing EPR through comprehensive theoretical and practical training programs*
Benjamin Zorko

17.30 *The hazard assessment for the Italian national plan for the management of nuclear and radiological emergencies*
Silvia Scarpato

17.42 *RescEU CBRN strategic reserve in Finland*
Maarit Muikku

17.54 *Methodology for evaluating radiological consequences from attacks on spent fuel dry casks*
Luke Lebel

18.06 *Theoretical study on physiochemical properties and dispersion of radioactive particles/aerosols and their effect on minimum detectable dose in exposed humans for European spallation source releases*
Belikse Ramljak

18.10 *Mapping radiation in Italy - An innovative model for monitoring and alarm*
Riccardo Quaranta

18.14 *Efficiency analysis and detection limits of HPGe detectors in drinking water monitoring*
Jonathan Sundström

18.18 *OpenRadiation: a collaborative project for radioactivity measurements in the environment by the public*
Jean-Marc Bertho

18.22 *Strengthening the EU capability in CBRN protection with the design of novel laboratories for RN identification*
Giada Gandolfo

18.26 *Novel approach to mitigate the scanning orientation effects in radiochromic film dosimetry*
Hassna Bantan

Session 7C

REDUCING SCIENTIFIC AND SOCIETAL UNCERTAINTIES RELATED TO RADON AND NORM

16.30 *Advances in risk management of Radon & NORM through the RadoNorm project*
Warren John

16.50 *Radon biology - past, present and future*
Maria Gomolka

17.10 *Lung cancer mortality attributable to residential radon in Germany*
Felix Heinzl

17.22 *Pathogenic timeline and radiation risk in radon-exposed rats for lung cancer and its histological types from multi-stage clonal expansion models*
Stefania Trentin

17.34 *The effect of asthma and COPD on the radiation burden of the bronchial airways*
Peter Füri

17.46 *Parameter uncertainty analysis of the effective dose for intake of Radon progeny in underground mines using INTDOSKIT tool*
Thomas Makumbi

Thursday, 14 November 2024

9.20 Plenary Lecture
From protection to participation: the role of ART in radiation protection and oncology
Vincenzo Valentini

Session 8
ROUND TABLE: SITUATION IN UKRAINE

9.50 *Disinformation as the major threat in nuclear and radiation research: Ukrainian experience during the full-scale invasion of Russia*
Olena Pareniuk

10.10 *How the war in Ukraine has affected the ALLIANCE Platform field of research*
Rodolphe Gilbin

10.15 *How the war in Ukraine has affected the EURADOS Platform field of research*
Vadim Chumak

10.20 *How the war in Ukraine has affected the EURAMED Platform field of research*
François Paris

10.25 *How the war in Ukraine has affected the MELODI Platform field of research*
Balàzs Madas

10.30 *How the war in Ukraine has affected the NERIS Platform field of research*
Paulo Nunes

10.35 *How the war in Ukraine has affected the SHARE Platform field of research*
Yevgeniya Tomkiv

10.40 Discussion

11.00 Coffee break

Session 9

BEYOND THE SILO: UNION PROGRAMMES AND PRIORITIES THAT INTERSECT WITH RADIATION PROTECTION RESEARCH AND HOW TO PUT SYNERGIES INTO PRACTICE

11.30 Introduction: *ERPW: connecting radiation protection research. Platform session on EU funding/programme synergies*
Florian Rauser, Domenico Rossetti di Valdalbero, Stefan Mundigl, Ida Cosentino, Daria Julkowska, João H. Garcia Alves, Gianni D'Errico

12.15 Panel discussion with speakers and questions from the session

13.00 Lunch

Session 10A

DEBATE ON SKIN DOSIMETRY

14.00 *Towards an improved computational phantom for skin dosimetry: current status and future directions of EURADOS Task Group 6.3*
Jonathan Eakins

14.25 Panel of discussion
Osvaldo Rampado

14.35 Q&A session

Session 10B

BIOLOGICAL EFFECTS OF LOW DOSE EXPOSURE DURING MEDICAL APPLICATIONS

14.00 *Molecular markers for biological dosimetry in radiation protection, cancer risk assessment and optimization radiotherapy*
Pavol Kosik

14.12 *Biological effects of radiation exposure in patients treated with X-ray-guided endovascular aortic repair*
Tian Yeong

14.24 *Evaluation of oncogenic risk and cumulative dose from radiological investigations in intensive care unit patients: variability between BEIR VII vs RADRAT vs ICRP 103 vs US EPA model risks*
Chiara Zanon

14.36 *Development of novel piperazine derivatives as enhanced radioprotective agents*
Vojtěch Chmil

14.40 *Individual radiosensitivity of breast cancer patients*
Katarína Vigašová

14.44 *Implementation of theranostic system for nuclear medicine application: preliminary biological data*
Ludovica Binelli

14.48 In vitro *study of radiosensitivity in colorectal cancer cell lines associated with Lynch syndrome*
Jayne Moquet

Session 10C
COSMIC RADIATION

14.00 *Long-term radiation signal persistence in urine and blood: a two-year analysis in non-human primates exposed to an acute 4 Gy total body gamma radiation dose*
Evagelia Laiakis

14.12 *Biological effects of chronic low dose rate exposures of neutrons on plants*
Carla Sandri

14.24 *Space radiation dosimetry in aerospace*
Patrycja Baldyga

14.36 *Radiobiological effects of protons or gamma rays and UVB radiation on human cells: implications for radiation protection*
Angeliki Gkikoudi

15.00 Poster session P4 and Tech Sharing Corner

15.30 Coffee break

16.00 EURAMED awards

Session 11
REVOLUTIONIZING RADIATION PROTECTION WITH AI

16.25 *AI in dosimetry*
Filip Vanhavere

16.45 *AI-driven dosimetry: personalizing patient radiation safety*
John Damilakis

17.05 *AI-enhanced image reconstruction and image quality in medical imaging*
Christoph Hoeschen

17.25 *Ethical and regulatory considerations for AI in medical applications*
Hugo de las Heras Gala

17.45 *AI-driven framework for internal dose assessment in radiological emergencies: integration of multiphysics, biokinetics, dose reconstruction, and* in vivo *analysis*
Shaheen Dewji

17.57 *Evaluating the robustness of AI-based models for patient dose optimization in medical imaging*
Giorgia Stendardo

18.09 Closing remarks

Plenary Lectures

FACING THE CHALLENGES OF NORM: STRATEGIES FOR RADIOLOGICAL PROTECTION

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Naturally Occurring Radioactive Materials (NORM) are ubiquitous and when are utilized in human activities may determine exposures, planned or existing, to workers, members of the public and non-human biota of the surrounding ecosystems. Given the considerable presence, scope and diversity of NORM-related exposures, the effective and optimized management of radiation protection remains an open challenge. Since the issuing of the 2013/59/Euratom European Directive and the consequent increase in attention to NORM, significant progress has been made towards unifying and harmonising the radiological protection approach in the Member States of the European Union. However, given the different initial conditions of the Member States, the process is not yet complete, and a major challenge remains the harmonization in both the implementation of the Directive and the practical management of radiation protection in planned and existing situations determined by NORM. In fact, some important aspects still require efforts from the scientific community, such as, just to mention a few, the development of standards and operational protocols for the radiological characterisation of processes for the different types of NORM involving industries and legacy sites, as well as for the estimation of the dose to workers, the members of the public and non-human biota from residues, waste and effluents. Other emerging issues include the need to develop, with an optimised approach, specific clearance levels to clear the large quantities of NORM typically generated during the operational phase of using NORM involving industries or during the remediation of legacy sites. It is also important to note that all these activities can be more effectively developed with the aid of an inventory of NORM industrial activities, which would facilitate a more comprehensive understanding of potential exposures of workers and members of the public. These aspects, along with others not mentioned for the sake of brevity, will be discussed in detail during the presentation.

NEW INSIGHTS IN RADIATION LEUKAEMOGENESIS

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To improve health risk estimates and radiological protection for low dose and dose-rate exposures of Ionising Radiation (IR) encountered in occupational, medical, and public/emergency situations, further research is required. Epidemiological studies provided clear evidence for increased leukaemia incidence following IR exposure even at low doses with Acute Myeloid Leukaemia (AML) being the most prevalent. Animal studies greatly contribute to improve the understanding of radiation-induced AML (rAML). Murine rAML feature both hemizygous chromosome 2 deletions and point mutations (R235) within the haematopoietic regulatory gene Spi1. Analysing 123 rAML, we identified new pathways without Spi1 R235 where the decrease in Spi1 gene expression is negatively correlated with Spi1 promoter DNA methylation at specific CpG sites. Moreover, we generated mouse models to track preleukemic cells *in vivo* to reveal the sequence of molecular events and identify the cell(s) of origin. A new model carrying a hemizygous Spi1 R235C point mutation was developed which confers hypersensitivity to rAML. The increased rAML sensitivity and shortened latency of this model allow to quantify rAML risk at low doses/dose-rates, otherwise prohibited by the high numbers of animals to reach statistical significance. Similar SPi1/PU.1 polymorphisms in humans could lead to IR enhanced susceptibility following medical or environmental exposure. We also identified an epigenetic signature of IR in therapy-related AML patients. Data generated are being used to assemble biologically based risk projection models to evaluate low dose rAML incidence and the role of Hyper-Radiosensitivity (HRS) in rAML by altering the probability of Spi1 mutations occurrence/persistence relevant for human populations. Finally the data generated allowed to rethink the role of IR in radiation leukaemogenesis.

FROM PROTECTION TO PARTICIPATION: THE ROLE OF ART IN RADIATION PROTECTION AND ONCOLOGY

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Radioprotection, by focusing on the codified, monitored, and justified use of radiation, has developed a defensive perspective that is reasonable given the complex history of this technology. From the emergence of late effects, such as secondary cancers, to the industrial use of atomic energy, radioprotection has become a necessity to mitigate the associated risks. However, while radiation use must be closely monitored to ensure the safety of the public, workers, and patients, we must not lose sight of its potential to benefit humanity. In this era of globalization and post-ideology, a crucial question arises: what does it mean to be "human" today? This question is fundamental for all professionals who work with radiation and, consequently, for all of us. As physicians and oncologists, we increasingly observe that illness represents an existential upheaval, bringing forth a deep demand for relationship, which intertwines with the need for timely and effective treatments. In this demand for relationship, there also emerges a search for meaning, which activates a deeper awareness of human potential and transforms illness into an opportunity for new generativity. Failing to recognize this interconnection and focusing solely on performance and protection limits the possibilities for cure and undermines the sense of our mission. Promoting Advanced Radiotherapy (ART) requires not only technical innovation but also the ability to foster broader awareness. Art in healthcare settings, as demonstrated by several pilot experiences (Art4ART), has proven to be a powerful tool in facilitating this humanistic vision. Moving from protection to participation, tied to the human aspect of every technology, becomes an essential pathway to guide regulation and research towards that "beyond" which defines our existence.

Session 1

Current scientific developments and challenges for the application of environmental radiological protection

SCIENCE-BASED EVOLUTION OF THE ICRP REFERENCE ANIMALS AND PLANTS APPROACH

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The framework for environmental radiological protection was established by the ICRP some 15 years ago. Given its relative infancy and the growing societal awareness of sustainable development including nature conservation, there are areas for potential improvement that might be important consideration in the next General Recommendations of the International Commission on Radiological Protection (ICRP). One key improvement is to ensure that our current knowledge of radiation effects on non-human species serves as the foundation of the Reference Animals and Plants (RAPs) approach, while maintaining the approach's suitability and ease of implementation. The ICRP System's graded approach to demonstration of environmental radiological protection (ERP) for planned, emergency and existing exposure situations involves simplifications using ecologically relevant taxonomic groups based on the RAP approach, including the derivation of the Derived Consideration Reference Levels (DCRLs). In this context, the ICRP Task Group 99 (TG99) reviewed existing effects data and methods for deriving effects benchmarks in order to broaden the representativeness of RAPs and provide a flexible, transparent, reproducible and robust approach for demonstrating ERP by technical experts and decision makers (e.g., risk assessors, policy makers, regulators, operators). Statistical extrapolation models, based on transparently selected quality-checked effects datasets, were used to determine the range of radiosensitivity of population-relevant effects (or endpoints) within taxonomic classes or phyla - called the endpoint sensitivity distribution (ESD) - with uncertainties quantified to the extent possible. These ESDs allowed for the derivation of a $DCRL_{ESD}$ for each $RAP_{class/phylum}$ to represent the range of absorbed dose rates at which adverse population-relevant endpoints may occur in organisms of a given group. Discussions on the application of the updated RAP approach, including the current RAPs defined at the family level (RAP_{family}) with DCRL derived solely through critical literature review and expert judgement ($DCRL_{EJ}$), will be presented, notably based on the conclusions of case studies being undertaken by ICRP Task Group 105.

CURRENT STATUS OF ICRP TASK GROUP REVIEW OF THE POTENTIAL ROLE OF ECOSYSTEM SERVICES IN ENVIRONMENTAL RADIOLOGICAL PROTECTION

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Ecosystem services refer to the various benefits humans derive from their environment. The concept of ecosystem services is being explored within International Commission on Radiological Protection (ICRP) Task Group 125 as a complementary supplement to the current approach to environmental radiological protection, the latter of which is largely rooted in the conservation of species. Ecosystem services lies at the intersection of human well-being and environmental health; it is ultimately a strategy or tool for reflecting on and evaluating our connection to, and influence on, our environment and the associated impact to our quality of life. The evaluation of ecosystem services is anthropocentric, but it can contribute to a broader ecosystem approach for environmental protection that includes consideration and recognition of the intrinsic or inherent value of nature. In addition to natural ecosystems, consideration of ecosystem services also specifically allows for inclusion of managed ecosystems, such as agricultural or recreational areas, in environmental decisions. As such, it may potentially be able to provide direct support for "taking into account economic and societal factors" of the optimization principle and contribute to the promotion of sustainable development. The mandate of ICRP Task Group 125 includes providing appropriate definitions and elaborating on the concept of ecosystem services in the context of environmental radiological protection and sustainable development, to specifically include consideration of the practical aspects and examples of application. This presentation summarizes the mandate and current reflections of ICRP Task Group 125 related to ecosystem services with connection to sustainable development

CONSIDERING THE ENVIRONMENT WHEN APPLYING THE SYSTEM OF RADIOLOGICAL PROTECTION

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ICRP Task Group 105 is building on ICRP Publication 124 to review and further develop how environment is integrated into the system of radiological protection. To illustrate how protection principles should apply in the context of both human and non-human exposures and corresponding environmental impacts, several case studies are being examined across planned, existing and emergency exposure situations. TG105 is working closely with other ICRP TGs, including TG99, which is updating the Derived Consideration Reference Levels (DCRLs) for Reference Animals and Plants, taking into account the latest effects data and demonstrating the value in broadening the taxonomic level from that of the family to, for example, class. The taxonomic mapping of species of interest in assessments maybe helped by a shift to broader taxonomic groups although there remain gaps, for example when considering reptiles. Several case studies identified strong environmental protection requirements from the outset, sometimes driven by the presence of co-contaminants, conservation needs or interests by stakeholders, such as indigenous peoples using the environment for traditional purposes. It is also important to recognise that protective actions may result in harm to the environment which should be balanced against the benefits from reducing radiation exposure. Many case studies indicate the need for an integrated approach to assessment that considers a wide range of factors in the short and the long-term including environmental costs/harm and benefits, and social, economic, and ethical aspects. For example, conservation drivers may mean that potential radiological impacts could have more significance for small populations of threatened species. Risk and impact assessment is subject to various uncertainties, for example in the characterisation of the exposure scenarios, data and in the conceptual and quantitative model predictions. TG105 is addressing the different types of uncertainty that may arise in assessments including technical and social uncertainties. Examination of the impact of proposed changes to DCRLs on the outcomes of assessments is ongoing but early findings suggest minimal impact for planned exposure situations. In some case studies involving existing exposure situations, implementing the proposed changes to some of the lower bounds of the DCRLs could potentially lead to different assessment outcomes or protective actions than may be required using the current approach. Protecting the environment is an essential pillar of sustainable development from ecocentric and anthropocentric perspectives. Human health, wellbeing and socio-economic development depend upon on ecosystems that are healthy and perceived to be so. Therefore, environmental radiological

protection is now a well established and explicit part of the radiological protection system. TG105 considers that the environment should be confirmed as the fourth category of exposure alongside public, medical and occupational exposure categories.

ADDRESSING ENVIRONMENTAL RADIOLOGICAL PROTECTION IN THE FRAMEWORK OF REASONABLENESS AND TOLERABILITY

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The terms “reasonableness” and “tolerability” hold significant roles within the framework of the System of Radiological Protection for the evaluation of the protection of people and the environment. In its Publication 138 on the Ethical Foundations of the System of Radiological Protection, ICRP highlighted that the aim of protection is “to do more good than harm, avoid unnecessary risk, establish a fair distribution of exposures, and treat people with respect. In this pursuit, the two concepts of reasonableness and tolerability, although supported by quantitative methods, definitively remain of a deliberative nature”. Current reflections by ICRP Task Group 114, focussed on tolerability and reasonableness, emphasize the importance of reaching a “good” level of protection in the context of the given situation. In evaluating what is “good,” consideration of course needs to be given to individual and societal level of risk associated with ionizing radiation in the context of the prevailing circumstance, but not in isolation. For example, other important considerations include additional hazards that may be present, potential impacts to well-being, quality of life and quality of the environment, and more broadly the application of the sustainable development goals. In this perspective, embarking environmental radiological protection emphasizes the importance of promoting a holistic approach with due consideration of the relevant criteria to characterise the quality of environment and to further develop the process of deliberation to reach a desirable level of protection for people and the environment, while taking the prevailing circumstances into account. Interestingly, studies performed in Fukushima after the accident highlight that most non-human species exposures of are below the derived consideration reference levels (DCRLs) adopted for environmental protection. Only a few values were observed above the upper limit of DCRLs, but this was for a limited period. Thus there are unlikely to be meaningful impacts on species’ biodiversity or reproduction. On the other hand, the residual contamination in areas affected by the accident induces disturbances in the socio-economic activities (i.e. modification of agriculture production, restrictions on access to forests, impact on fisheries, waste management strategies including recycling of soils…). In addition, the implementation of some protective measures to reduce the contamination also had indirect impacts on the quality of the environment. This presentation will address the challenges for a better integration of environmental considerations in the process of optimisation of radiological protection, relying on the lessons from the Fukushima accident.

ATMOSPHERIC Be-7: ITS IMPORTANCE IN RADIOPROTECTION, ENVIRONMENTAL PHYSICS, AND SPACE WEATHER. DATA COLLECTED AND PRELIMINARY ANALYSIS

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The Be-7 radionuclide is produced in the high atmosphere by cosmic rays through the spallation processes of carbon and nitrogen nuclei naturally present in the terrestrial atmosphere. The cosmogenic origin of this radionuclide implies that the study of its air concentration is of particular interest for various research fields, as radioprotection, space weather and environmental physics. In the radioprotection context, Be-7 has been used since the Chernobyl incident as natural tracer to exclude new atmospheric releases of radionuclides such as Cs-137. In environmental physics, the study of the Be-7/Pb-210 air activity concentration ratio provides important information on atmospheric mixing dynamics, as these two radionuclides are produced respectively above and below the mixing layer. Finally, the Be-7 atmospheric concentration variation over different time scales is directly influenced by space weather, which is driven by solar activity. The ENEA Laboratory for Environmental Radioactivity Monitoring (IRP-AMB) samples air particulate daily at three collection points around the Casaccia Research Center near Rome. This study presents the data on airborne Be-7 concentration from the collected samples (cellulose filters) as measured by gamma spectrometry at various temporal scales, ranging from daily to monthly data. The data collected and their preliminary analysis, in the context of radioprotection, environmental physics, and space weather, are presented and discussed.

ANALYSIS AND PREDICTION OF RADIONUCLIDES EFFECTS IN ECOSYSTEMS AT MULTIPLE SCALES

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Promising advances have recently been made in the analysis and predictive modelling of radionuclides effects on biota at the suborganismal, organismal and ecological scales. State-of-the-art biomolecular and computational approaches (Adverse Outcome Pathways, Toxicokinetic-Toxicodynamic modelling, Population matrices, *in situ* population genetics, etc.) have significantly improved our mechanistic insight into relationships that link toxicity responses across biological levels. Yet, major knowledge gaps continue to hinder the prediction of ecosystem-level effects (i.e., biodiversity, community dynamics, ecological functions) and the ability to extrapolate between species. One of the reasons is that approaches at different scales have remained largely separate. In this situation, experimental data sets, simultaneously covering different biological levels, are needed to fill the gaps and capture the entire phenomenon of toxic effects. To address this major challenge, integrative indices of toxic damage, physiological status, and reproductive success (DNA alterations, energy content, genetic fluxes, for example) should be quantified at organism and population scales. At large spatial and temporal scales, ecological responses are governed by global drivers of environmental change, such as multipollution and global warming. In this context, suborganism- and organism-level responses to radionuclides need to be investigated in interaction with other components of environmental change, including chemical contaminants and thermal stress. Current ecological risk assessments of chemical and radiological mixtures are scarce and usually based on the assumption that toxic effects (measured in single-species tests) are additive between separate contaminants. However, this assumption remains to be validated, both at organism level in single-species experiments and at a community level in multiple-species experiments. In particular, indirect effects through trophic interactions are rarely addressed due to practical issues in multiple-species experiments (low repeatability and statistical power, dosimetry etc.). Indirect effects could be investigated in small-scale tritrophic systems, where effects on community dynamics are studied in three interacting species. These standardized multiple-species systems could provide the required balance between adequate simplification and essential complexity.

AOP IN THE CONTEXT OF RADIOECOLOGY: CHALLENGES AND INSIGHTS

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The definition of reference levels for radiological protection of the environment is dependent on the methodologies and applicability domains considered by the relevant expert groups (ICRP, IAEA, ERICA European Consortium). However, these methodologies share common limitations regarding the derived reference levels, mainly due to the use of available data, coming from laboratory experiments with the observation of biological endpoints that are not necessarily representative of the wildlife chronically exposed to various sources and levels of ionising radiation. Furthermore, the potential presence of other pollutants and stressors (abiotic parameters, etc) that interact with radionuclides makes it challenging to assess the risk to wildlife in realistic exposure scenarios. The Adverse Outcome Pathways (AOP) framework appears to be a valuable tool that helps to structure a sequence of causally linked events at different biological levels (Molecular Initiating Event, Key Events (KE), and Adverse Outcome (AO)). In the context of ecological risk assessment, AOP provide a way of linking molecular data, usually obtained in laboratory conditions, to ecological levels, i.e., community and ecosystem, for which the definition of relevant key events is still challenging. In addition, AOP networks can be proposed to help to compare effects between different types of stressors; to deconvolute biological effects in the context of exposures to multiple stressors. AOP provides an efficient summary of existing data through a clear and standardized framework accessible via the open access database AOP-KB, shared by research and regulators communities. This work proposes a review of the challenges of developing AOP for radioecology. A few guidelines are proposed to overcome some of the identified challenges. These include the assessment of possible relevant ecological endpoints regarding ionising radiation for AOP development, proposal of integrated and multidisciplinary approaches to fuel AOP development, and discussions of AOP applications to inform ecological risk assessment.

Session 2A

Radiation protection in medical applications (I)

STREAMLINING THE DETERMINATION OF DIAGNOSTIC REFERENCE LEVELS PER CLINICAL INDICATION (DRLSCI) FOR COMPUTED TOMOGRAPHY AT HOSPITAL CUF SANTARÉM, PORTUGAL

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Purpose. To streamline the process to establish standardized clinical protocols based on the most frequent Clinical Indications (CI), for Computed Tomography (CT) examinations, was designed by a multidisciplinary team of the radiology department at Hospital CUF Santarém, Portugal.

Materials and Methods. Computed Tomography Dose Index ($CTDI_{vol}$), total Dose Length Product (DLP) were collected and Size Specific Dose Estimate (SSDE) was determined for CT procedures performed on a GE Revolution Ascend, for at least 30 adult standard patients with the following CI: head (trauma, headaches, dizziness, sinusitis); lumbar spine (back pain); chest (Interstitial Pathology (IP), Pulmonary Embolism (PE) and asthma/COPD); abdomen-pelvis (kidney stones, cholecystitis/pancreatitis/appendicitis) and chest-abdomen-pelvis (2 staging protocols and follow-up). The median $CTDI_{vol}$, DLP and SSDE were obtained for each CI and compared with the previous audit results presented at ERPW 2023.

Results. Head CT (dizziness, headache, trauma) $CTDI_{vol}$ [50.7-51.1 mGy], DLP [1033-1140 mGy.cm], SSDE [101-105 mGy]. Head CT (sinusitis) CTDIvol 4.9 mGy, DLP 78 mGy.cm, SSDE 8 mGy. Lumbar Spine (back pain) $CTDI_{vol}$ 12.7 mGy, DLP 443 mGy.cm, SSDE 15 mGy. Chest CT (IP, PE, asthma/COPD) $CTDI_{vol}$ [5-7.5 mGy], DLP [192-471 mGy.cm], SSDE [6-9 mGy]. Abdomen-pelvis (kidney stones, cholecystitis/pancreatitis/appendicitis) $CTDI_{vol}$ [4.4-6.4 mGy], DLP [225-688 mGy.cm], SSDE [5-9 mGy]. Chest-abdomen-pelvis CT $CTDI_{vol}$ [4.2-11 mGy], DLP [384-788 mGy.cm], SSDE [6-11 mGy].

Conclusions. The median SSDE, $CTDI_{vol}$ and DLP were 5-60% lower compared to the previous study. Higher values compared to published international references still exist for some protocols. The preliminary analysis indicates that updating radiological equipment, investigating dose levels, taking corrective actions such as reviewing protocols and raising team awareness on radiological protection have a significant impact on medical exposures. This work will progress to include more protocols and implement this methodology in other CUF Hospitals and clinics.

CONTEXT-AWARE SOFTWARE FOR EDUCATION AND TRAINING

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Purpose. The potential of large-language models in education and training is recently being investigated. The purpose of this study was to develop a software based on a large-language model for continuous education in radiation protection. The software can be used by health professionals to ask questions and receive answers through selected and reliable material. The study was performed in the context of a European project, which develops tools for risk appraisal for detrimental effects of radiation exposure.

Materials and Methods. The software was developed based on the ChatGPT-4 language model (OpenAI, USA). A first Proof of Concept of the software, with fixed technical parameters, and trained on the use of contrast media showed promising results in the provided answers. As a next step, an interface was developed for users to create and train their own data models with selected material, and alter technical parameters (e.g. embedding model, chunk size, similarity cutoff), to identify the accuracy of the provided answers. Two data models were created: Model 1 was trained on the user manual of a Radiation Dose Management System (RDMS) for medical imaging with the purpose of providing answers to questions of RDMS users without the need of manually searching the document. Model 2 was trained on a scientific publication on contrast and radiation dose, to provide context to a reader of the article. The testing of the software included asking each model eighteen relevant questions, which were repeated for the fifteen different combinations of technical parameters. The accuracy of each combination was calculated per model.

Results. Embedding and similarity cutoff had noticeable effects on the performance of the models. Specifically, accuracy ranged between 80-96%, 76%-91%, and 78%-81% for different embeddings, similarity cutoff, and chunk size, respectively. The optimal combination was determined as text embedding-ada-002, similarity cutoff = 0 and chunk size = 5000 for both models, where the majority of the responses were correct and satisfactory (overall performance 96% for Model 1 and 93% for Model 2).

Conclusion. A user-friendly software that can be trained with reliable, scientifically accurate documentation and answer questions in a fast way without the need to search manually for the answer, can potentially save time to health professionals and support continuous education activities.

Limitations. The models were trained on limited training materials.

ASSESSMENT OF PATIENT'S AWARENESS AND KNOWLEDGE OF RADIATION DOSE AND RISKS ASSOCIATED WITH DENTAL RADIOGRAPHY AND COMPUTED TOMOGRAPHY: A QUESTIONNAIRE BASED STUDY

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The number and types of radiological procedures are increasing worldwide. The patient voice and patient experience is important to the radiologist profession as it provides a clear picture of how appropriate services are delivered. The main goal of our study was to find out what kind of perception have the patients about X-ray radiation and how much they need to know about it. We were interested in the attitude of patients towards procedures with two different dose loads. Accordingly, two different questionnaires with similar content were developed, each of which consisted of 9 questions. A total of 233 participants answered the questionnaires. The first questionnaire was intended for patients who underwent dental radiographic procedures, and the second one for computed tomography. The self-assessment of patients who had knowledge about radiation and its effects was significantly dependent on their baseline knowledge. 15.9% and 11.7% of patients in each category, respectively, searched for information via the Internet or mass media. A total of 63.4% of patients involved in dental procedures and only 52% of CT patients felt safe. Regarding the use of protective equipment, only 15.4% of respondents felt safe during CT procedures and 25.9% during dental procedures. Patients who did not feel safe were only 20.8% for CT procedures and 13.2% for dental procedures because protective equipment was not used. In case of CT procedures, 64% of respondents had no information about the received dose, in case of dental procedures - 59%. The patient's radiation awareness is unsatisfactory. For informed consent, it is very important to inform the patient correctly and completely. It is necessary to raise the radiation awareness of patients and provide them with the necessary information in various forms, including using Internet resources and posters.

A VALIDATED, VENDOR-INDEPENDENT, AUTOMATIC TOOL FOR PATIENT SIZE-SPECIFIC-DOSE-ESTIMATE CALCULATION IN ADULT ABDOMINO-PELVIC CT

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Background. Accurate estimation of patient Size-Specific-Dose-Estimate (SSDE) in CT requires accurate contouring of the patient boundary in axial images. Contours must be free of foreign objects, such as the patient couch. Additionally, the patient must fully fit in the scanned field-of-view, i.e. no truncated images should be included in the calculation of the SSDE. As each CT study is composed of hundreds of images, manual contouring and truncation flagging is not feasible. This work sought to provide a full automation of the contouring process, flag truncated images and calculate the Size-Specific-Dose-Estimate as recommended by the American Association of Physicists in Medicine Report 204 (AAPM204). Method. The developed tool used a deterministic image morphological processing pipeline for contouring and truncation flagging using the Python programming language. Validation was performed by four medical physics experts using a 5-point Likert scale on 700 individual images sampled from 368 studies performed on fifteen different CT scanners from three different manufacturers. Results. 98.5% of contoured images were assigned a score of 4 or 5 (5 being perfect) in terms of accuracy of contouring whilst 98.9% of images were correctly flagged with respect to truncation. The average speed for contouring and truncation flagging was 47.6 images per second on a six-core CPU. Conclusion. Validation based on a random sample of images from across CT models and manufacturers showed that the tool is highly accurate in terms of both contouring accuracy and truncation flagging. The speed of processing means that the tool can be operated in real-time on large datasets. The tool may be used within local institutions, hence avoiding image uploads to online systems and attendant data protection issues.

AUTOMATIC RECONSTRUCTION OF PATIENT-SPECIFIC WHOLE-BODY CT

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Radiotherapy is an effective treatment against cancer; however, peripheral dose carries an associated risk of causing a Second Cancer (SC) in organs outside the treatment volume. Reliable estimation of this dose and the SC risk of the treatment requires the whole-body anatomy of the patient. However, in most cases radiotherapy planning Computed Tomography (pCT) contains only limited volume of the patient near the tumour site. IS^{2}aR (Interactive Software for Image Segmentation and Registration) is a simple and user-friendly computational tool that generates synthetic whole-body CTs (wbCT). This tool registers the pCT with the ICRP-110 phantom to obtain a transformation matrix, which is later applied to the ICRP phantom. Consequently, this synthetic wbCT is representative of the patient's size. The aim of this work is to introduce updates to this tool, making it fully automatic with the additional feature of replacing the original pCT in the corresponding region within the synthetic wbCT. This ensures that the whole-body phantom accurately reflects the actual geometry around the tumour. MATLAB, along with the Image Processing and Medical Imaging Toolboxes, was used to implement a graphical user interface. The improved tool automatically: i) estimates the equivalent section of the pCT in the whole-body reference phantom, ii) segments the bones from the pCT, iii) performs a rigid registration between the bones of the pCT and the phantom, and iv) adjusts the position and the pCT is mounted on the phantom based on the first and a second rigid registration. This process results in the final synthetic wbCT of the patient while preserving the known anatomy of the pCT. Visual inspection is used to evaluate the result. The final wbCT maintains the original resolution of the pCT, but both matrix and voxel sizes can be changed by the user before exporting. Additionally, the interface works as a DICOM viewer, allowing the visualization of the organ segmentations along with the dose cube of a RT plan. The wbCTs generated could be used for the personalized calculation of peripheral doses by analytical models or Monte Carlo simulation, thereby advancing in the assessment of the risk of second cancer induction in epidemiological studies.

THE IRIDE PROJECT FOR PERSONALIZED RETINOBLASTOMA TREATMENT WITH BRACHYTHERAPY

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The IRIDE (*Innovative RadIation Dose Estimation for pediatric retinoblastoma treatment enhancement*) project seeks to enhance brachytherapy for pediatric retinoblastoma, an eye tumor, by introducing personalized treatment planning, a currently missing element. Brachytherapy has the potential to preserve the eye, but its optimization demands precise dose estimation and detailed knowledge of radiation sources. The project aims to develop a dose assessment tool based on Monte Carlo (MC) simulations. This tool will enable medical physicists and ophthalmologists to input specific plaque dose profiles, measured with a newly developed experimental setup, along with actual eye images, to determine the optimal plaque position and necessary exposure time. We have implemented and simulated a model of a ruthenium plaque implanted in an eye, based on literature data. The simulation was conducted using the MC Geant4 code, and tests were performed to identify the most appropriate physics models and parameters (Geant4 physics list) to ensure optimal system reproducibility. A computational eye model was used to evaluate the dose delivered to the tumor and surrounding healthy tissues. The average dose delivered to the tumor and adjacent organs at risk (optic nerve and crystalline lens) was estimated, yielding expected results. The IRIDE project aims to improve the application of brachytherapy as the primary treatment option for retinoblastoma by addressing gaps in information regarding the dose absorbed by healthy tissues and the tumor volume. Initial simulations have shown promising results in accurately assessing dose distribution within the eye, representing a significant advancement in personalized retinoblastoma treatment.

VIRTUAL TRAINING HELPS RADIATION PROTECTION: A FREE TOOL FOR INTERVENTIONAL STAFF

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Introduction. Virtual Reality (VR) environments are ideal training tools enabling to perform complex operations in a controlled setting that perfectly simulates a real scenario. Assuming that direct experience provides the most powerful learning effect, we designed, programmed and published a free VR-tool to train in radiation protection staff working in interventional rooms, who are the professionals that are most exposed to man-made radiation.

Materials and methods. An interventional room was recreated as a virtual environment, where a fluoroscopy C-arm and radiation protection equipment can be operated. Thanks to a specifically developed simulation that runs in the background, it is possible to visualize the radiation exposure (organ and effective dose rates) of the user in real time, as well as the exposure reduction when protective behaviour is implemented (e.g. using radiation protective clothing, shielding panels, different frame rates and collimation diameters, or varying distance from the patient or from the X-ray tube). The estimations provide a realistic impression of the protection factors offered by the different measures available. During a training session 30 participants performed a diagnostic coronary angiography with fixed exposure times, testing the effect of using the protective measures, as well as changing their distance to the radiation source and the patient. The session included a fixed VR-tutorial. All participants filled in a survey before and after the 20-minute training session.

Results. A pre-post-comparison showed increased awareness (81%) of the protective factor for the available measures, indicating that short, focused training sessions in the VR-environment are helpful for learning a proper use of radiation protection measures in interventional procedure rooms. The app is now freely available in English and German: http://www.bfs.de/vr-medicine.

Conclusion. The VR application can be used to learn about the effect of shielding and protective behaviour without the need to expose oneself or others to radiation.

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INVESTIGATION AND FEASIBILITY STUDY OF A NEW COMPACT X-RAY DARK-FIELD IMAGING SETUP AND CORRESPONDING IMAGE ANALYSIS AND OPTIMIZATION

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Learning objective. Talbot effect-based X-ray imaging technology demonstrates promising precision in micro-structure detection but relies critically on system composition complexity to reach sufficient spatio-spectral interference coherence. In our work, we aim to provide a simplified, compact X-ray Talbot-interferometry Dark Filed Imaging (DFI) system prototype, which consists of two gratings (one phase grating, one absorption grating) in the beam path, combined energy-resolving detectors with a polychromatic microfocus X-ray source. With such a system prototype, neither a third grating nor monochromatic source is required by X-ray interferometry imaging to expand the experimental applications in laboratory settings and to match the feasibility in clinical.

Methods. The experimental investigation of the proposed setup was implemented by scanning a metallic screw with a 0.5 mm thread pitch, which distributes small-angle scattering for DFI. To match the design energy of phase grating for maximum amplitude modulation, we optimized the photon spectrum by incorporating 2 mm aluminum and 1 mm iron as filters to Microfocus X-ray tube at 40 kV. We utilized the phase-scanning approach for experimental measurements. To reconstruct the micro-structured screw images in different modalities (attenuation, phase, and visibility contrast (domination of dark field image)), we employed the curve-fitting methods for each pixel to acquire Fourier Series coefficients and consequently compute image signals.

Results. We figured the matching ratio of visibility values between the measurement data obtained from the proposed setup and the simulated Talbot patterns in the Matlab platform by applying weighted photon energy aligned with the experimental spectrum. We analyzed the DF image Contrast-to-Noise Ratio (CNR) across different reconstruction conditions and found comparable CNR values. We optimized the reconstructed images through various conditions, including BIN of Interest (BoI) selection, comparison of original and slightly transformed fitting equations, poor fitting studies, and histogram analysis of images.

Conlusion. We validated the proposed DFI system prototype and achieved the initial research objective. The optimized DF image demonstrated better edge differentiation of fine structure than both attenuation contrast and phase contrast images, which shows promising potential feasibility for expanding the application in laboratory settings.

SRA AND ROADMAPS FOR RADIATION PROTECTION METROLOGY

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EURAMET EMPIR 19NET03 supportBSS project *Support for a European Metrology Network (EMN) on reliable radiation protection regulation*, started in June 2020 and completed in May 2024. One of the tasks of the supportBSS project was the preparation of a Strategic Research Agenda (SRA) based on the identified metrology needs to support the European legislation and regulation in Radiation Protection, and of two Roadmaps for metrology services and capabilities, one under the European Council Directive 2013/59/EURATOM and the other under the EURATOM Treaty. The preparation of the SRA started with a literature review based on the analysis of the SRAs of the MEENAS Radiation Protection platforms and of strategic documents from other relevant organization such as IAEA, BIPM-CCRI, HERCA, EURAMET, among others. Information was also collected from the stakeholders at different stages of the project, through the organization of workshops, as well as by way of a questionnaire that circulated addressing specific questions for metrology laboratories and specific questions for stakeholders from the different fields of activity. It is the aim of this paper to present the first SRA and Roadmaps produced as outputs of the supportBSS project. Taking into account the technological

developments in the field it is foreseen the European Metrology Network for Radiation Protection will need to revise these documents for update in the forthcoming future.

Project 19NET03 supportBSS has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

THE CONTRIBUTION OF THE IONISING RADIATION METROLOGY LABORATORY TO LEGAL METROLOGY IN PORTUGAL

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The Ionising Radiation Metrology Laboratory (LMRI) is part of the Laboratory for Radiation Protection and Safety (LPSR) of Instituto Superior Técnico (IST) at the University of Lisbon (UL). LMRI ensures ionising radiation (IR) metrology in Portugal since 1989. LMRI is appointed by Instituto Português da Qualidade (IPQ), the National Metrology Institute (NMI) as Designated Institute for IR. LMRI is also a member of the IAEA/WHO SSDL Network, of the EURAMET's Technical Committees for IR and for Quality, as well as of the European Metrology Network for Radiation Protection (EMN-RP). A Quality Management System based on the EN NP ISO/IEC 17025 standard is implemented at the laboratory and its facilities and activities are licensed by the Portuguese Regulatory body. LMRI is responsible for ensuring traceability to the SI, for the maintenance of national standards, for providing calibration services supported by Calibration and Measurement Capabilities (CMS) registered in the Key Comparison Data Base (KCBD) of the *Bureau International des Poids et Mesures* (BIPM), as well as for education, training and research in radiation metrology and dosimetry. Additionally, IPQ appoints LMRI as responsible for the metrological control of IR measurement devices operating nationwide in the areas of nuclear medicine, radiology, radiation therapy and radiation protection. The enforcement of Council Directive 2013/59/EURATOM through Decreto-Lei n. 108/2018 raised the awareness of licensing and inspecting authorities, as well as end-users to compliance with appropriate standards and to the periodic verification (in the scope of legal metrology) of IR measurement devices. End-users of such devices originate from different fields of activity, e.g. hospitals, clinics, industry, radiation protection companies, NRBQ units of military and defense forces, inspection and regulatory bodies. LMRI has therefore observed a steady increase of requests for the periodic verification and calibration of IR measurement devices. In this paper, the activity of LMRI over recent years will be presented and discussed and its impact to the community will be highlighted.

DEVELOPMENT OF SELF-ASSESSMENT INDICATORS FOR THE IMPLEMENTATION OF A PILOT CLINICAL AUDIT IN INTERVENTIONAL RADIOLOGY

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The Istituto Superiore di Sanità (ISS) together with the Italian Ministry of Health, promotes the creation of periodic evaluation tools (clinical *audits*) to monitor the national patient radiation protection state of the art, in order to ensure the achievement of high safety and quality standards, also in compliance with the Legislative Decree 101/2020 of the Italian law. In this context, a project funded by the Italian Ministry of the Health, led by the ISS and involving six Health Physics structures distributed across the national territory, is active. During the first year, the project's Scientific Committee, made up of multidisciplinary figures, developed 14 clinical self-assessment indicators on 19 interventional procedures among those most widespread in Italy and delivering high doses to the patient. The indicators, based on the logic of Continuous Quality Improvement, were sent, for validation purposes, to 4 Health Physics structures external to the project, to verify their ease of compilation and identify their critical issues. Once validated, the indicators were sent to the pilot project partners who collected the data. A preliminary analysis of data will be presented at the conference.

The project is conducted with the technical and financial support of the Italian Ministry of Health-CCM 2022 programme - "Ottimizzazione dell'esposizione medica a radiazioni ionizzanti: progetto pilota per l'implementazione di audit clinici e prima attuazione dell'art. 168 del d.lgs. 101/2020 in Radiologia Interventistica".

RADIOPROTECTIVE AND RADIOSENSITIZING EFFECTS OF GINGKO BILOBA ON THE HUMAN LYMPHOCYTES AGAINST IONIZING RADIATION AS USED IN RADIOTHERAPY

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Radiotherapy either alone or with chemotherapy and surgery remains an important component of cancer treatment. Different chemical agents were utilizing in order to maximize the effects of radiotherapy but they showed short term and long term side effect during the course of treatment. However, there are very few studies related to plant derived agents who will acts as radioprotective to normal cells and radiosensitizing to cancer cells. Gingko biloba (GB), a phytochemical, has gained importance in the phyto-pharmaceutical industry due to the growing interest in natural compounds for application in preventive medicine. In our study, we investigate the radioprotective and sensitizing effects of GB against high dose ionizing radiation as used in radiotherapy. We evaluated oxidative stress through lipid peroxidation assay, DNA damage through comet assay and apoptosis through FACS in human lymphocytes *in vitro* after treating lymphocytes with different concentrations of GB (10, 50, 100 and 150 μg/ml) before irradiation. Although we didn't find any radioprotective effects from selected lower concentrations but higher concentrations showed damaging effects to normal cells after irradiation. So we are planning to use these higher concentrations of GB against cancer cell-lines to check their radiosensitizing effects against 2 Gy radiation used in radiotherapy. Moreover, we are conducting clinical trials with breast cancer patients during their radiotherapy to investigate possible radioprotective effects of GB.

Acknowledgement: This research work is supported and funded by VEGA 2/0082/23 from Slovakia Republic.

FISH ANALYSIS OF APPARENTLY SIMPLE TRANSLOCATIONS FREQUENCY IN PERIPHERAL LYMPHOCYTES OF VICTIMS OF RADIATION ACCIDENT IN BULGARIA

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Purpose. The purpose of this study is to provide a retrospective FISH analysis over a period of 3 years for detection of stable chromosome aberrations in three victims of a radiation accident that occurred in Bulgaria in 2011.

Materials and methods. Serious radiation accident with very high activity ^{60}Co source (137 TBq) occurred in an industrial sterilisation facility in Stamboliyski, Bulgaria on 14 June 2011. A retrospective FISH analysis was performed on three of victims, one female (patient 1) and two males (patients 2 and 3 respectively) using the peripheral blood lymphocytes collected half to one year after accident and three years later. DNA probes specific for whole chromosomes 1 (green), 4 and 11 (red) were used. The genomic frequency estimation was performed using a total number of Apparently Simple Translocations (AST).

Results. Frequencies of apparently simple translocations detected by FISH in the samples of the three exposed victims decrease slightly for a period of 3 years. We observed 17.5% decrease for patient 1 and 13.8% for patient 2. For patient 3, cells with AST declined by 4.1% 3 years later relative to a half year after accident. The dose assessment by FISH was performed using a calibration curve generated in our laboratory based on the frequency of apparently simple translocations. The estimated absorbed radiation doses one year after accident and 3 years later were 2.97 Gy and 2.68 Gy respectively for patient 1. For patient 2 the estimated doses were 2.29 Gy (1 year after accident) and 2.11 Gy (3 years later). For patient 3, half year after accident the estimated dose was 1.66 Gy and three years later was 1.62 Gy.

Conclusions. Our results showed a decreasing tendency with time for apparently simple translocations frequency detected by FISH in the peripheral blood lymphocytes. The degree of reduction is related to the received dose. The dose estimation by FISH using AST frequency shows no significant reduce over a period of 3 years compared to assessed dose 1 year after accident.

FOCUSING OPTICS FOR HIGH-RESOLUTION X-RAY FLUORESCENCE IMAGING APPLICATIONS

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Purpose. Advanced techniques such as X-Ray Fluorescence (XRF) Imaging (XFI) are emerging as potential *in vivo* biomedical imaging modalities for molecular diagnostic and theranostic applications. For human applications, XFI may reduce radiation burden by achieving the same or much higher low-contrast spatial resolution at optimized dose levels compared to present nuclear medical methods (e.g., PET/SPECT). Furthermore, prior studies suggest XFI may surpass MRI in sensitivity and specificity while achieving comparable spatial resolution. While current benchtop systems, like those using liquid-metal-jet and a multilayer monochromator optic, offer high resolution, they are limited to lighter elements due to inherent constraints arising from the optics and X-ray source. This work investigates the feasibility of using Bragg-reflecting curved-mosaic graphite monochromators to focus hard X-rays from bremsstrahlung X-ray tubes and to achieve sub-millimeter spatial resolution. We explored this concept using Monte Carlo (MC) simulations for the localization of diagnostic or theranostic entities within biological samples and *in vivo* murine models utilizing mid-Z (i.e., elements with atomic number $42 \leq Z \leq 64$) nanoparticle (NP)-based probes.

Methods and Materials. MC simulations were performed using the Geant4 toolkit. The Bragg diffraction process was modeled within Geant4, and other low-energy electromagnetic interactions were implemented using the Penelope model. Multilayer Bragg-reflecting crystallites with mosaic spread (and thickness) combinations of m=0.12° (80μm), 0.24° (100μm), and 0.46° (120μm) were investigated. Tumor-bearing digital mouse models were used, loaded with either multiplexed Palladium (Pd) NPs and Barium (Ba) NPs or singleplex Ba NPs. Six Silicon Drift Detectors (SDDs) were employed. The statistical significance (p=2.868×10^{-5}%) of XRF signals was estimated to provide quantitative predictions on the imaging sensitivity for small-animal imaging scenarios.

Results. Lower mosaicities (m=0.12°) show better spatial focusing, with 600-800 μm transversal FWHM resolution. The detection limit for tumor target sizes of 1.25 mm and 5 mm in mouse abdomen (per scan position) is estimated to be 0.05 wt% and 0.01 wt% Pd, respectively, at a target radiation dose of 0.3 mGy and full-body dose of 0.7 μGy.

Conclusions. The investigated optics concept presents a promising approach for achieving high-resolution XFI with conventional X-ray tubes at low dose levels and high sensitivity. This could be of significant interest for pre-clinical applications that require sub-millimeter resolution, e.g., for studying lesion and healthy tissue characterization using functionalized mid-Z NP-based probes *in vivo* murine cancer models.

USING DEEP LEARNING DENOISING TECHNIQUES FOR LOW-DOSE *IN VIVO* BENCHTOP X-RAY FLUORESCENCE COMPUTED TOMOGRAPHY

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X-ray Fluorescence Computed Tomography (XFCT) is a novel non-invasive imaging method that can deliver high-resolution molecular-level information. This method has the potential for sensitive detection and quantification of trace elements within biological tissues, offering valuable insights into the specific processes and mechanisms underlying disease heterogeneities. As the technology progresses, XFCT promises to achieve detailed molecular images, crucial for advanced medical diagnostics and targeted therapeutic interventions required for clinical applications. However, enhancing sensitivity with existing benchtop X-ray sources requires high radiation exposure to achieve the same level of low-contrast spatial resolution. Artificial Intelligence (AI), especially Deep Learning (DL), has significantly transformed medical imaging by offering automated solutions for noise reduction and improved image quality. In XFCT, conventional methods use intricate algorithms to reduce background noise that can be cumbersome or need substantial user intervention; however, AI offers advantages in automation and potentially better solutions for high-dose issues. Using AI, researchers can develop efficient denoising techniques, reducing the radiation exposure required for high sensitivity imaging. We introduce an enhanced DL model designed to minimize background noise in X-Ray Fluorescence (XRF) images. While numerous denoising techniques are available for X-ray and Computed Tomography (CT) imaging, very few specifically target XFCT. Our DL model is trained and evaluated using augmented datasets, with an emphasis on reducing noise levels from low-dose images. This advancement is crucial for improving image clarity and accuracy in XFCT applications, while minimizing X-ray exposure. Image quality is evaluated using two measurement factors of Peak Signal-To-Noise Ratio (PSNR) and Structural Similarity Index (SSIM). The model is compared with four existing DL models in both visual and quantitative evaluations, especially in high-noise conditions. The findings show that the proposed algorithm produces high-quality images from low-dose inputs, achieving a maximum PSNR of 49.00 and an SSIM of 0.88.

CT OPTIMIZATION FOR STROKE DIAGNOSIS: IS IT ONLY A PROTOCOL REVIEW?

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AIM. Within the regional project SIRDImm of Innovapuglia (POR Puglia FESR/FSE+ 2014/2020) 8 hospitals in Taranto area-ASL TA (Italy) were equipped with a Radiation Dose Management System (RDMS) allowing metadata extraction of CT exams. Since RDMS allows us to identify the most frequent procedures, our first analysis highlighted the stroke procedure as very frequent (up to 300 patients/year) with high patient Effective Dose, often > 10 mSv. Aim of this study was to assess radiation exposure of CT Stroke protocol and progress in optimization process.

Methods. We extracted retrospectively Volume-weighted CT Dose Index (CTDIvol) of 210 CT Stroke procedures, January- September 2024, from 10 CTs installed across ASL TA (GE, Siemens). The Stroke diagnosis involves a multiphase CT: Non-contrast CT (NCCT), Triphasic CT Angiography (CTA) and CT Perfusion (CTP). For each phase we derived median values of CTDIvol using PHYSICO®, RDMS software installed in our departments.

Results. Our results showed comparable median CTDIvol values for NCCT and CTA phases (within international Diagnostic Reference Level), whereas CTP data revealed the highest median $CTDI_{vol}$, 525 mGy, for one Emergency Room (ER) CT due to the lack of Dose Reduction Software (DRS). Indeed, we observed a reduction of $CTDI_{vol}$ to 105 mGy for CTP phase showing the enormous impact on dose when DRS are installed. Protocol adjustments of CT without DRS were investigated and when a significant dose reduction could be achieved, clinical image quality might be easily compromised. Purchasing DRS for all CTs is not always quick to get approved by administration and we proposed in the meantime a different workflow for ER stroke patients when CT with DRS in other departments are available.

Conclusions. Optimization process must be seen not only as a tool to review protocols and reduce radiation dose, but also to improve process and stroke care pathway involving medical exposure.

EFFECTS OF IONIZING RADIATION AND GOLD NANORODS COMBINED TREATMENT ON GLIOBLASTOMA CELLS STUDIED BY MAGNETIC RESONANCE SPECTROSCOPY: A POSSIBLE NUCLEAR MEDICINE THERAGNOSTIC TOOL

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Magnetic Resonance Spectroscopy (MRS) is a non-invasive technique and a powerful tool for studying biological systems *in vitro*. MRS can provide information on cultured tumor cells metabolism, with the aim of gaining a deeper insight into the response of cell to anticancer therapies. In particular, the most relevant metabolic signals (spectroscopic markers) can be identified, variations in which may provide information on the response of tumor cells to different treatments, including ionizing radiation and drug delivery systems based on gold nanorods (AuNRs). AuNRs are attracting great interest in the biomedical field, thanks to their peculiar physiochemical properties and the possibility to easily functionalize the surface with different stabilizing agents. They can therefore offer an important contribution to the field of nuclear medicine, enabling the transport of radiopharmaceuticals for diagnosis, treatment and follow-up of diseases, including tumors. This study focused on characterizing the metabolic profile of glioblastoma tumor cells (T98G) using ^{1}H MRS, to identify key metabolic markers and observe their changes after treatment with ionizing radiation (gamma rays, ^{137}Cs) and AuNRs. ^{1}H MR spectra of intact T98G cell samples were acquired at different times after incubation with AuNRs and subsequent acute dose irradiation (20 Gy). The effects on lipid, energy and glutathione metabolic pathways were observed.

Session 2B

Planned and existing exposure of workers due to artificial radiation in normal operational condition

WHAT DO WE NEED TO USE THE FULL RANGE OF ICRU REPORT 95?

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The operational quantities for radiation protection are specified in legislation, having been recommended in the EURATOM and IAEA Basic Safety Standards. They are defined by the ICRU & were subsequently included in the ICRP Recommendations: most recently ICRP Publications 60 & 103. For external radiations these are: ambient dose equivalent, $H^*(d)$, for measurements of strongly penetrating radiation using instruments; directional dose equivalent, $H'(d)$, for measurements of weakly penetrating radiation using instruments; $H_p(d)$ for measurements of strongly & weakly penetrating radiation using personal dosemeters worn on the body. Conversion coefficients for these quantities are published in ICRU Report 57 & ICRP Publication 74. New operational quantities have been published in ICRU Report 95, which has been endorsed by the ICRP. The new quantities are Ambient Dose; Personal Dose; Directional & Personal Absorbed Dose in the Lens of the Eye; Directional & Personal Absorbed Dose in Local Skin. In addition to the new quantities, conversion coefficients have been published for a much wider range of particles & a broader energy range, with extension to lower energy but more particularly to much higher energies. It is hence widely anticipated that these quantities will be included in the next ICRP Recommendations and subsequent international Basic Safety Standards, with consequent widespread inclusion in national legislation. The implications of these new quantities have been widely analysed, with EURADOS 2022-02 perhaps including the most thorough analysis to date. For operational quantities to be useable, it is necessary for there to be instruments/dosemeters that can measure them and performance standards that define the minimum accuracy requirements for those instruments/dosemeters. Because the new quantities extend to energies/particles not previously considered, currently much of the new data cannot be used. There is a chicken/egg issue to be addressed: how do we design instruments/dosemeters without performance standards, but how do we specify performance standards without instruments/dosemeters to assess? Personal dosemeters & instruments for protons, muons, pions and helium ions will be needed or those conversion coefficients will never be used. This paper hence looks at the areas where we cannot currently use the new quantities and makes an early attempt to work out what steps are required to use them, if it is possible. Innovations in instrument and personal dosemeter design that could help with the application of these quantities are considered along with discussion about the cohorts of workers who could benefit from such advances.

AN ARTIFICIALLY INTELLIGENT SYSTEM FOR DEFECT DETECTION IN LEADED PERSONAL PROTECTIVE EQUIPMENT

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Healthcare professionals working in controlled X-ray environments are routinely exposed to scatter radiation during fluoroscopy, and CT-guided radiological procedures. To minimise occupational risk from potentially harmful radiation exposure, staff must wear lead-equivalent garments as a mechanism of Personal Protective Equipment (PPE). In MMUH, the quality control process for PPE involves a Clinical Specialist Radiographer screening garments with fluoroscopy, or using CT topogram protocol. Acquired images are manually reviewed, and any identifiable defects are measured to determine whether the PPE should be removed from clinical use. This is a time consuming and costly process. This study aims to develop an Artificially Intelligent (AI) system that can 1) automatically detect defects in PPE from fluoroscopy and CT, 2) calculate the area and length of the defect and 3) determine whether the leaded PPE should be decommissioned based on rejection criteria developed by the British Institute of Radiology (BIR). A comparative analysis of the AI system's accuracy on CT versus fluoroscopy will then be conducted. For this analysis, 79 pieces of leaded PPE were scanned with both fluoroscopy and CT with a standardised protocol. This dataset was split into train and test subsets. The training set was used to develop the AI system, while the test set was used to assess the system's performance. The objective of the AI system is to learn the features of PPE that contain no defects. In practice, it can then detect and localise true defects by identifying substantial differences from the learned features of defect-free PPE. The system can then calculate the area and length of the defect based on the system's localisation. This can be used to automatically determine if the PPE should be removed from clinical use. To evaluate the system, an expert reviewed each PPE and determined 1) if there was a defect, 2) the area and length of the defect and 3) if the PPE should be removed from clinical use. The system's output was then compared to the expert, and the system's accuracy and localisation ability was assessed in terms of sensitivity and accuracy. The next step is to compare the system's ability to detect and localise defects from fluoroscopy versus CT.

FITNESS-TO-WORK AND OCCUPATIONAL EXPOSURE TO IONIZING RADIATION: CRITERIA FOR THE EVALUATION IN WORKERS WITH NEOPLASTIC DISEASES

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Introduction. The evaluation of the fitness-to-work of cancer-affected subjects with full recovery or good remission from the disease who need to go back to their workplaces poses several issues, in particular if there is a potential exposure to a carcinogenic agent, such as Ionizing Radiation (IR).

Methods. Based on pertinent scientific literature, the Italian Association of Medical Radiation Protection (AIRM) identifies various elements that must be considered by the medical practitioners in charge for the Health Surveillance (HS) of IR-exposed workers when evaluating the fitness-to-work of cancer-affected subjects.

Results. Four main areas were identified:

1. Characteristics of the neoplastic disease: time after the clinical onset; target organ(s); histological type, grade, stage; prognosis; rank on the radio-inducibility scale; Probability of Causation (PC).
2. Work activities and job-tasks: radiation protection classification; type of potential exposure: global/partial external irradiation, possible internal contamination; PPE used.
3. Worker's Health condition: concomitant diseases; previous/ongoing therapies; psychological conditions; worker's professional qualification, position and career; worker's willingness.
4. Legislation and guidelines.

Discussion. Clinical evaluation and assessment of fitness-to-work are strictly related. AIRM suggests additional important aspects that the practitioners need to consider when carrying on HS of IR-exposed workers. The four main aspects above-mentioned may have different weights in the decision-making process, according to the particularity of the specific cases.

Conclusion. AIRM supports medical practitioners in charge for HS of IR-exposed workers with a list of four main areas of criteria to be considered when evaluating fitness-to-work of cancer-affected workers.

A DIFFERENT METHOD FOR ASSESSING ELECTRIC FIELD EXPOSURE IN HOSPITAL ENVIRONMENTS

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In a hospital environment there are various workers that perform daily procedures with medical devices that emit Electromagnetic Fields (EMF). Those devices include electrosurgical units, diathermy systems for muscle or aesthetic related treatments, and radiofrequency ablation devices. The EMF emitted are generally complex signals, hence – according to ICNIRP and European Union guidelines - exposure assessment must be performed under unperturbed field conditions and using the weighted peak method. Currently, this procedure involves measuring the external emitted field, but real-life measures are in some cases far from being unperturbed. Moreover, the probes used for the electric field are relatively large, and this factor might cause a disturbance when performing a measurement at close contact with the operator's hand. ICNIRP 2010 *Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz)* recommends: *"for a very localized source with a distance of a few centimeters from the body, the only realistic option for the exposure assessment is to determine dosimetrically the induced electric field, case by case".* In addition, only a few commercial instruments are able to directly apply the weighted peak method and they function within a limited frequency range. This work proposes a different approach for evaluating exposure to electric fields, which is the measurement of induced currents to the limbs. Measurements and tests have been carried out for different types of electro-medical equipment, and both the values of external electric fields and induced current are presented. These values are then compared with European reference values. However, since reference values for induced currents are not available in the 2013/35/EU Directive for the frequency range of interest, those proposed by IEEE 2019 *Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300* GHz and ICNIRP 2020 *Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz)* were adopted.

OCCUPATIONAL RADIATION RECEIVED BY ORTHOPAEDIC SURGEONS AND RISK TO WORKERS

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It has been reported that breast cancer prevalence is higher among female Orthopaedic Surgeons than the general population of U.S. women. A recent study of female orthopaedic surgeons reported increased doses of scatter radiation to the most common breast cancer site, the upper outer quadrant, compared to the lower inner quadrant of the breast due to insufficient shielding from the protective apron. It has been suggested that this higher dose could be a contributing factor to the increased prevalence of breast cancer in the population, causing concern amongst female surgeons and trainees. This monitoring exercise aims to clarify whether an increased risk of breast cancer in female orthopaedic surgeons is related to occupational exposures to ionising radiation. Doses received by orthopaedic surgeons will be monitored over a continuous 3-month period using existing UKSA provided dosimetry equipment (TLDs), and data will be collected via a self-reporting survey to capture sex, the training experience, if any, for working with ionising radiation, use of Personal Protective Equipment (PPE) and its availability and appropriateness, and career stage of each participant. These results will help to identify the long-term health risks of occupational radiation exposures in orthopaedic surgeons, and whether there are any associations between dosimetry readings and sex, career stage and PPE usage and other confounders surveyed.

DESIGN OF ENVIRONMENTS DEDICATED TO THE HANDLING OF UNSEALED SOURCES AND THE PRODUCTION OF RADIOPHARMACEUTICALS

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The use of radionuclides in healthcare is becoming increasingly widespread in nuclear medicine applications, which involve the production and use of radioactive sources for medical purposes. The presented work aims to provide practical guidelines for effectively addressing the challenges related to designing a comprehensive nuclear medicine service, with a particular focus on management and organizational aspects. The objective is to guide the user in evaluating and selecting the most suitable features and equipment to minimize radiation risks and prevent contamination of both workers and the environment. To support professionals in implementing the proposed guidelines, several self-assessment checklists are presented. These checklists, organized in a point-by-point format, guide the reader through all stages of the design process. The approach taken in developing these checklists includes listing the key points of the process and assigning four levels of priority to each point. These checklists serve as a useful tool both during the preliminary project phase and later for the development of internal audits aimed at assessing compliance with the provided guidelines.

AN ESTIMATION OF THE VALUE OF A MAN SIEVERT

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Introduction. The ALARA principle includes taking into account economic and societal factors. To consider these factors, decision-aiding techniques such as cost-benefit analysis were introduced by ICRP in 1973. Since then, developments in health economics have led to new ways of deriving the concept of a value of a statistical life, which now are influencing the value assigned to save a man-Sievert (the α value) which is used in cost-benefit analysis.

Aim. The aim was to estimate an α value useful for occupational radiological protection within the healthcare system of Sweden.

Method. A survey constructed on the stated preference approach was sent by e-mail to staff who are exposed to ionizing radiation at their work in a group of hospitals in Sweden. In the survey the respondents were given two scenarios and were asked about their willingness to pay for measures against radon exposure in their home and their willingness to accept getting compensated for x-ray exposure at work.

Result. Answers were gathered from 718 respondents. The median value of a statistical life based on the two scenarios was calculated to be $50 million (IQR $10-363 million). The corresponding α value was established to $1,600 per saved man-mSv. If excess burden of taxes is excluded the α value was increased to $2,100 per saved man-mSv.

Conclusion. Compared to other studies the recommended α value is in the high end. Our estimation is in line with ICRP's recommendation about stakeholder involvement as an important part of the optimisation process.

MULTIFUNCTION AIR-RADIATION MONITORING SYSTEM SUITED FOR EARLY WARNING AS WELL AS FOR ENVIRONMENTAL SURVEILLANCE

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The author has promoted, also being involved in the design and project with his historical coworkers, air radiation monitors for the last 45 years, including, among others, the instrumental core of the Air Radiation Monitoring Network of the USEPA. This paper describes a sort of "instrumental synthesis" coming from the above mentioned experience, also based on updated technologies and modern applied solutions, also proven on field. The concept design is related to an Air Monitor based on a long autonomy Tape Filter, that the author has designed/selected for these applications about ten years ago, and on modern Detector/Electronics/MCA both for alpha/beta and for gamma collected particulates (long lived isotopes as well as Rn-222/Rn-220 progenies), with a Gamma Dose-rate (GDR) unit, to cover most of the required tasks for 'outdoor' radiation monitoring, including Radon. All employed electronics has been studied, developed and tested by the author as well as all the applied measurements algorithms, updated along years of effective experimentation. Then a dedicated multi-timing facility has been provided in order to have, as default, data related to 10-minutes intervals (short time, with default refresh time 2 minutes) together with 1-hour intervals (intermediate time) and to 24-hours intervals (summary-filter time). The short intervals may cover the early warning requirements, while the others are dedicated to environmental/statistical requirements, and it is obviously possible to reduce or increase the three above default timing values in order to meet other specific needs. The design has been practically tested with a typical default set-up (10 min, 1 h, 24 h) for several months fully automatically running, and all results have been found to be quite satisfactory, also concerning long-time stability and reliability, the statistical characteristics and repeatability, and the associated sensitivities and uncertainties. In the paper several data and graphs are provided together with the characterization of the Radioactivity in-Air Monitoring System with particular regard to the innovative layout portions and to the performances both for alpha/beta and gamma also in terms of typical sensitivities (MDC, Minimum Detectable Concentration in air) and uncertainties for the three default measuring times, in different background (Rn-222, Rn-220 and GDR) conditions. As example, with Rn-222 around 5 Bq/m3, Rn-220 around 0.1 Bq/m3 and GDR around 0.1 uSv/h the MDCs for a confidence level of 96%, 10 min, 1 h, 24 h timings and sampling flow-rate 3 m3/h, have been respectively found to be: 0.58, 0.06, <0.002 Bq/m3 for long-lived alpha emitters, 2.70, 0.35, <0.005 Bq/m3 for long-lived beta emitters, 9.50, 0.51, <0.01 Bq/m3 for the gamma emitter Cs-137. Silicon and CeBr3 Detectors employed. The layout is quite flexible: "Only Alpha/Beta" or "Only Gamma" units may be easily set-up, and a suitable adding "Alpha/Beta Delayed" section (not described here) is available.

INTERVENTIONAL RADIOLOGISTS HAVE A HIGHER RATE OF CHROMOSOMAL DAMAGES IN SOUTH KOREA

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There are growing concerns regarding radiation exposure in medical workers who perform interventional fluoroscopy procedures. Owing to the nature of certain interventional procedures, workers may be subjected to partial-body radiation exposure that is high enough to cause local damage. We aimed to investigate the level of radiation exposure in interventional radiologists in South Korea by performing cytogenetic biodosimetry. Interventional radiologists (n=52) completed a questionnaire, providing information about their work history and practices. Blood samples were collected and processed for chromosomal aberration assays. We determined Papworth's U-value to assess the conformity of dicentrics with the Poisson distribution to estimate the partial-body exposures of the radiologists. Radiologists had a higher number of chromosomal aberrations than the normal population and industrial radiographers. Indeed, subjects with a U-value of >1.96, an indicator of heterogeneous exposure, were observed more frequently. Our findings suggest that interventional radiologists had greater chromosomal damages than those in normal and other occupational groups, and their partial-body exposure levels might be high enough to cause local damage. Use of special dosimeters to monitor partial-body exposure, as well as restricting the time and frequency of interventional procedures, could help reduce occupational radiation exposure.

SURVEY OF PHYSICIANS' PERCEPTIONS OF OCCUPATIONAL EXPOSURE MANAGEMENT: DIFFERENCES IN PERCEPTIONS BY GENDER

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In Japan, medical personnel involved in radiological work are legally mandated to wear an individual dosimeter inside their protective aprons (chest for men and abdomen for women) and another one outside the protective aprons when wearing such attire. Additionally, they are required to wear an individual dosimeter when not using protective aprons. However, it has been observed that many physicians do not comply with these legal requirements. This study aims to shed light on the gender differences in physicians' attitudes towards occupational exposure, which could potentially influence their adherence to these regulations and the Wearing Status (WS) of individual dosimeters. A comprehensive questionnaire on occupational exposure control was administered to 243 physicians (62 female) in radiological work at a university hospital. The questionnaire consisted of thirteen questions, all answered on a 5-point Likert scale, ranging from strongly disagree to strongly agree. Comparisons between the genders were performed using the Mann-Whitney *U* test. The correlation between WS and each questionnaire item was rigorously analyzed using Spearman's rank correlation coefficient, with a statistical significance level set at $p<0.05$. The analysis of 166 valid responses (31 female respondents) revealed a significant finding ($p=0.001$): female physicians demonstrated a higher tendency for WS than their male counterparts. For male physicians, a correct understanding of the three principles of radiation protection (time, distance, and shielding), protective behavior aligned with these principles, and the habit of checking exposure doses positively correlated with WS. In contrast, high WS among female physicians was associated with a lack of anxiety and doubts about their health, the availability of necessary protective equipment, and a support system for discussing exposure and protective methods. This suggests that female physicians may feel more protected by adhering to safety measures, using appropriate equipment, and having a platform for addressing concerns.

EVALUATION OF SPATIAL DOSE RATES FOR WORK AREA OF THE STEAM GENERATOR PRIMARY SIDE

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In Korea, about 90% of total radiation doses to workers in Nuclear Power Plants (NPPs) occurs during overhaul period (O/H). Maintenance works of Steam Generator (SG) are typical tasks during O/H, and external exposure doses are mainly caused by deposited crud in SG primary side. In particular, maintenance works on the SG primary side are likely to be performed in the vicinity of deposited crud. The workers of SG primary side often perform tasks inside the water chamber and around the man-way of the primary side. This may result in somewhat higher dose levels to workers as they perform tasks in the vicinity of the deposited crud. Therefore, it is necessary to perform a dose assessment to optimize the exposure dose through SG maintenance work planning. Therefore, in this study, the spatial dose rates of the maintenance work area of SG primary side were evaluated prior to the evaluation of the worker radiation doses. For this purpose, the SG was simulated using Monte Carlo method. Then, the spatial dose rates of the maintenance work area of the SG primary side were evaluated. In this study, the SG was simulated using the MCNP computer code, and the geometric structure and the source term were simulated respectively. The geometric structure and source term were simulated using the Design Control Document (DCD) of APR1400 and the design information in the Safety Analysis Report (SAR) of APR1400 NPPs in Korea. The geometry was simulated focusing on the primary components, taking into account the source term and maintenance work points. The source term was simulated using specific activity, equilibrium thickness of the crud as presented in the APR1400 DCD and SAR. The simulated SG was then utilized to evaluate the spatial dose rates around the SG. The mesh tally function of the MCNP was utilized for the spatial dose rates evaluation. Mesh tally was set up a total of 4 maintenance work areas for the workspace inside the water chamber and the workspaces outside the man-way of the SG primary side. The results showed that the spatial dose rates for the workspace inside the water chamber were in the range of 1.14×10^{2} to 4.44×10^{2} mSv/hr. The spatial dose rates for the 3 workspaces outside the man-way were in the range of 1.96×10^{-2} to 2.50×10^{1} mSv/hr, 1.99×10^{-2} to 2.31×10^{1} mSv/hr, 1.34×10^{-3} to 3.99 mSv/hr, respectively. Since the dose rates were evaluated based on the design value of crud, it is judged to be conservatively evaluated value. The results of this study will be utilized as basic data for assessments of maintenance workers of SG primary side.

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IMPLICATIONS OF THE REALIZATION OF CHARACTERIZED REFERENCE RADIATION FIELD IN A PRIMARY STANDARDS DOSIMETRY LABORATORY

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The realisation of the reference radiation fields in the Primary Standards Dosimetry Laboratories (PSDLs) can be done in two ways known as “matched” and “characterized” techniques. The first method requires a validation with the reference values indicated in the ISO 4037:2019 norm to assure that the deviations of the actual parameters from their nominal values are within given limits. The actual spectral distribution is not considered because air kerma-to-dose-equivalent conversion coefficients (conversion coefficients) are those tabulated in the ISO 4037:2019 norm. On the contrary, the “characterized” reference radiation fields are realized following more relaxed requirements. Consequently, a characterization of the field parameters, including the spectral distribution, is needed to determine the conversion coefficients. In this study, the two approaches have been compared for the Narrow-spectrum (N) series of ISO 4037. In implementing the ISO 4037:2019 norm, the matched N-series radiation qualities were defined according to strict requirements on the material and thickness of the additional filtration, and according to metrologically traceable measurements of high voltage bias applied to the X-ray tube. For three cases, characterized N-series qualities were realized with more relaxed requirements. Actual spectral distributions were obtained by means of a Cd-Te spectrometer and an unfolding procedure for generating potentials up to 80 kV. Computational spectrometry (SpekPy toolkit) was used as alternative method, to offer a comparison to the experimental data, and to provide a means to evaluate the conversion coefficients for characterized reference radiation fields of beam qualities at higher energies. We confirmed that, for both methods, the expanded overall uncertainty (k=2) of the dose rate value of about 6% to 10% for the phantom related quantity is not exceeded. The mean energy in keV with respect to fluence agrees within 2% with the nominal value as reported in ISO4037. At lower tube voltages, the energy dependence of the conversion coefficients is notably sharp and, depending on the specific realisation of a radiation quality, the actual conversion from air kerma to operational quantity varies substantially with respect to the nominal values. We investigated the differences of the N-Series conversion coefficients between the realization of matched and characterized radiation qualities realised at ENEA-INMRI. Characterized reference fields have been implemented thanks to computational and experimental spectrometry, resulting particularly useful for the lower tube voltages.

Session 2C

Advances in preventing and managing exposure to radon and NORM

RADON RISK COMMUNICATION: LESSONS FOR RADIATION PROTECTION

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The objective of radon risk communication is to increase the number of radon testing and mitigation actions in dwellings, public spaces and working places if radon concentration exceeds the national reference level. Thus, risk communication supports authorities in their implementation of the European Basic Safety Standards Directive following the legal requirement to increase radon awareness. Despite the high number of awareness campaigns conducted in different European Member States, the levels of testing and mitigation actions hardly increase. Why is radiation protection behavior not improving despite all these efforts? This study presents a systematic overview of awareness campaigns in all EU MS, it details the interventions conducted and the effect of awareness campaigns on knowledge about radon in specifics and radiation protection in general. Moreover, it provides empirical evidence on whether is knowledge the most important factor for radiation protection behavior or if there are other factors on which risk communication should focus. The data used in this study was collected through group interviews and document analysis in the context of the DG Energy project EU-RAP (27 EU Member States) and Computer assisted web interviews conducted for the RadoNorm European Behavioral Atlas including respondents from 13 EU MS. The results from the radon risk communication case, explained through behavioral protection theory, provide empirical evidence which can better inform radiation risk communication strategies.

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COMPARATIVE ANALYSIS OF END-USERS' PERCEPTIONS OF THE REUSE OF NORM-CONTAINED BY-PRODUCTS IN BUILDING MATERIALS

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The cement industry is the world's third-largest CO_2 emitter. Utilising secondary raw materials in cement production offers a viable path for reducing emissions, in line with circular economy principles. However, some industrial by-products, are categorised as NORM, leading to environmental and health concerns due to their accumulation in landfills. In our study, we aim to understand end-users' perceptions of the use of alternative cement made with NORM-contained by-products in the construction of their dwelling. We target individuals who have built or renovated their house in the last 10 years. Employing CAWI (Computer Assisted Web Interviewing) in Belgium (N=394), the Czech Republic (N=407) and Slovenia (N=408) we investigate the factors affecting end-users' perception and intention to use alternative cement through investigating their perceived risk and benefits related to health, financial, performance and environmental aspects. We use psychometric characteristics to further describe end-users' perceived health risk regarding the use of this alternative cement. We expect country-specific differences related to the country's prior experiences with hazardous materials in construction. This study pioneers a comparative examination of end-users' acceptance of naturally occurring radioactive materials in building materials stemming from circular economy practices. These novel insights offer guidance on communication and policy strategies designed to meet the unique concerns of end-users in each country, aiming to decarbonise the cement and concrete sector.

NORM DATABASE IN THE REGULATORY ITALIAN FRAMEWORK

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The Council Directive 59/2013/Euratom (EU-BSS) has been transposed in Italy into the Legislative Decree n. 101 of 31 July 2020, modified and integrated by the Legislative Decree n. 203 of 25 November 2022. For the first time, an entire chapter is dedicated to practices involving naturally occurring radioactive material (NORM). Compared to the previous Italian legislation, important innovations have been introduced, extending the field of application to industrial sector never involved before, considering NORM activities as planned exposure situation and identifying exemption and clearance levels in terms of activity concentration and effective dose for workers and members of the public. In the framework of the regulatory control, it has been foreseen that a section dedicated to NORM shall be established in the national database of environmental radioactivity, called SINRAD, implemented by the National Inspectorate for Nuclear Safety and Radiation Protection (ISIN). In the NORM section data and information relating to the measurements of activity concentration in raw materials, residues, products and effluents contained in the NORM relating industrial production cycles have to be collected and dosimetry services, commissioned by the operator of NORM plants, are the data providers. The data base has been implementing by ISIN and the technical specification have been defined taking into account previous national inventory experiences, scientific literature review, national project outcomes and technical relations transmitted by NORM plants operators to ISIN. From a preliminary data analysis, the most represented industrial sectors are oil and gas production, ground water filtration facilities, zircon and zirconium industry, processing of phosphate and potassium ores and geothermal energy production. The NORM section of SINRAD will guarantee to get an updated national inventory of NORM industries, to obtain an overview of the radiological content in the different matrices, to provide guidance for establishing strategies and priorities in supervisory activities and to identify useful hints for a regulatory review.

CONSIDERATIONS OF NECESSARY MODIFICATION OF EXISTING WASTE DISPOSAL AND RECOVERY OPTIONS WHEN APPLIED TOWARDS NORM

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The content of radionuclides and the related issue of radiological protection is a property that determines the manner of dealing with materials, residues and waste considered as NORM. In many cases, waste currently classified as NORM had existed since industry contributed to intensification of their formation was set working. Over the following decades, the development of industry also led to the creation and subsequent improvement of tools in the form of appropriate legal regulations specifying the method of dealing with waste that is almost always generated as a result of industrial processes. Therefore, if materials, residues or waste with an increased content of radionuclides are not strictly classified as radioactive waste, it is possible that applicable regulations on waste management, including processing, recovery and disposal, also apply to NORM. The increased content of radionuclides should not discredit NORM and determine the only option of treatment based on disposal, because there is also an option of their recovery, and the main factor determining such a possibility is the value of exemption limit. Even exceeding the exemption limit does not rule out the possibility of recovery or the selected method of disposal, because the final decision on such issues related to limiting the radiation hazard should depend on individual proceedings and the decision made by the authority control based on radiation protection rules of justification and optimization. Under the currently used waste management system, 15 disposal methods and 13 recovery options have been identified. As this system is based on non-radioactive waste, and NORM, apart from its distinctive property related to the increased content of radionuclides, has features typical of conventional waste, an exemplary analysis of the possibility of using the above-mentioned methods of disposal and recovery in relation to NORM was made, taking into account primarily the issue of radioactivity. For this purpose, three wastes were selected that are well-defined, typical representatives of NORM, i.e. coal fly ash, red mud generated during production of alumina and phosphogypsum. The analysis based on European directives and a specific case study, i.e. Polish laws showed that majority of disposal and recovery options do not need significant modifications in case of natural radionuclides occurrence considerations. Some of them identified may be easily enforced based on work organization and limiting of mass/volume of materials processed at once. Currently, however, analysis of applicability of available conventional waste disposal and recovery options towards NORM is an issue being considered and constituting a block of activities undertaken as part of the international RadoNorm project. Examples are discussed in the presentation.

CHARACTERIZATION OF THE FYCDY-P30 ELECTROSTATIC COLLECTION CHAMBER FOR MEASUREMENTS OF Rn-220 AND Rn-222 AT ENEA INMRI LABORATORIES

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The radon laboratories of INMRI ENEA, in collaboration with MiAm, have characterized a new instrument for measuring Rn-222 and Rn-220, based on electrostatic collection cell and alpha spectrometry of radon and thoron decay products. The instrument of Chinese production is called FYCDY-P30 (here in after referred to as P-30) and is very similar to the well-known Durridge Rad7. In the initial tests, measurements were made in a mixed Rn-222 Rn-220 atmosphere to verify that the multichannel analyzer provided a spectrum with adequate distinction of the Po-218, Po-216, Po-214, and Po-212 peaks, the alpha emission of Bi-212 practically coincides with Po-218. The results in this respect are very satisfactory as will be shown in the work. Subsequently, the instrument was calibrated for Rn-220 measurements in the thoron chamber of INMRI ENEA. The instrument under examination was connected to the thoron chamber through a closed circuit with a continuous sampling flow of 1.1 L/min generated by the P-30 pump. For this type of measurements, it is relevant to determine the "filling factor" of the electrostatic chamber, as the half-life of Rn-220 is particularly short (80.5 sec.) and for this reason thoron decays before filling the measurement cell of the instrument. The problem was solved by inserting a second instrument based on a Lucas scintillation cell (MR1 Tesys) into the circuit with two different circuit configurations, namely placing MR1 alternatively downstream or upstream of the P-30. From the difference in counts of MR1 in the two configurations, it is easy to estimate the thoron activity in the P-30 cell as will be shown in the text. Finally, the instrument was calibrated for Rn-222 measurements by connecting the P-30 to the one-cubic-meter radon chamber of INMRI through a closed circuit. Calibrations were first performed in standard configuration, i.e., with a desiccant cartridge on the sampling line; subsequently, several tests were carried out without the desiccant cartridge and with different humidity values in the radon chamber. Laboratory tests showed a 30% decrease in instrument sensitivity with increasing humidity, from 14% to 35% RH inside the electrostatic collection cell. Subsequently, tests carried out in the archaeological museum complex of the Domus Aurea in Rome, in collaboration with INAIL, the P-30 instrument showed excellent results in thoron measurements in situ, confirming the results obtained in the laboratory.

RADON EXHALATION CAMPAIGN TO ESTIMATE GREENHOUSE GAS EMISSIONS USING THE "RADON TRACER METHOD" - JRC-ISPRA

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Within the framework of the institutional project "GHG emission monitoring in support of EU Climate targets" (GEM), the JRC-Ispra Dosimetry Service conducted a campaign to measure the radon gas exhalation rate from soil. The results, in terms of exhalation, together with radon concentration data in air, allow the estimation of greenhouse gas emissions through the Radon Tracer Method (RTM). The GEM project aims to provide greenhouse gas emissions, based on experimental observations, atmospheric models and inventories, which are used as independent data for verifying the accuracy and reliability of official emissions reported under the United Nation Framework Convention on Climate Change. For the measurement of the exhalation rate of radon gas, the Laboratory relied on the accumulation method according to the reference ISO, using an active radon gas concentration monitoring instrument coupled to an air pumping system and an accumulation chamber via high-density polyethylene tubes. Known the volume of the chamber and the surface area of the sampling point, the analysis of the radon concentration trend inside the accumulation chamber allowed the estimation of its exhalation from the soil. The measurement campaign covered an entire year, highlighting the seasonal variability of radon gas exhalation from the soil and the influence of the main physical parameters of the soil. The campaign is aimed to reduce the uncertainty of the estimates of greenhouse emissions obtained using the Radon Tracer Method.

EVALUATING THE IMPACT OF CITIZEN SCIENCE PROJECTS IN THE FIELD OF RADIATION PROTECTION: THE RADON CASE

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Citizen Science (CS) has emerged as a powerful approach to engaging the public in scientific research, with significant potential to address societal issues including radiation protection. In the case of radon, a carcinogenic radioactive gas, CS initiatives may play a crucial role in motivating citizens to take radiation protective measures. This research aims to evaluate the impact of CS projects in the field of radon by proposing an evaluation framework to assess their influence on scientific outcomes, participants themselves, societal benefits, researcher learning gains, and the CS process. This is motivated by the absence of a comprehensive framework in this field. Without a holistic evaluation, we still lack empirical evidence to determine whether citizen science projects meaningfully contribute to radiation protection behavior, science and/or policy making. The framework is tested on the European RadoNorm CS Incubator, an initiative hoisting eleven citizen science project in the field of radon conducted between 2021 and 2024 across ten European countries: France, Hungary, Ireland, Italy, Norway, Poland, Portugal, Slovakia, Slovenia and Spain. Projects varied from testing for radon in dwellings, workplaces and public places to mitigation of dwellings. The evaluation involved a mixed-methods, two-stage process. The first stage employed qualitative techniques, including content analysis of project reports and deductive analysis of semi-structured interviews with citizen scientists and project coordinators from four initial citizen science projects. The second stage will employ quantitative method: computer-assisted personal interviews with citizen scientists (N=231) and qualitative method: group discussions with citizen science project coordinators and semi-structured interviews with executive management board members of the RadoNorm project, all of them conducted at the end of the CS projects. Preliminary findings demonstrate that although the citizen science projects did not significantly contribute to the research and development of the RadoNorm project (as the results were not incorporated into any research work packages except the one related to societal aspects), the citizen science projects had significant secondary effects: enhanced participants' knowledge of radon risks and motivated protective actions, such as testing and mitigation. Nonetheless, building on the pilot's experiences, RadoNorm funded six CS projects in six European countries, forming the RadoNorm Citizen Science Incubator. This Incubator, recognized with an EU Best Citizen Science Project - Honorary Mention, signifies a collaborative effort to further engage citizens in radon risk management. The evaluation framework proved effective and can be adapted for various citizen science projects, particularly those addressing environmental and public health risks in the field of radiation

protection. The authors recommend making this evaluation framework mandatory for all citizen science projects in radiation protection, especially those funded by the ongoing PIANOFORE initiative.

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PERCEPTIONS, PERFORMANCES AND PRESENTATIONS OF RADON IN HEALTH SPAS

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Health and radiation authorities across Europe emphasize the health risks posed by radon gas exposure. However, various European spas offer treatments claiming health benefits from the same radon gas. Our study explores the potential controversy between "radon as a threat" and "radon as a treatment" in the context of these radon spas and their communication activities. Through semi-structured interviews with spa employees and managers (n=11) in Austria and Germany, we gain insight into how radon is perceived and utilized by spa operators. A frame analysis of European radon spa websites (n=26) reveals how radon is presented to the public. Additionally, surveys using computer assisted web interviews among citizens in Austria (n=1394), Germany (n=1263) and Czech Republic (n=1029), show awareness and perceptions of radon spas in these countries. This mixed-method approach demonstrates how the apparent contradiction between 'radon as risk' and 'radon as remedy' is not first and foremost an issue of seemingly divergent perceptions of a shared reality, but rather extends to the performance of different radon realities altogether. Whereas in radiation protection, radon is performed as an indoor air pollutant and a carcinogenic threat to human health, in the context of radon spas, emphasis is put on radon as a natural medicine, a valuable asset, and a controllable ally in the fight against various health complaints. The fact that both of these radon realities co-exist in different European countries, entails clear challenges in terms of public health campaigns and communication. This contribution will also delve into some of these challenges, and provide recommendations on how to handle them.

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STANDARDS AND QUALITY: LABORATORY FOR CALIBRATION OF DOSIMETRIC AND RADON INSTRUMENTS IN POLAND

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The Central Laboratory for Radiological Protection (CLOR) is a research institute based in Warsaw. CLOR was established in 1957 by decree of the Prime Minister to ensure the radiological protection of the country. The Institute's main activity is to protect the public and occupationally exposed persons from the effects of ionising radiation. As an accredited laboratory, CLOR operates under the strict standards of the Polish Centre for Accreditation (PCA) and is supervised by the Polish Atomic Energy Authority (PAA). This double layer of oversight ensures that CLOR's operations meet both national and European quality benchmarks, reinforcing its credibility and reliability in the field of radiation protection. CLOR's main focus is the calibration of instruments used to measure ionising radiation. These instruments play a vital role in various sectors, including healthcare, nuclear energy, environmental monitoring and industrial applications. Accurate calibration is essential to ensure that these instruments provide accurate readings, which are fundamental to maintaining safety standards that protect human health and the environment from the potential hazards of ionising radiation. The Laboratory for the Calibration of Dosimetric and Radon Instruments (LWPDiR), which is part of the Dose Control and Calibration Division of the Central Radiation Protection Laboratory, provides calibration services for 1) dosimetric quantities (gamma, beta, X-rays), 2) surface radiation emission (alpha and beta radioactive sources) and 3) radon measurements. It is the only calibration laboratory in Poland offering such a wide range of measurement services. Statistics from recent years on the calibration of measuring instruments at CLOR will be presented. This analysis will include a classification by different types of instruments (dosimeters, radiometers, contamination monitors, spectrometers), by type of calibration method (e.g. using gamma, X-ray, beta or neutron radiation) and by sectors (hospitals, uniformed services, universities, waste management) using the laboratory's services. The aim is to present prevailing trends and changes in the demand for calibration services, as well as a presentation of the most frequently calibrated instruments.

Session 3A

Radiation protection in medical applications (II)

FOETAL DOSE ESTIMATION IN PREGNANT PATIENTS UNDERGOING CT EXAMINATIONS USING DIFFERENT DOSE CALCULATORS

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A developing foetus is highly radiosensitive. Monitoring and limiting the radiation exposure of pregnant patients is therefore of great importance. However, in certain situations, such as trauma, suspected appendicitis, and suspected pulmonary embolism, a CT scan during pregnancy is necessary and justified. Various dose calculators are available on the market that can be used to estimate the foetal dose from a CT scan. Limited information is available on the accuracy of these tools. This study investigates the accuracy of six computational dosimetry tools (ImPACT CT , VirtualDose-CT, NICICT, CoDE, Waza-ari1 and Fetaldose.org) when used for foetal dose estimation. It does so by comparing the foetal dose estimates for a range of standardised protocols (chest, abdomen, pelvis, chest-abdomen-pelvis) at different pregnancy stages. These estimates are compared against each other and against experimental measurements obtained using a modified anthropomorphic phantom subjected to equivalent CT protocols. The foetal doses estimated by the different tools for 1st, 2nd, and 3rd trimester pregnancy stages for the chest, abdomen, pelvis, and chest-abdomen-pelvis protocols were <0.5mGy, <3.0mGy, 3.5mGy – 10.0mGy, and 5.3mGy – 11.0mGy. The biggest variation between doses were seen in the 3rd trimester chest and abdomen protocols, where the ImPACT CT and Waza-ari tools estimated the foetal doses to be at least double of what the other tools estimated. The foetal doses measured using TLD chips placed inside the modified anthropomorphic phantom representing 1st and 2nd trimester pregnancies were 0.4mGy and 1.3mGy for a chest protocol, and 13.0mGy and 11.1mGy for an abdomen-pelvis protocol. All six tools estimated lower foetal doses when compared to the experimental values. VirtualDose-CT consistently underestimated the foetal dose by around 50%. NCICT, CoDE, ImPACT CT, Waza-ari, and Fetaldose.org had much larger variations, foetal doses being underestimated by 10%-95% in both protocols and pregnancy stages. These results call into question the accuracy of these tools, with risks that foetal doses are systematically underestimated when compared to experimental results. This is especially the case when estimating foetal doses where the foetus is not in the primary radiation field. Practitioners may need to exercise caution when relying on these tools. However, these results may to some degree be explained by limitations of the particular anthropomorphic phantom used, the differences between the simulation phantoms and Monte-Carlo codes. Further research is currently undertaken to measure foetal doses in a modified anthropomorphic phantom representing 3rd trimester of pregnancy.

THERAPEUTIC ^{131}I DOSE FOR HYPERTHYROIDISM TREATMENT OF UNIFOCAL AUTONOMY IN COMPLIANCE WITH COUNCIL DIRECTIVE 2013/59/EURATOM OPTIMIZATION PRINCIPLE

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Purpose: European guidelines for radiometabolic treatment of hyperthyroidism suggest a target dose of 300-400 Gy for unifocal autonomies. Aim of this study was to demonstrate that a lower dose and a personalized pretreatment dosimetric study can be effective in obtaining a stable euthyroid status avoiding both hyperthyroidism persistence and onset of hypothyroidism and in complying with the Council Directive 2013/59/Euratom optimization principle.

M&M: We considered 128 patients with a minimum follow-up of 12 months (89F, mean age 61±13y, 79/49 with subclinical/overt hyperthyroidism) with a single nodule of mean weight of 14.8±10.7g (range: 3.8-57.3g). They were studied with a pretreatment patient-specific dosimetric study (based on the administration of 48-111 MBq of ^{123}I, on multiple uptake measurements with a gammacamera and on the MIRD formula corrected for the reduced uptake in therapy with respect to dosimetry) in order to calculate the therapeutic ^{131}I activity necessary to release to the nodule a dose of 140 Gy. Afterwards, the dose released after the administration of the calculated ^{131}I therapeutic activity was evaluated by means of 6 uptake measurements with a gammacamera at 2, 4, 24, 48, 96 and 168 hours and the use of the MIRD formula. After the first 12 months each patient clinical outcome was monitored with biochemical analysis (TSH, FT3 and FT4) and then once a year. Two subgroups of 72 and 42 patients had a follow-up of 5 and 10 years, respectively.

Results: All patients were given a single therapeutic ^{131}I administration with a mean activity of 296±147MBq [range: 87-614 MBq]. The mean dose released to the nodules was 143±38 Gy. Twelve months after therapy hyperthyroidism was healed in 97% of the patients but 8% were hypothyroid (serum TSH level >4.2 uU/ml). In the subgroup followed for 5 years, 100% of the patients solved hyperthyroidism but 22% became hypothyroid and in the subgroup followed for 10 years they were 29%.

Conclusions: This study demonstrated that a released target dose of about 140 Gy is effective in solving hyperthyroidism due to unifocal autonomy and to maintain a long lasting euthyroid state. This dose is quite lower than the value indicated by the European guidelines for hyperthyroidism treatment. The wide range of administered activity indicates the importance of a personalized pretreatment dosimetric study in order to obtain the clinical goal with the lowest activity.

DEVELOPMENT OF AN AI-POWERED VIRTUAL ASSISTANT FOR RADIATION DOSE MANAGEMENT IN PREGNANT PATIENTS UNDERGOING CT AND X-RAY GUIDED INTERVENTIONAL PROCEDURES

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Advances in Artificial Intelligence (AI) present transformative opportunities for medical education and training. Particularly, AI-powered tools can significantly enhance the learning experience in specialized domains such as radiation dose management for vulnerable populations like pregnant patients undergoing Computed Tomography (CT) scans and X-ray-guided interventional procedures. This study explores the development and preliminary evaluation of a virtual assistant designed to train medical physicists and other health professionals in these critical areas. An AI-powered virtual assistant was developed based on Large Language Models (LLMs), specifically tailored for the education and training of healthcare professionals in radiation dose management. The model was trained using a curated dataset comprising high-quality, scientific material relevant to radiation safety, dose optimization in pregnant patients, and best practices in CT and interventional radiology. Additionally, the assistant integrates a real-time PubMed retrieval system, enabling up-to-date literature searches with a focus on the most recent five years of publications. The system architecture includes modules for natural language understanding and context-aware dialogue management. Preliminary internal evaluations indicate that the virtual assistant is proficient in delivering accurate, contextually relevant information sourced directly from its controlled knowledge pool. Users can query the assistant on complex dose management scenarios, receiving guidance that aligns with current standards and recommendations in radiology. The real-time PubMed article retrieval and summarization feature was tested, demonstrating the assistant's ability to provide recent evidence-based responses, thus supporting ongoing professional education and training. Despite its potential, the current evaluation phase has identified areas for improvement, including the enhancement of the model's ability to handle ambiguous queries and its integration with broader clinical decision-support systems. Ongoing development and more extensive validation studies are planned to address these issues and to fully establish the assistant's role in medical education and training.

MAIN ACHIEVEMENTS OF THE HARMONIC PROJECT - HEALTH EFFECTS OF CARDIAC FLUOROSCOPY AND MODERN RADIOTHERAPY IN PAEDIATRICS

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HARMONIC aims to better understand increased risk of cancer and non-cancer effects after exposure to medical ionising radiation in children. Two international paediatric cohorts were set up for long-term follow-up of i) cancer patients treated with modern external beam radiotherapy and ii) cardiac patients treated with cardiac fluoroscopy procedures. The objectives are to investigate potential endocrine dysfunction, cardiovascular and neurovascular damage, health-related quality of life, and second (and subsequent) primary cancer following photon and proton therapy while also investigating further potential risks of cancer together with the modifying factors of the observed association in the cardiac paediatric population. Dosimetry software tools were developed in the framework of the project to facilitate the reconstruction of organ doses in both cohorts and enable epidemiological investigations, as well as future optimisation of treatments. With the creation of a biobank of blood samples, HARMONIC aims to provide a mechanistic understanding of radiation-induced adverse health effects and identify potential biomarkers that can predict these effects. The main achievements of the project and its exploitable results will be presented, along with some perspectives for the future.

COMPARATIVE ANALYSIS OF EFFECTIVE DOSES FOR CHILDREN UNDERGOING CHEST CT EXAMINATIONS: PHOTON-COUNTING *vs* ENERGY INTEGRATING DETECTOR CT

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Background. The application of Photon-Counting-Detector (PCD) technology in Computed Tomography (CT) enhances image quality and expands spectral imaging options, while also offering a significant dose reduction. This is especially beneficial for children with their elevated sensitivity to ionizing radiation.

Purpose. To compare the organ doses and effective doses measured with Thermoluminescent Dosimeters (TLD) in an anthropomorphic phantom of a 1-year-old child for two typical chest CT protocols on CT devices with PCD and Energy-Integrating-Detector (EID) technology.

Materials and Methods. The anthropomorphic phantom of a 1-year-old child (Atom model 704; CIRS inc., Norfolk, USA), was undertaken typical chest CT examinations at tube voltages of 70 kV and 100 kV with tin-filter (100kV+Sn) using two different CT devices (Siemens Force (EID), Siemens Neaotom Alpha (PCD); Siemens, Erlangen, Germany). The CT dose indexes (CTDI) associated with the tube current were adjusted to ensure that the Signal-to-Noise Ratios (SNR) of the images are similar for all four examinations. The doses to all relevant organs were measured using TLDs (TLD-100, Bicron-Harshaw, Cleveland, USA) during each examination and the respective topograms. Effective doses were calculated according to the definition of ICRP Publication 103.

Results. While the displayed $CTDI_{vol}$ does not differ between the two CT devices for the 70 kV protocol, the measured effective dose is 30% lower for the PCD-device. For the 100kV+Sn protocol, the displayed $CTDI_{vol}$ is 66% lower, and the effective dose 61% lower for the PCD-CT device. In general, effective doses for the 100kV+Sn protocols are 42% lower with the EID-CT and 77% lower with the PCD-CT device compared to their respective 70 kV protocols. When examining the organ doses, more efficient dynamic shielding of the abdomen was observed with the PCD-CT device, resulting in a reduced dose to abdominal organs. It should be noted that the effective dose from the topogram for the 100kV+Sn protocol on the PCD-CT device is comparable in magnitude to that of the chest scan itself.

Conclusion. For both investigated protocols the effective doses were significantly lower for the PCD-CT device than for the EID-CT device at the same SNR. Application of PCD-CT is therefore well suited to decrease the radiation risks associated with CT examination for paediatric patients.

A NATIONAL PILOT PROJECT FOR THE IMPLEMENTATION OF CLINICAL AUDIT INDICATORS IN INTERVENTIONAL RADIOLOGY

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The European Directive 2013/59, transposed in Italian national legislation with the D.Lgs. 101/2020, and European national laws recommend performing clinical audits to improve the quality and outcome of patient care through structured review, including patient dosimetry, image quality assessment and radiation optimization. The objective of this national project, supported by the Ministry of Health, was the implementation of a pilot clinical audit programme with appropriate indicators in interventional radiology. As a part of the audit, Technical Image Quality (TIQ) was evaluated on 24 angiographic systems installed in 6 hospital using clinical acquisition protocols. In order to simulate patient scattered radiation, a PMMA phantom of different thickness was used for three main districts: cardiac 24 cm, abdominal 24 cm and neurological 16 cm. Test images were evaluated in term of threshold-contrast detail detectability TCDD (with a statistical approach and a dedicated test object) and limiting spatial resolution (with Leeds TOR FG18 test phantom). Both fluoroscopy (with normal and low dose level) and fluorography acquisition modes (non-subtractive or DSA) were tested. Test objects were positioned at the isocenter of the angiographic system, in the hemi-thickness of the PMMA phantom and the entrance surface air kerma per each pulse was measured at the phantom surface. Results showed a great variability among equipment and acquisition protocols. TCDD depends on dose, beam quality and on the implemented post-processing algorithm. Angiographic system equipped with modern noise reduction algorithm are able to maintain TCDD with a strong reduction in entrance surface air kerma. Limiting spatial resolution depends on field-of-view and implemented post-processing algorithm. As a tool of clinical audit, Technical Image Quality has been confirmed very useful in evaluating equipment performance over time and in comparing different acquisition protocol.

The project is conducted with the technical and financial support of the Italian Ministry of Health-CCM 2022 programme - "Ottimizzazione dell'esposizione medica a radiazioni ionizzanti: progetto pilota per l'implementazione di audit clinici e prima attuazione dell'art. 168 del d.lgs. 101/2020 in Radiologia Interventistica".

RADIOBIOLOGICAL KIDNEY PROTECTION: ASSESSING THE EFFECT OF DIFFRENT COADMINISTRATION SCHEDULES WITH HUMAN RECOMBINANT ANTIOXIDANT rA1M AND ^{177}Lu-OCTREOTIDE

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The risk of late-onset radiation-induced kidney toxicity limits the systemic treatment of metastasized neuroendocrine tumors with ^{177}Lu-octreotate. Enhancing kidney protection could enable higher activities of ^{177}Lu-octreotate administrations. Previous studies have demonstrated nephroprotective effects when recombinant human Alpha-1-Microglobulin (rA1M) is coadministered with ^{177}Lu-octreotate in mice. Additionally, there is a pressing need for early-response biomarkers to identify patients who can safely tolerate higher activities of ^{177}Lu-octreotate. This study aimed to assess the impact of various rA1M admini stration schedules in conjunction with ^{177}Lu-octreotate on urine levels of Retinol-Binding Protein 4 (RBP4) and creatinine. Mice were administered 60 MBq of ^{177}Lu-octreotate intravenously, along with none, one, or multiple injections of rA1M. RBP4 and creatinine concentrations were measured 6-10 weeks post ^{177}Lu-octreotide injection. The results indicated that urinary RBP4 levels in mice treated without rA1M+^{177}Lu-octreotide in various administration schedules were comparable to those in mice injected with only ^{177}Lu-octreotide, although individual variability was observed across most groups. Urinary creatinine concentrations vary significantly between groups. Consequently, further research is necessary to establish whether rA1M offers long-term renal protection.

PROPOSAL OF A NEW APPROACH FOR MOLECULAR RADIOTHERAPY DOSIMETRY

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Internal Radiation Dosimetry is essential for dose-effect relationships and therapy effectiveness in Molecular RadioTherapy (MRT). Accurate assessment of absorbed dose to lesion and Organs At Risk of toxicity (OAR) is only possible if the radioagent uptake and washout, namely the biokinetics, is individually monitored and characterised in detail. Furthermore, current European regulation (EU Directive 59/2013) considers mandatory the treatment planning and verification in all patients undergoing radiotherapy procedures, including MRT. However, it is not an easy task, since the dose absorbed to tissues depends on several interconnected key factors, and the uptake and excretion largely fluctuate from patient to patient. A new approach for individual radioagent biokinetics determination is proposed with the Wearable Individual Dose Monitoring Apparatus (WIDMApp). The WIDMApp system is conceived as a wearable multi-channel detector system for *in vivo* radiation detection, a Montecarlo simulation for individual anatomical structure modeling and particle interaction calculation, and a data analysis tool to determine the activity distribution and its evolution over time in different organs. This system could provide an effective tool to characterize more accurately the time integrated activity in MRT patients, reducing the need of resources of nuclear medicine departments, such as sanitary staff involvement and scanner occupancy. The proof-of-principle of WIDMApp showed that reconstruction of the individual biokinetics using small portable detectors is in principle possible. The relatively simple hardware proposed would allow its application to large numbers of patients. Taking advantage of the data sampling more frequent than conventional dosimetric studies, the WIDMApp approach can be an effective tool for MRT dosimetry. The full characterization of the radiopharmaceutical accumulation and retention will provide essential information for treatment optimization, such as the proper activity to be administered for each subject.

ASSESSMENT OF THE CURRENT CT PROTOCOLS IN USE FOR ONCOLOGICAL IMAGING IN SLOVENIAN HOSPITALS: IVIOLIN PROJECT

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Objectives. The aim of this study is to assess the CT oncology protocols in use in a group of eleven Slovenian hospitals and to identify the variations in radiation doses between those hospitals.

Methods. An electronic survey has been designed using Microsoft Excel to identify current CT oncology protocols in eleven Slovenian CT centres. The three most frequent oncology CT protocols were targeted: lung, colon, and stomach cancer and sites asked to report CT parameters and typical doses for diagnosis, staging, and follow-up protocols as well as the available dose optimisation features on each scanner. The survey was addressed to CT staff. A single response per CT scanner was required.

Results.Responses received from eleven Slovenian CT centres representing over 70% of hospitals in the country. Data was returned for 16 CT scanners (Siemens: 75%, GE: 13%, and Canon: 13%). Results revealed that a number of sites (n=2) do not have CT protocols for specific clinical indications in which a single standard CT protocol used for diagnosis, staging, and follow-up of disease. The number of available optimisation tools correlated inversely with scanner age. Siemens scanners were of an average 6.9 years old and had the lowest average radiation doses (270 mGy.cm) of all centres followed by GE (493 mGy.cm, average age: 7 years), and lastly Canon (689 mGy.cm, average age: 11.5 years). Doses for some identical CT models varied by 80% while the largest variation between CT vendor was 87%.

Conclusion. Considerable variations in routine oncology CT protocols and associated radiation doses were noted between CT centres in Slovenia. A maximum sixfold difference in radiation doses were noted between scanners. The age of CT scanner inversely correlated to radiation doses. Newer CT scanners have more optimisation tools available for use, yet some differences were observed in the application of basic CT parameters for the same population but in different sites.

ASSESSMENT OF DENTAL RADIOGRAPHY QUALITY ASSURANCE PRACTICES AMONG DENTAL OFFICES EQUIPPED WITH INTRAORAL X-RAY DEVICES IN GEORGIA

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Like other countries, nowadays digital radiography is the most common in dentistry in Georgia. Consequently, Quality Assurance (QA) of digital equipment is an essential part of both ensuring consistent high-quality imaging and radiation safety in dental radiography. Qualified and trained personnel employed in the offices is also a significant factor affecting compliance with quality assurance requirements. The purpose of this study was to assess the quality assurance practices of digital dental radiography in Georgia. In order to achieve the goal, we tried to determine whether the following factors influence the fulfillment of quality assurance requirements: type of practice (private office, specialized dental clinic or whether it is part of a multi-functional clinic), age of the practice and follow internal instructions by personnel. Assessments were conducted through visits by using the basic multifunctional radiation measurement tool and specially designed questionnaires. Basic parameters of the X-ray devices and information on quality assurance methods were collected. Each office was equipped with one or two intraoral X-ray units. Most practices demonstrated a high level of compliance with quality assurance requirements. Georgian dentists also try to comply with the national legal requirements and the recommendations of the Georgian Dental Association by following the internal instructions and using the knowledge gained during trainings on radiation safety.

A FREE AND OPEN-SOURCE SEMI-AUTOMATED QUALITY CONTROL WORKFLOW FOR PLANAR X-RAY IMAGES DESIGNED FOR INTEGRATION INTO QATRACK+

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Problem statement Routine Quality Control (QC) of radiological installations is an essential part of any comprehensive Quality Assurance (QA) programme and is a crucial pre-requisite for personalised clinical protocol optimisation. Such processes are mandated by European Directive 2013/59 and considered an essential component of patient radiation protection. Diagnostic medical physicists are often under intense pressure to perform QC of a large number of radiological systems. Current methods, predominantly spreadsheet-based, suffer from data/formula fragmentation, leading to inadequate data control and increased risk of errors in the acquired data. Open-source image quality QC tools that include the possibility of automation or semi-automation are limited.

Aim. This work provides a free, open-source tool for QC of diagnostic X-ray imaging systems that can be semi-automated and easy to integrate into the existing free, open-source tool QATrack+. Method A custom QC tool was written in Python and integrated into QATrack+. The approach is similar to the well-established tool for radiotherapy, PyLinac. As proof-of-concept, the following QC tests were implemented: Signal-Transfer-Property, uniformity, and pixel drop out. Results were validated against existing tools: namely the ImageJ plugins DRIQ and COQ.

Results. A free, open-source tool for QC testing of diagnostic X-ray images was written in Python and results compared favourably with existing tools. The tool is simple to integrate to an existing QATrack+ workflow and is easily extendible to cover additional QC tests. As an open-source tool it may be easily managed using a modern version control system, to ensure that modifications in analysis steps are fully audited and controlled, avoiding the main pitfalls of spreadsheet-based systems.

Conclusion. This work provided a platform for image quality testing of planar X-ray images that can be easily integrated into a QATrack+ workflow, permitting semi-automated QC testing that is easily available to the medical physics community.

Session 3B

Dosimetry in extreme situations: high dose rates, mixed fields, low dose rates, unknown radiation fields

DOSIMETRY IN EXTREME SITUATIONS: RADIOLOGICAL EMERGENCIES AND ARMED CONFLICTS

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In the case of large-scale radiological or nuclear emergency, dosimetry, based on modelling or measurement data is the key element for a fast and effective response, ensuring the safety of first responders and mitigating public health risks. In the early or pre-release phase of a radiological emergency, dose projections are usually based on modelling data (dispersion calculations), which are fast and effective but can be associated with large and difficult to quantify uncertainties, particularly concerning the source term. As the radiological incident progresses, a gradual transition from pure model predictions to a complete radiological characterization based on measurement data takes place, which can lead to adjustments and corrections in the previously recommended early protective actions. Individualized dose calculations based on monitoring data can be used as a filter to effectively target more time-consuming individual dose measurements (e.g. thyroid screening, bio- and fortuitous dosimetry) for a more accurate assessment of the individual health risk. In Germany, radiological situation reports are used as a basis for decision making in a radiological crisis, compiling all relevant information on the radiological situation, its impact and likely future development. Core of the report is again the dosimetry-based illustration of affected areas, where radiological criteria for certain protective actions are exceeded. New challenges in emergency dosimetry have arisen due to armed conflicts and the threat of the use of tactical nuclear weapons, which require further development of decision support systems, testing of the robustness of radiation sensors, concepts to deal with partial loss of monitoring networks and the integration of citizen measurements. Ultimately, the aim is to enhance the resilience of emergency response systems through improved dosimetry, ensuring rapid and effective action in the face of radiological threats.

RADIATION PROTECTION IN THE EXPERIMENTAL HALL OF THE ELETTRA STORAGE RING

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Elettra-Sincrotrone Trieste is a multidisciplinary research centre specialized in the generation of high-quality synchrotron and free-electron laser light, with applications in materials and life sciences. The Elettra storage ring operates with electrons at nominal energy of 2.0 or 2.4 GeV, generating the synchrotron radiation that is currently channelled into 27 beamlines devoted to scientific research. Together with synchrotron radiation, parasitic bremsstrahlung and secondary radiation (high-energy gamma and neutrons) are produced as well, and can represent a radiological hazard for the scientists and all the workers in the experimental hall. Therefore, massive concrete shielding walls surround the storage ring to reduce the level of radiation to values that do not exceed the effective dose limit for the public (1 mSv/year). The experimental hall is thus an area not subject to the radiation protection constraints, and users working at beamlines do not need a personal dosimeter. Moreover, since the bremsstrahlung radiation may be channelled into the beamline, the first part of the beamline is always enclosed inside lead shielding walls, forming the so-called "hutch". Depending on the beamline characteristics, additional hutches and local lead shielding protections may be used. To minimize the radiological risk, a Personnel Safety System (PSS) is in place to control the access inside the hutches. The radiation in the experimental hall is monitored through real-time ionization chambers for gamma radiation and rem-counter detectors for neutrons, together with passive thermoluminescence dosimeters. The gamma/neutrons monitors can be interlocked with the beamlines' PSS by stopping the radiation and forbidding the access inside the hutches if certain dose thresholds are exceeded.

RENEB INTERLABORATORY COMPARISON – BIOLOGICAL DOSIMETRY FOR DOSES HIGHER THAN 2.5 GY

Bucher Martin (a), Endesfelder David (a), Pojtinger Stefan (b), Oestreicher Ursula (a) on behalf of the RENEB ILC participants
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A central focus of RENEB's (Running the European Network of Biological and Physical retrospective dosimetry) network activities is the organisation of Interlaboratory Comparisons (ILCs) to ensure high quality in sample preparation, analysis and dose estimation. In previous ILCs of the RENEB network, a tendency for systematic overestimation of the dose for reference doses above 2.5 Gy was detected for the Dicentric Chromosome Assay (DCA). However, only three out of 19 reference doses were higher than 2.5 Gy in the past RENEB ILCs and in all cases only an initial dose estimation in cytogenetic triage scoring mode was performed. Therefore, the aim of the RENEB ILC 2023 was to investigate whether the suspected systematic overestimation of reference doses above 2.5 Gy by the DCA could be confirmed by an ILC designed specifically for this research question. For this purpose, an acute, homogeneous whole-body γ-radiation exposure was simulated by *in vitro* irradiation of blood samples using a radionuclide Co-60 source at the Physikalisch-technische Bundesanstalt (PTB) in Braunschweig, Germany. Irradiations were performed in air with three reference doses (2.56; 3.41 and 4.54 Gy) at an air kerma dose rate of 527.4 mGy/min. In total 14 laboratories from the RENEB network participated in this RENEB ILC 2023. All participants received blind coded blood samples, performed the DCA and scored 250 cells per dose point manually or as many cells as possible semi-automatically according to the laboratory's standard procedure in a real radiation accident. All participants were able to provide dose estimations >2 Gy and almost all dose estimates were within ±1 Gy of the reference dose. No general trend for systematic under- or overestimation could be observed for manual scoring compared to the air kerma reference dose as observed in the past. Furthermore, the importance of harmonisation of calibration practices within a network and the need for regular intra-laboratory quality checks was demonstrated in order to achieve comparable results.

RADIATION PROTECTION AND SAFETY FOR THE EUPRAXIA@SPARC_LAB PROJECT

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The EuPRAXIA project aims at the construction of an innovative electron accelerator using laser- and electron-beam-driven plasma wakefield acceleration that offers a significant reduction in size and possible savings in cost over current state-of-the-art radiofrequency-based accelerators. The foreseen electron energy range of 1 to 5 GeV and its performance goals will enable versatile applications in various domains, e.g. as a compact free-electron laser, compact sources for medical imaging and positron generation, table-top test beams for particle detectors, as well as deeply penetrating X-ray and gamma-ray sources for material testing. The EuPRAXIA facility for beam-driven plasma acceleration is going to be constructed in Frascati, Italy, and is ready to proceed. The host lab is INFN National Laboratory of Frascati, and the electron beam driver will rely on the most compact RF technology available, namely, X-band structures developed in collaboration with CERN. User applications for EuPRAXIA@SPARC_LAB will focus on a 1 GeV free-electron laser with an upgrade to 5 GeV, an inverse Compton scattering photon source, high-energy positron beams, and test beams. EuPRAXIA is designed to be the required stepping stone to possible future plasma-based facilities, such as linear colliders for the high-energy physics research frontier. Consistent with a high-confidence approach, the project includes measures to retire risk by establishing scaled technology demonstrators. The actual time schedule would allow operation of the full EuPRAXIA facility within 8-10 years. A facility as unique as EuPRAXIA@SPARC_LAB poses unique challenges from a Radiation Protection (RP) point of view. An overview of the RP and safety requirements for general electron accelerator will be discussed but focusing on the RP challenges of a plasma-based accelerator such as the EuPRAXIA@SPARC_LAB one, together with the required safety procedure. In addition, some preliminary RP evaluation and Monte Carlo dose estimate are reported, considering the project's state of the art.

CALIBRATION OF DOSIMETRIC INSTRUMENTS IN POLAND

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In the field of radiological protection, the accuracy and reliability of radiation measurements are of paramount importance. This presentation examines the practical aspects of calibrating dosimetry instruments, providing a comprehensive understanding of the processes and principles involved. It also explores the theoretical foundations of ionising radiation dosimetry, which covers various types of radiation, including alpha, beta, X, gamma, and neutron radiation, as well as their interactions with matter. The core of the presentation addresses the calibration process, which is a critical step to ensure that dosimetry instruments produce consistent and comparable results. Calibration is achieved by comparing instrument readings with a standard reference, thereby correcting any discrepancies. The session will also cover the legal requirements for dosimetry instrument calibration as stipulated by Polish Atomic Law and related regulations, which mandate the possession of a valid calibration certificate for instruments used in radiation exposure control. This certificate must be renewed every 12 months, or every 24 months if a control radioactive source is used. The presentation will provide practical advice on how to commission the calibration of a dosimeter and how to effectively utilise the calibration certificate. It will also guide the selection of suitable dosimetry instruments, taking into account the type of radiation, measurement and energy range. The presentation will discuss the various types of detectors, including gas-filled, scintillation, and semiconductor detectors, in terms of their specific applications and performance characteristics. Furthermore, the presentation will emphasise the importance of measurement traceability, which ensures that results are linked to national or international standards through a continuous chain of calibrations, contributing to the overall measurement uncertainty. Participants will emerge from the presentation with a comprehensive understanding of the principles of dosimetry instrument calibration, thus equipping them to ensure precise radiation measurements and adherence to legal standards in their professional practice.

PRELIMINARY BEAM DUMP DESIGN RELATED TO THE FRASCATI LASER FOR ACCELERATION AND MULTIDISCIPLINARY EXPERIMENTS (FLAME) INSTALLATION UPGRADE

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The Frascati Laser for Acceleration and Multidisciplinary Experiments (FLAME) is an installation placed in the SPARC_LAB Test Facility, at the Frascati National Laboratories (LNF-INFN), to study the laser-matter interaction with solids and gases at high laser intensities, up to 10^{20} W/cm^2. Its upgrade consists of modifying the positioning of the interaction chamber inside the bunker, as well as structural changes to the bunker itself, such as the access staircase. For purposes related to the radiological protection of working personnel and members of the public, the design of a beam dump was conducted, aimed at absorbing the radiation produced in the interaction between the gas jet and laser, particularly electron bunches with energies up to 300 MeV. The proposed beam dump was structured to avoid the classification of areas within the entire building housing FLAME, to minimize activation contributions as much as possible as well as to meet the clearance levels outside the building itself. Thus, these radiation protection studies, performed through the Monte Carlo code FLUKA-INFN, were centered on the operational quantities estimation, mainly the ambient dose equivalent contribution related to the radiation field produced, and radionuclides production related to the normal working conditions.

TESTING DIFFERENT LUMINESCENCE MEASUREMENT PROTOCOLS FOR DISPLAY GLASS AS AN ACCIDENT DOSIMETER

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Luminescence dosimetry is a crucial tool in retrospective dosimetry for assessing the absorbed dose after a radiological overexposure. Components of a mobile phone serve as useful proxies for measuring the dose received by an individual. Various research groups have extensive experience in characterizing different elements of mobile phones (i.e. electronic components, display or touch screen glass) for physical retrospective dosimetry. In recent years, several measurement protocols have been developed for display glass using Thermoluminescence (TL) or Optically Stimulated Luminescence (OSL) methods. However, realistic testing through an irradiation experiment was lacking. This paper aims to collect the protocols, such as pre-bleached TL, Photo-Transferred TL (PTTL), and Thermally Assisted OSL (TA-OSL) protocols, which use different stimulation wavelengths and readout temperatures, and perform a dose recovery test. For this purpose, an intact mobile phone (Samsung Galaxy S3) was exposed to a Cs-137 gamma radiation source at the Korea Atomic Energy Research Institute (KAERI) and then disassembled for a chemical pre-treatment of the glass samples. The glass samples were then shipped to the Salzburg laboratory and stored in a drawer for 15-20 days to simulate a delayed dose reconstruction in a real-world exposure scenario. The available protocols were applied in Salzburg using a Lexsyg Research reader, and the so-called accident dose was reconstructed. The various measurement protocols were subjected to a realistic performance test, and the results are critically discussed and summarized.

AN INTERLABORATORY COMPARISON ON EPR ON TOOTH ENAMEL WITHIN THE EURADOS WG10

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EPR dosimetry of tooth enamel is known to be a powerful tool for individual retrospective dosimetry in accidental situations to assure that the dose threshold for deterministic effects or the annual dose limits, for workers and for the general public, were not exceeded. Common uses of the method are radioepidemiological studies (the dosimetric information is retained by teeth over many millennia) along with any other specific radiological event(s) where conventional dosimetry was not available. This contribution presents the preliminary results of a new Inter-Laboratory Comparison (ILC) on EPR with tooth enamel. A subtask was formed within the WG10 "External dosimetry" of the European Radiation Dosimetry Group. The design was based on an identified need for modern methodological validation based on prior ILCs. The idea of repeating a new ILC arose: 1) for the established EPR dosimetry laboratories, which have the necessity to maintain the harmonization and accuracy of their methods; 2) for the new laboratories, who have recently developed EPR dosimetric capabilities, which can now be compared to the prior established laboratories which previously participated in the ILCs. Twelve laboratories provided their results. Each of these reconstructed five blind doses after building a calibration curve with powdered samples irradiated at known doses. Primary consideration is given to correctly assessing delivered doses within uncertainties. After this, the implications on detection limits were evaluated.

RADIATION MONITORING SYSTEMS FOR THE TOP-IMPLART PROTON ACCELERATOR

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TOP-IMPLART (Terapia Oncologica con Protoni-Intensity Modulated Proton Linear Accelerator for Radiotherapy) is a pulsed RF proton linear accelerator developed as a prototype of a full linear accelerator for proton therapy applications in the framework of a Project funded by Regione Lazio. It consists of a 425 MHz injector followed by a 3GHz booster composed by eight linear modules accelerating the beam up to 71 MeV in 3 μsec pulses at a typical repetition frequency of 25 Hz. The modules are grouped in two sections and each section is powered by a 10 MW peak power klystron. The radiation monitoring system for Top-Implart performs the following functions:

1) Keep radiation doses of workers as low as possible, without exceeding established dose limits.
2) Keep the radiation dose to the public below the relevant dose limits.
3) Assess working conditions and individual exposures.
4) Ensure acceptably safe and satisfactory radiological conditions in the workplace.
5) Keep monitoring records, over a long period of time, for regulatory or good practice purposes.

The monitoring system is composed of the following subsystems:

1) Four fixed stations for monitoring the area and environment of gamma field and two fixed stations for neutron fields.
2) Two Portable Radiation Monitoring Equipment for Direct Radiation and Contamination Control.

Each measurement station is connected to a local control unit which displays the data expressed in equivalent quantities of ambient doses or equivalents and acoustically signals to exposed workers if the permitted doses are exceeded. The radiation monitoring system provides:

1) The recording of dose data to be able to carry out temporal analyses.
2) Reporting via email of malfunctions of the monitoring stations.
3) Reporting via email of malfunctions of exceeding the pre-alarm and alarm threshold of the doses allowed in the controlled areas.
4) The possibility of monitoring dose data, with synoptic panels and dashboards, accessible via web browsers on any device connected to the Local Area Network.
5) The possibility of exporting recorded data in the form of tables or files in an open format.

The radiation monitoring system integrates commercial hardware and open-source software for database management and data visualization through dashboards and graphic panels. In-house code developed in Python on Linux-like platforms integrated to the aforementioned software provides alarms communication and management.

RADIOBIOLOGIC IRRADIATION SETUPS EMULATING MEDICAL, NATURAL AND OCCUPATIONAL RADIATION CONDITIONS

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Introduction. Natural and artificial radioactive conditions such as exposure to radon and nuclear fissioning products are made up of multiple radiation qualities. This results in mixed field irradiation conditions with low and high Linear Energy Transfer (LET). Reproduction of these conditions for radiobiologic investigations as lifelike as possible, is, in most cases, very challenging and is rarely available in all institutions. This led to x-ray irradiation as most popular choice for biological investigations. However, recent studies show that a more individualized radiation protection approach is needed, as gender, age and inflammatory background have an influence on radiation responses. To further expand the relevant knowledge towards an individualized radiation protection, is to make controlled and stable irradiation facilities easier accessible. Therefore, the aim of this study is to present various technical schematics and ideas making use of radioisotopes/accelerators to emulate high and low dose, single and mixed-beam radiation conditions.

Methods. Conducting of literature research and generation of technical drawings, schematics and ideas for irradiation setups utilizing various radiation sources and qualities in a portable modular system that is easily combinable with already existing accelerators and radiation sources with dosimetric considerations and simulations.

Results. Different setups for radiobiologic irradiation reproducing exposure conditions as lifelike as possible accompanied with technical drawings and simulations were developed as well as a cell culture irradiation protocol with radon gas enriched media.

Conclusion. Individualized radiation protection requires extensive research with the inclusion of factors such as e.g. sex or radiation quality. Therefore, the goal to give access to easily buildable and reproducible irradiation facilities is a crucial step into making individualized radiation protection a reality.

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Session 3C

Dosimetry of medical operators

PROTON THERAPY - SPECIFIC RADIATION PROTECTION ISSUES

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In the last decade, the number of proton therapy centers has been quickly growing. As the treatment methods develop, knowledge and experience in the operation of these types of facilities increases and should be shared among regulatory bodies, radiation protection officers, medical physicists, radiation therapy technologists, standards organizations, equipment manufacturers, and suppliers. This experience contributes to the establishment of good safety practices for operating proton therapy facilities worldwide. The presentation focuses on radiological protection aspects at proton beam therapy facilities. Protons with energies up to 250 MeV interacting with equipment and patients produce secondary neutrons and induce short and long-living radioactive isotopes. Appropriate management and control are required for the therapy equipment which the particle beam and its secondaries can activate. The presentation highlights important radiation safety issues regarding protecting patients, staff, and the public. Many of the conclusions drawn from this work result from the experience gained during the operation of the Cyclotron Center Bronowice (CCB) at the Institute of Nuclear Physics of the Polish Academy of Sciences in Krakow - the first proton therapy center in Poland.

IMPACT OF CLINICAL WORKLOADS ON SHIELDING EVALUATION IN INTERVENTIONAL RADIOLOGY

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With the increasing use of interventional radiology techniques, reviewing the workloads to calculate the thickness of barriers and operator workload has become necessary. The study aims to provide updated workload distributions for various interventional rooms and update transmission curves through the lead to determine the shielding thickness. We have gathered the latest workload values for interventional radiology facilities covering angiography, haemodynamics, vascular surgery, electrophysiology, and neuroangiography. A comprehensive dose monitoring system (DoseWatch) acquired all necessary parameters, including kV and mAs, ensuring the reliability and accuracy of our data. We conducted a study of 3,066 procedures involving 214,697 individual exposures to determine kVp distribution and mAs normalised per patient for each speciality analysed. Using the mAs distributions, we obtained new transmission curves, using Archer's formula, for lead, which are useful in calculating the thickness of shielding required. Based on our workload and tube output, we calculated an annual unshielded air kerma of 33 mGy/year (d=2m) in haemodynamics and 81 mGy/year in neuroangiography. We used the new transmission curves to determine the necessary thickness of the lead barrier, which was found to be xhaem=0.6mm and xneur=1mm. If the tube output is unavailable, we derived the leakage and scattered radiation values from NCRP 147. In this case, we obtained an annual unshielded air kerma of 150 mGy/year in haemodynamics and 196 mGy/year in neuroangiography. The required thickness for shielding is xhaem=1.1mm and xneur=1.3mm. The work presented in this study is a pioneering effort, focusing on updating the workload distributions for interventional specialities as provided by NCRP 147. As far as we know, no such detailed analysis has ever been proposed before for interventional radiology, especially for such a long period. Our data analysis shows that the workload for neuroangiography exhibits an increased distribution at higher voltages. Using the NCRP 147 transmission curve suggested for peripheral angiography in a neuroangiography room may result in underestimating the barriers. In conclusion, our software could be useful to conduct regular analyses and detect any variations in workload and to enable multi-centre studies.

DEVELOPMENT OF A SPREADSHEET FOR CALCULATING BARRIER THICKNESS FOR RADIOTHERAPY BUNKER

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The purpose of radiation shielding is to limit radiation exposures to members of staff, patients, and the general public to an acceptable level within safe limits. Reference documents on this topic are NCRP Report No. 151 concerning structural shielding design for standard radiotherapy facilities that use megavoltage x-rays and gamma rays and IPEM Report No. 75 for non-conventional radiotherapy treatment facilities, such as vaults hosting CyberKnife radiosurgery systems and Tomotherapy machines. In recent years, the development of new technologies has underscored the limitations of the NCRP report. For instance, NCRP 151, while comprehensive, does not provide detailed guidance on the increased shielding requirements associated with Flattening Filter-Free (FFF) beams. These beams, with their significantly higher dose rates than conventional beams, could potentially increase the shielding requirements and affect the scatter and leakage calculations due to their more peaked dose distribution. Furthermore, both reports rely on analytical methods and simplified models for shielding calculations, which may not fully capture the complex interactions of radiation with materials and the environment, thereby limiting their applicability in certain scenarios. Due to the increasing number of factors that need to be considered when calculating barriers and to provide a more accurate calculation model, we have developed a functional spreadsheet on Microsoft Excel to ensure a correct and complete calculation of the thickness of the door, primary and secondary barriers. This spreadsheet implements the models proposed by the NCRP and IPEM reports and calculates the unlisted parameters by interpolation, thus enabling the simulation of various situations. The proposed spreadsheet facilitates the simulation of various vault geometries, the calculation of scattered radiation at different angles for energies ranging from 6 to 18 MeV, including FFF beams, and the estimation of the simultaneous production of neutrons. Implementing the interconnection between equations, formulas, and look-up tables enables real-time analysis by changing even one factor. Our method has been successfully tested with several examples of real situations, resulting in a reliable and efficient process. In conclusion, our proposed functional spreadsheet for performing site-specific calculations and simulations offers a practical solution to tailor shielding designs to the specific configurations and technologies in use. The integration of our spreadsheet not only enhances the effectiveness of shielding designs but also ensures that they meet the specific needs of radiotherapy bunker facilities, thereby improving the safety and efficiency of these facilities.

RADIATION DOSE MONITORING DATA ANALYSIS TO ESTIMATE RADIOLOGICAL RISK ALLOWANCE FOR INTERVENTIONAL RADIOLOGY STAFF

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This study aims to present a methodology for estimating radiological risk to staff members based on the analysis of updated workload distributions for different interventional procedures. Italian law 460/1988 stipulates that workers outside the radiology sector but exposed to similar risks as radiology staff may be eligible for radiation risk allowance. To address this, the Tuscany Regional Commission for the Prevention of Risks from Ionising Radiation, a recognized authority in the field, has published a document outlining a practical procedure for estimating the effective dose received by an operator. This method considers various factors such as parameters used, patient anatomical characteristics, personal protection devices, equipment characteristics and position of the operator. Our calculation method, starting from the proposed formula, is designed to consider the specific workload of our institution. This ensures that we can accurately calculate the radiation dose received by interventional radiology staff members during their daily activities. Using the dose monitoring system (DoseWatch), we acquired all necessary parameters, including kilovoltage (kV) and milliampere (mA) of 3,066 procedures involving 214,697 exposures divided into angiography, haemodynamics, vascular surgery, electrophysiology, and neuroangiography. We then determined the distribution of kV frequencies and the distribution of mA as a function of kV from each speciality. By inserting all parameters derived from our meticulous analyses, we used the formula proposed by the Commission to calculate a threshold time at which the effective dose limit of 1.5 mSv is exceeded. This value was set to provide a degree of precautionary protection to obtain the radiation risk allowance. In conclusion, our research not only enables us to implement a more accurate and centre-specific method for assessing the radiation risk allowance to interventional radiology staff members for each speciality, but also provides practical implications. The accurate data we have gathered could be instrumental in giving risk assessments to an employer before commencing a new activity, conducting regular analyses, and monitoring the staff exposure involved in these high-dose procedures. This underscores the relevance and usefulness of our findings in real-world scenarios.

EXPOSURE TO ACTIVATED AIR AND WALLS OF CLINICAL STAFF IN PROTON THERAPY CENTERS

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Radiotherapy using accelerated-protons has a growing potential in dealing with some tumors, and consequently, in the last decade the number of Proton-Therapy Centers (PTC) is increasing fast across the world, with a forecast that will double by the next five years. In Spain, there are two operating centers and eleven more under construction. In these facilities, prompt radiation attenuation is essential to achieve legal dose limits, but not enough to develop efficient radiation protection. Activation of mechanical elements (accelerator, beam parts), the environment (air, water, ground) and, of course, the shielding, is also a relevant issue. Activation affects the future dismantling of the facilities and the management of the radioactive materials produced along the operation, as well as, specially, the safe operational radiation protection conditions. Consequently, the goal of this work was to carry out exposure from neutron activation in shielding of PTC, depending on the type of concrete in barriers, and in the air of the vaults of the facility. Two different Monte Carlo codes (MCNP6 and PHITS) and the state-of-the-art of nuclear data evaluations have been used to estimate the ambient dose by activated walls to staff and users of the proton therapy center facilities. Considering the energy of neutrons, up to 230 MeV, and the generation of radioisotopes through capture and spallation reactions, both, several physics models, and nuclear data libraries were used and benchmarked. The most demanding venue is logically the accelerator room, with an increasing ambient dose rate that could reach up to 10 uSv/h, after 20 years of operation, depending on the type of concrete used. In terms of air activation the main source of exposure is ^{41}Ar, produced by neutron capture.

OCCUPATIONAL RADIATION EXPOSURE OF MEDICAL STAFF INVOLVED IN ERCP

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In Japan, the Regulation on Prevention of Ionizing Radiation Hazards was revised in April 2021, and the equivalent dose limit for the lens of the eye was reduced from 150 mSv/y to 20 mSv/y. This significant reduction from the previous dose limit requires strict control. The lens of the eye equivalent dose for physicians performing Endoscopic Retrograde Cholangiopancreatography (ERCP) in Japanese hospitals has been reported as relatively high. One reason for this is that many facilities use over-table fluoroscopic equipment. Similarly, medical staff who work beside physicians should also be aware of radiation exposure. In particular, nurses have many opportunities during fluoroscopic procedures to approach the patient's body, representing the source of scattered rays, and care for the patient, and thus need to take extra precautions. However, few reports have investigated radiation exposure for medical staff involved in ERCP, so further investigation is needed. This study evaluated the exposure of non-physician medical staff involved in ERCP, focusing mainly on physical positions. Eighty-four cases of ERCP performed between January and December 2023 were included in the study. Active dosimeters were attached to the outside collar of the lead apron worn by medical staff during ERCP. Medical staff positions were classified as: A (n=10), <1.0 m from the X-ray tube at the patient's head; B (n=64), <1.0 m from the X-ray tube at the patient's foot; C (n=76), 1.0-2.0 m from the X-ray tube at the patient's head; and D (n=36), 1.0-2.0 m from the X-ray tube at the patient's foot. Exposure doses were analyzed. The fluoroscopic equipment was an over-table type with leaded radiation protective curtains. Median doses to medical staff per case were 2.0 (0.0-12.0) μSv in A, 15.0 (0.0-295.0) μSv in B, 2.0 (0.0-47.0) μSv in C, and 11.0 (0.0-107.0) μSv in D, showing a difference in exposure dose depending on the position ($p<0.001$, Kruskal-Wallis test). Positions closer to the X-ray tube and closer to the patient's feet showed higher exposure doses. The maximum value of 295.0 μSv for B was higher than that of physicians, and some cases showed maximum values as high as 107.0 μSv for D, representing a position far from the X-ray tube. Passive dosimeters are unsuitable for determining the cause of unexpectedly high exposure doses. So, active dosimeters should be worn, and dose values should be checked at least at the end of each treatment. Whether staff are positioned too close to the X-ray tube or not properly utilizing protective equipment should be reviewed.

EFFECT OF FURNISHING ON MONTE CARLO DOSE ESTIMATION IN NUCLEAR MEDICINE THERAPY PROTECTED ROOMS

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This work is part of a wider research project aimed at developing an online dose calculation tool, which integrates environmental dose field maps and motion tracking, for workers exposed to patients undergoing radionuclide therapy in protected rooms. This system can be used in situations where conventional dosimeters may be inadequate or unavailable, such as in case of an accident, and relies on a library of radiation field maps collected from simulations of both routine and accidental scenarios. The presence of diffuse radiation from walls and furniture can modify the dose field maps and, consequently, the estimated dosimetry for workers, in a not easy way. A Monte Carlo code, based on Geant4, was developed to estimate the external dose in a nuclear medicine therapy room in order to investigate, in some preliminary scenarios, the impact of the walls and furniture (such as the bed, chairs, metal accessories, etc.) in the room, together with their geometrical and material properties, when included in the simulations. The I-131 isotope, widely used in a nuclear medicine, was simulated as a point source according to its electron and gamma emissions spectra. This allowed to separate the contribution of the two primary particles to the total external dose. In the first simulated scenario, the source was positioned on a chair close to the wall. The effect of the presence of the wall and/or the chair was studied in four scenarios, where the absence of each was simulated by filling them with air: i) no walls and no chair; ii) only walls and no chair; iii) only chair and no walls; iv) both chair and walls, i.e., the real-world scenario. The field maps calculated for the different scenarios were compared. As a preliminary result, the four scenarios showed an increase in the external dose in the range of 5-10%, which could be roughly added to the simple air scenario if a fast simulation is desired. Further studies are in progress, involving more complex and realistic scenarios, to confirm or not the obtained results.

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PRELIMINARY DISCUSSIONS ON IMPROVING OCCUPATIONAL RADIATION PROTECTION FOR PREGNANT FEMALE WORKERS

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The Radiation Council of Japan discussed the incorporation of the International Commission on Radiological Protection (ICRP) 2007 Recommendations in domestic regulations. A key theme of these discussions is the occupational radiation protection of pregnant female workers. The second interim report of the Basic Committee of the Radiation Council on the incorporation of the ICRP 2007 Recommendations, issued in 2017, states the appropriateness of considering dose management for female workers in collaboration with relevant government ministries and associated academic institutions that are familiar with radiation protection. In other words, the report emphasizes the need for preparing dose control for female workers in the government and academic sectors. A future challenge lies in scientifically demonstrating the evidence that the additional dose to the embryo/fetus remains <1 mSv during the remainder of the pregnancy after notifying employers and others involved, as recommended by the ICRP 2007 Recommendations. The authors discuss two perspectives on radiation protection for scientific evidence: external and internal exposures of the mother. Generally, managing to keep the maternal effective dose from external exposure not to exceed 1 mSv in general situations ensures that the dose to the embryo/fetus is <1 mSv under conceivable conditions, and further confirmation of the scientific basis of this association is warranted under various scenarios such as different irradiation energies, geometries (e.g., AP irradiation, PA irradiation), and maternal physiological changes with fetal growth. Regarding internal exposure management, the authors need to confirm the latest findings on the association between maternal effective dose and fetal dose for different pathways of internal exposure because of radionuclides, such as inhalation and ingestion, from pregnancy notification to childbirth. Further studies may be warranted as deemed necessary after confirming these findings. Moreover, discussions are required on managing radionuclide intakes by the mother before pregnancy from the perspective of fetal exposure management as the ICRP Publication 88 recommended.

Session 4

Debate: Future approaches for low dose research

CAN SEQUENCING TECHNOLOGY LEAD US INTO A HIDDEN GARDEN OF RADIATION RESEARCH?

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Topics central to radiation protection research are the shape of the dose response curve at low dose and low dose rate, the impact of inhomogeneous delivery and further confounding factors such as age, gender and genetic susceptibility. Epidemiological studies, aided by our mechanistic understanding of the DNA damage response, have been central and highly valuable approaches to generating risk estimations but substantial uncertainty remains and epidemiological approaches have limited capacity to enable the interplay of these factors to be dissected. Advanced technologies in life sciences could have the potential to address some of the critical questions, opening a hidden garden. Indeed, gaining insight into the genome and epigenome changes caused by radiation will be an important step in understanding mechanism. Making the assumption that the induction of DNA damage and its subsequent misrepair to generate mutations is a key step for radiation induced carcinogenesis, then probing the nature of these changes in DNA sequence has the potential to provide a surrogate biomarker of late occurring radiation induced cancer. Importantly, the mutational data obtained can then be tested and probed using model systems, such as mice. There will certainly be additional factors, such as chronic inflammatory reactions, which could facilitate the growth of mutated pre-neoplastic cells, but that could also be unravelled using new life-science technologies. Once a marker of radiation-induced mutations and epimutations is identified (as is being initiated for mutation, for example by Matusda, Y., et al. 2023, we can assess the dose and dose-rate dependency, the impact of genetics and epigenetics to assess the influence of proliferation on outgrowth of mutated cells. The impact of bystander mutations, which should have a different signature, could also be assessed. Probing the epigenetic changes could provide a further layer of insight. Thus, sequencing technology is progressing enormously and has the ability to help advance radiation research through providing insight into mechanism with a route to experimental dissection. Further, additional advancing technologies, which, for example, can assess the role of stem cells, can provide insight into mechanism. To address and exploit these rapidly advancing technologies, we may need to ask the questions initially using higher doses, and subsequently tackling what happens at low doses. We need also to interface with bioinformatics and similar emerging technologies. Such approaches can be important for ecologists, oncologists and other radiation focused stakeholders. The costs of these technologies are high, so that interacting in a cross disciplinary manner can be beneficial. Over the past years, the fields of radiation oncology, radiation protection, radiation ecology have become increasingly separated, especially in funding categorisation. Is now the time to refocus and use the emerging technologies in a united manner.

CHALLENGES IN ASSESSING TRANSGENERATIONAL EFFECTS OF LOW DOSE RADIATION EXPOSURE USING WHOLE GENOME SEQUENCING

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In considering radiation protection, it is important to understand the transgenerational effects of radiation exposure. RERF has conducted a long series of clinical, biochemical and epidemiological studies of the effects of radiation on the children of atomic bomb survivors. So far, no clear effects of parental exposure on the children have been observed. Recent advances in DNA sequencing technology have facilitated the analysis of mutations at the whole-genome level in humans and mice. Therefore, we are planning to use this technology to study the effects on the population of the children of atomic bomb survivors. This research will facilitate our understanding of radiation's transgenerational effects at the genomic level and may lead to the development of a new dosimetry system that uses the number of radiation-induced mutations as an indicator. To elucidate the effects of lower doses of radiation exposure, we are collaborating with outside researchers to conduct studies in mice. We have bred mice under varying dose rates (0.05-20 mGy/day gamma-ray exposure) and investigated the occurrence of de novo germline mutations. The results showed an increase in the number of mutations occurring in the 20 mGy/day irradiation group. This result suggests that analysis of mutations occurring at the whole genome level is useful for quantifying the effects of low-dose exposure. We have also succeeded in developing a new method to easily examine the history of mutation occurrence *in vivo* by applying sequencing technology. This method can be used not only for the analysis of transgenerational effects, but also for the study of the effects on the exposed individuals themselves. In this presentation, we will introduce the application of whole genome sequencing, which can quantify the biological effects of radiation, including low doses. In addition, future research that may become possible with further technological advances will be discussed.

STRATEGIES AND TECHNOLOGIES FOR ELUCIDATING THE BIOLOGICAL EFFECTS OF LOW-DOSE RADIATION

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To improve radiological protection, understanding the biological effects of radiation based on new scientific findings, particularly those of low-dose/low dose-rate exposure, is critical. The research required to address these effects spans from the quantum level to the organismal level, necessitating an integrated approach. As such, a comprehensive research strategy must include both a versatile metric that applies across different fields and a robust technical methodology. We have developed and implemented a variety of technologies based on the working hypothesis that carcinogenesis results from mutations in tissue stem cells caused by DNA damage, especially DNA Double-Strand Break (DSB). These technologies include lineage tracing to elucidate the turnover of gastrointestinal stem cells, live-cell imaging of DSB foci and the cell cycle, organoid culture, and predictive mathematical models. Using this strategy, we aim to verify the dose-rate effect on the dynamics of stem cell competition. In recent years, however, the notion that carcinogenesis is driven not only by mutations in stem cells but also by interactions with their surrounding microenvironment has gained increasing attention. To incorporate this perspective, we are developing new technologies, such as lab automation for the acquisition of precise multidimensional data and tissue clearing techniques to assess the dynamics of whole-tissue responses. In the future, we plan to explore how the combination of these technologies can help clarify the effects of low dose and low-dose rate radiations, presenting this as a key issue for further investigation.

Session 5A

Biological and health effects of low dose exposure (I)

INVESTIGATING PERSISTENCE OF RADIATION DAMAGE IN HAEMATOPOIETIC STEM CELL SUBPOLULATIONS INDUCED BY DIRECT IRRADIATION OR BY BYSTANDER SIGNALS

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Haematopoietic Stem and Progenitor Cells (HSPCs) have key roles in haematopoiesis and in maintaining the long-term functional integrity and regenerative capacity of the haematopoietic system. HSPCs are a heterogeneous group of cells composed of minimum three main subgroups: long-term HSCs, short-term HSCs and multipotent progenitors. Long-term consequences of ionizing radiation might manifest in multiple ways. A forced proliferation within the stem cell pool to recover ionizing radiation-induced cytopenia might lead to stem cell exhaustion and bone marrow insufficiency in the long run which might result in the development of a myelodysplastic syndrome. A deficient or inefficient repair of radiation-induced DNA damage might lead to persistent genomic instability with the potential to increase the risk of leukaemias. While these processes were identified at the level of HSPCs, there are very few studies investigating the most sensitive target cell types within the HSPC population. Moreover, the role of low doses as well as the contribution of radiation-induced bystander signals to HSPC damage are not yet well understood. Our study aims at investigating the time kinetics of cellular damage after low (0.1Gy) and high (2-3 Gy) irradiation in the different HSPCs. We also investigate the role of radiation-induced bystander signals (transmitted via extracellular vesicles released by the bone marrow of irradiatied mice) in these processes. We measured proliferation capacity, cell cycle distribution and persistence of DNA double strand breaks in the individual cell populations. Mice were either irradiated with the indicated doses or were treated systemically with bone marrow-derived extracellular vesicles of irradiated mice. Cellular damage is measured at regular intervals up to three months after irradiation or extracellular vesicle treatment. Our preliminary data indicate that HSPC subpopulations are sensitive to both low and high dose irradiation but their sensitivity varies. Decreased HSPC numbers were detected both after 0.1Gy and 3 Gy irradiation but DNA double strand breaks were only seen after high doses. A strong and persistent increase in the proliferative capacity was present in HSPCs from mice irradiated with high doses. The contribution of bystander effects is currently under investigation. In conclusion, our studies will contribute to the identification of the most sensitive target cells within HSPCs for the long-term radiation damage within the bone marrow.

SEX DRIVEN EFFECTS OF OSTEOIMMUNOGENIC CELLS AFTER LOW-DOSE IRRADIATION

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Upcoming new technologies in science and medicine from the radiation community are accompanied with great interest of radiation protection of the individual. Safety regulations are mainly derived from male data although the immune system, one of the targets of irradiation, has sex-specific differences. Due to a close interaction between the immune system (e.g. Macrophages MPH) and bone metabolism (e.g. Osteoclasts OC), alterations in these cells and in their interplay with each other are possible. Here, we investigated alterations in murine MPH and OC after Low Doses of X-ray (LD-RD) in a sex-dependent approach. Bone marrow of hind legs from wildtype C57/BL6 mice of both sexes was isolated. MPH were generated via stimulation with cytokines into M0, M1, M2 subsets while OC were derived into general and inflamed-like OC. MPH were exposed to single doses of 0, 0.1, 0.5, 1, 2 Gy while OC received also 0.3 Gy and respective fractionated doses applied in two sessions. Reactive Oxidative Species (ROS) and surface markers were assessed via multicolor flow cytometry. Furthermore, supernatants and RNA were taken and TRAP staining was used to observe differentiation patterns of OC. Irradiation led to no change in the expression patterns of surface markers in MPH subsets of both sexes. iNOS levels in M1 supernatants significantly decreased at 0.5 Gy while iNOS in males was significantly higher compared to the female cohort. ROS levels of MPH as well as OC decreased with increasing dose in female and male with particularly low levels in TNFα treated OC. Analysis of OC: precursor ratio in the female cohort showed a relatively decreased amount of OC in irradiated conditions with less fluctuations in non-inflamed OC in contrast to OC treated with TNFα. First results show a sex-dependent influence after LD-RD especially in oxidative stress of MPH. Apart from that, a radiation-mediated dose-dependent answer in the ROS levels of both cell types was seen as well as in the differentiation patterns of OC. Further analysis will reveal the impact on the communication between MPH and OC. In total, our results show the influence of relatively low-doses on osteoimmunogenic cells of both sexes in healthy individuals and discuss the potential need for improvement of safety in institutions with handling of X-ray. Supported by the BMBF (TOGETHER, 02NUK073).

BIOLOGICALLY-BASED ASSESSMENT OF MINIMUM LATENCY TIME BETWEEN RADIATION EXPOSURE AND CANCER

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After the initial cellular damage by ionizing radiation, a certain period of tumour development is required before radiation-associated cancer can be clinically observed. This period can be split into an arrival time of the first malignant cell and a tumour growth time until detection. The tumour growth time can be interpreted as a minimum latency time. It is difficult to assess such minimum latency times from radio-epidemiological data. In radiation risk models 5 or 10 years for solid cancers, and 2 years for leukaemia are often chosen for minimum latency. Here, we estimated minimum latencies for various cancers from clinical tumour growth data. A stochastic biologically-based model was developed that describes the growth from a malignant cell to an observable cancer. The parameters of the model depend on tumour volume doubling time, detection probability and cellular packing density. There was wide variation in tumour growth rates. While most solid tumours were compatible with a minimum latency time between 4 to 11 years, the growth rates were particularly slow for prostate and thyroid cancer and particularly fast for leukaemia. Two empirical latency functions have been used to model latency in a continuous form including uncertainties. They are implemented in the software tools ProZES and IREP for assessment of the assigned share of cancer from ionizing radiation. It was shown that by proper adjustments of the parameters both empirical latency functions closely approximated the predicted biological model cumulative probabilities. Minimum latency times are an important element of lifetime risk assessments and should, therefore, be considered in greater detail for specific organs or organ groups. Our results, illustrating use of a stochastic biologically-based model using clinical data not tied to any particular carcinogen, have implications for estimating latency associated with any mutagen. Furthermore, they can be useful in planning screening for cancer using medical imaging techniques.

EFFECTS OF LOW-DOSE RADIATION ON SENESCENCE IN THE CONTEXT OF AGING AND ASSOCIATED RISKS DISEASE

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Cellular senescence plays a major role in aging, as well as in a range of aging-related human diseases, including those of major concern in human radioprotection. Conflicting results have been reported regarding the effects of low doses and low-dose rates on cellular senescence. In a series of *in vitro* and *in vivo* studies, the modulation of senescence and associated mechanisms were examined using external acute gamma-irradiation at Low Doses (LDR). When C57Bl/6J male mice were exposed to LDR at a young age, reduced markers of cellular senescence were noted in the kidney at 26 months of age. A more pronounced effect was observed when mice were irradiated in mid-life. Exposure of normal human fibroblasts to LDR at early passages resulted in a slower rate of accumulation of senescent cells in culture, although control and LDR-exposed cells reached 100% senescence at the same time. Mechanistic studies revealed a role for epigenetic miRNA gene expression and suggested the involvement of Sirt7 and related pathways, including the regulation of inflammation. This was further confirmed using knock-down experiments in an oncogene-induced senescence model. The role of senescence in other LDR animal studies of non-cancer diseases will be discussed in the context of aging. The results of the presented studies and the proposed concepts on the role of aging in the development of human pathologies may be of great importance to the system of human radioprotection in the context of the ongoing reassessment of the foundational scientific knowledge base.

PLEASE MIND THE GAPS! HOW AOP APPROACH FOR RADIATION-INDUCED CVD STRENGTHEN THE ROLE OF BIOLOGY IN RADIATION PROTECTION?

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Biological studies are designed to elucidate the mechanisms underlying the development of radiation adverse effects. These mechanistic insights are critical for the development of targeted therapies and interventions. They are important for the evaluation of risk associated with radiation exposure and its potential health effects. In the Adverse Outcome Pathway (AOP) framework, researchers construct causal chains of key molecular and cellular events in the progression of diseases. This knowledge is critical for developing early detection methods and prevention strategies in at-risk groups. Radiation AOP has been applied traditionally to structure our knowledge of radiation-induced diseases and to facilitate the integration of biological and epidemiological data to provide a comprehensive understanding of radiation adverse effects. The application and compilation of biological data on radiation-induced CVD have demonstrated that their use in the AOP framework is useful. However, the AOP framework has also identified knowledge gaps and highlighted the need for research in radiation biology related to CVD. Even more than the knowledge gaps identified by the AOP approach, analysis of the quality and quantity of available data indicates that some of the experimental results do not meet the criteria for evaluation in the AOP framework. This presentation explores how our available data needs to be improved for use in the development of AOPs. It also highlights the identified research gaps that need to be addressed in the near future for the development of AOPs for radiation-induced CVD.

Session 5B

Exposure of members of the public and environment with regards to legacy, waste management and decommissioning issues

ESTIMATION OF NEARFIELD INHALATION DOSES FROM DECOMMISSIONING OF CONTAMINATED BUILDINGS

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Open-air demolition of radioactively contaminated buildings will lead to the dispersion of radionuclides in the immediate vicinity of the buildings. Characterizing the radiological risk to bystanders, especially on-site workers, is essential to developing appropriate decommissioning and demolition protocols. Of course, pre-decontaminating materials prior to demolition is the preferred option given the waste reduction options, but it is not always technically feasible for penetrating radionuclides like tritium. Open-air demolition, where the contaminants stay fixed in the building materials has the risk of radionuclide resuspension, but that risk could be managed through a combination of detailed bystander dose assessments ahead of time along with on-site monitoring regimes during the actual demolition work. The challenge with estimating radionuclide dispersion in a built-up area, however, is that the emission source is complex and wind-driven dispersion profiles in the vicinity of the source is strongly dependent on spatially varying surface topology and nearby buildings. This is also one of the known limitations of traditional Gaussian dispersion codes. In this work, we use high-fidelity Computational Fluid Dynamics (CFD) models for high-resolution assessments of nearfield radionuclide dispersion from an open-air demolition of a building on a complex site. The terrain and building geometries of the Chalk River site of Canadian Nuclear Laboratories, used as a test case, are reconstructed from detailed aerial scans and meteorological models are implemented using local climate data. A methodology for adopting CFD dispersion data for direct immersion from the plume and a model for radionuclide ingress into building spaces is proposed for estimating the expected annual inhalation dose, with outdoor and indoor (in adjacent buildings) being the two modes with which people would be exposed. The test case at the Chalk River site is used to determine general conclusions, recommendations, and the added value of the CFD-based methodology, with the expectation that the findings from this study could be applied to other decommissioning or demolition cases.

CLEARANCE LEVELS BUREAUCRACY AND RADIATION PROTECTION

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The dismantling of a nuclear plant produces large quantities of potentially contaminated and activated materials. An approach that combines sustainability and radioprotection allows to reduce the quantity of radioactive waste separating what can become a material for recycling and recovery from what will become radioactive waste. Italian legislation more stringently implements the clearance levels of Directive 2013/59/EURATOM. The values for some radionuclides with low radiotoxicity such as ^{63}Ni, ^{59}Ni, ^{3}H, ^{14}C or ^{55}Fe are considerably lower but so some other more dangerous radionuclides such as ^{241}Pu for example. This work starts from the set of typical radionuclides of a clearance formula and the related limits. We consider only the low radiotoxic radionuclides ^{63}Ni, ^{59}Ni, ^{3}H, ^{14}C and ^{55}Fe, the impact is assessed as committed equivalent dose to representative person in the hypothesis that the Italian legislation moving closer to the European Directive. The calculation methodology used is derived from the IAEA Safety Reports Series n° 44 and the work demonstrates how a significant variation of the clearance levels for these radionuclides produces an impact without radioprotection relevance (<0.2 μSv/y of committed effective dose). The work continues by taking the statistical distribution of the radioactivity content (Bq/g) of ^{63}Ni in an inventory of materials produced by the dismantling of a nuclear plant (BWR). The probability density of released materials is estimated as a function of the clearance level of ^{63}Ni. In order to achieve a sustainable approach, it is demonstrated that the increase of clearance level can produce a significant decrease in the quantity of waste (above 20%) with an irrelevant radiological impact (<0.02 μSv/y of committed effective dose).

DRONE-GAMMA: UNMANNED AIRBORNE VEHICLE FOR REMOTE DETECTION OF GAMMA-EMITTING RADIONUCLIDES

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There are scenarios in which radioactive material can be released into the environment, such as accidents involving nuclear material, installation decomissioning, or legacy sites, among others, which may pose a significant radiological hazard to the workers involved. The use of Unmanned Aerial Vehicles (UAV) for remote detection of radionuclides in these scenarios can avoid the exposure of this personnel, while accomplishing the radiological characterization of the area. In this sutdy, we present the developments already carried out in our laboratory with an unmanned airborne/aerial vehicle (drone type, octocopter FPV8) equipped with γ-spectrometres for the reamote detection of radionuclides. Several γ-spectrometres of different characteristics (CsI(Tl), $LaBr_3$(Ce), and NaI(Tl)) were tested in order to analyze their response, stability regarding temperature changes and angular response of the incident radiation. Additionally, a specific software was developed to communicate with the drone and integrate the measurements in the Early Warning Radiological Network of Extremadura (RAREx), which is able to report any anomalous radiological data, as well as isodose maps, directly to the Spanish regulatory body, the Nuclear Safety Board (Consejo de Seguridad Nuclear). Different scenarios were considered so as to provide an approximate quantification of the radionuclides involved in addition to their qualitative identification and estimation of the dose rate.

Acknowledgement: This work is funded by the Spanish Nuclear Safety Council (Consejo de Seguridad Nuclear) through the project "Drone-gamma: sistema de monitorización gamma remota en tiempo cuasi-real". We also thank the Junta de Extremadura for its support to the LARUEX research group (FQM001).

EVIDENCE OF CONTAMINATION OF THE URDZHAR DISTRICT OF ABAI, KAZAKHSTAN, FROM THE CHINESE NUCLEAR WEAPONS TESTING PROGRAM AT LOP NOR

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The contamination of eastern Kazakhstan from atmospheric nuclear tests performed at the Semipalatinsk Nuclear Test Site (SNTS) between 1949 and 1962 is well known. Here, we review archival and contemporary evidence that settlements in the Urdzhar district of SE Abai Region of Kazakhstan were contaminated by nuclear tests performed by China at Lop Nor, Xinjiang. The results of prompt sampling performed within days or weeks of the Lop Nor tests suggest highly elevated activity levels of short-lived fission products following two thermonuclear Lop Nor tests in particular, performed in June 1967 and June 1973. Evidence from Electron Paramagnetic Resonance (EPR) of tooth enamel of residents of the Urdzhar district suggests doses in excess of background levels. Contemporary evidence of contamination is limited. Soil activities of Cs-137 in the area are within the range expected from global fallout. Pu-240/Pu-239 isotope ratios in the study region are lower than typical of global fallout, but higher than for sites closer to SNTS. However, similar analysis of soil samples in China, between Lop Nor and Kazakhstan suggests contamination by global fallout only, although information on characteristic Pu-240/Pu-239 ratios for Lop Nor tests is limited. Future work will involve gathering further samples and investigating the potential for performing an epidemiological analysis of health effects in affected settlements.

STATISTICAL ANALYSIS OF THE SAMPLING GRID FOR THE RADIOLOGICAL CHARACTERIZATION OF A SITE

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Environmental reclamation involves the management, control and verification of significant quantities of land. In the nuclear field, in order to guarantee the radiation protection of the population, it is necessary to characterize the quantities of pollutants with the best possible care. On the other hand, the scale of sampling methods and related measurements can easily lead to a waste of resources, especially in the case of large areas associated with a dense sampling network. The analysis of the statistical parameters of some radiological variables of interest: the statistical distribution of total alpha and beta as well as of some gamma emitters, and their averages and variability, can lead the scholar to reconsider the procedures from a sustainability perspective. In particular, spatial analysis can give indications in this sense. In this work, we present a case study in which the variability of the parameters are used to obtain the optimal sizing of the sampling grid in terms of sustainability and safety of the population, examined through the open-source software R. The distribution of specific activities are approximately lognormal, as already reported in the literature. This is taken into account in the mixed model study that was carried out. The optimal number of meshes and samples per mesh is calculated through the analysis of the statistical power of the estimators.

CHARACTERIZATION AND REMEDIATION OF 8 UNDERGROUND TANKS CONTAINING WASTE POTENTIALLY CONTAMINATED WITH 3H AND 14C

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At a hospital facility, 8 tanks containing waste potentially contaminated with ^{3}H and ^{14}C were buried underground. Campoverde was appointed for the characterization of the tank contents, aimed at radioactive waste management and site remediation. The material in the tanks had a very heterogeneous composition, with a mixture of solid and liquid phase, the solid component being composed of vials, cuvettes, and other plastic material. The activity therefore presented multiple challenges, related to radiation protection and waste management aspects, due to the high degree of initial uncertainty. After creating a confined area above the tanks, these were emptied through a customized explosion-proof aspiration system. The liquid phase was then transferred in 1000-liters tanks (IBC-1000 type), while the solid materials were stored in 220-liters drums. In parallel, a working area was created, constituted of a pre-fabricated container, constantly kept in depression through a ventilation system with absolute charcoal filters, equipped with a decontamination circuit, a vibrating screen and a shredder with solid-liquid separation. The solid materials were radiologically surveyed on the vibrating screen before shredding, and the shredded materials were conveyed in a 220-litres drum after separation of the liquid component in a containment tank. The operations produced 25 m^3 of shredded solid material, stored in 128 drums, and 39 m^3 of liquid material, stored in 43 IBC-1000 tanks. Taking statistical representativity into account, a total of 128 solid samples were withdrawn and treated through leaching, while 25 solid samples were treated through controlled combustion, before being analyzed to determine the ^{3}H and ^{14}C concentration. Likewise, 43 liquid samples were withdrawn and analyzed. After emptying, wipe tests and scraping samples of the tanks were performed, as well as samples of the material underneath the tanks, in order to determine possible contamination traces. Based on these analyses, it was possible to release the area from any radiological constraint. The drums were eventually safely stored in containers and grouped based on the level of activity concentration detected in each drum, distinguishing different waste management scenarios, depending on whether they were potentially suitable for clearance. Approximately 73% of the solid waste and 72% of the liquid waste revealed to be potentially destined for clearance. All activities were performed under the supervision of a Radiation Protection Expert, and were carefully planned and carried out considering radiation protection risks as well as the other risks potentially present, as working in confined areas.

Session 6A

Biological and health effects of low dose exposure (II)

EXPLORING THE SYSTEMIC IMPACT OF IONIZING RADIATION: MIRNA CHANGES IN BLOOD-DERIVED EXTRACELLULAR VESICLES AND THEIR CELL-SPECIFIC EFFECTS

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The harmful effects of ionizing radiation on healthy tissues restrict the radiation dose that can be safely used in cancer treatment, thus limiting its effectiveness. Consequently, it is crucial to thoroughly understand how normal tissues respond to radiation to predict the risk of toxicity and develop strategies for tissue protection. Among the consistently affected non-cancer cells, Peripheral Blood Mononuclear Cells (PBMCs) exhibit high radiosensitivity and have the potential to induce systemic effects. This study aimed to explore how ionizing radiation impacts Extracellular Vesicles (EVs) produced by PBMCs, focusing on their miRNA content and biological functions as part of the systemic response. Whole blood samples from healthy donors were irradiated (0 Gy, 1 Gy, 2 Gy, 4 Gy) and EVs from PBMCs were isolated after 96 h by PEG precipitation or ultracentrifugation. Candidate microRNA were examined in PBMC-derived EVs from individual donors. The uptake of membrane stained fluorescent EVs by different recipient cells was quantified by fluorescence-activated cell sorting analysis. The biological effects of radiation-increased miR-34a-5p and of total EVs on recipient cells were assessed. Irradiation of PBMCs induced a dose dependent, however, individual upregulation of miR-34a-5p within EVs and PBMCs. Irradiation in presence of the ATM inhibitor KU 60019 demonstrated that this upregulation is dependent on ATM activation. Moreover, fibroblasts and keratinocytes were identified as preferred EV recipients. Increased miR 34a-5p levels led to a significant reduction in viability and induction of senescence in keratinocytes but not in fibroblasts, indicating a cell type-specific response. In conclusion, this study provided deeper insights into the complex cellular responses of normal tissues following radiation exposure. It verified that radiation induces deregulation of microRNAs in EVs from PBMCs, with a significant upregulation of miR-34a-5p in the small EV subfraction, highlighting this miRNA as a promising new candidate for developing biomarkers of radiation exposure. Additionally, the varying uptake efficiencies among different cell types indicated that EVs provoke cell type-specific responses in the intercellular communication of systemic radiation effects.

EFFECTS OF ACUTE AND CHRONIC IRRADIATION ON THE HIPPOCAMPUS IN APOLIPOPROTEIN E DEFICIENT MICE

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Apolipoprotein E (ApoE) is a lipid carrier active in both the peripheral and central nervous systems. ApoE lipoprotein particles, loaded with lipids, bind to various cell surface receptors to maintain membrane homeostasis and aid in brain injury repair. This study aimed to investigate the role of ApoE in the hippocampus of mice, particularly in response to radiation-induced injury. To this aim, 8-week-old, wild-type, and ApoE-deficient ($ApoE^{-/-}$) female mice were acutely whole-body irradiated with 3 Gy of X-rays (0.89 Gy/min), then sacrificed 150 days post-irradiation. In addition, age-matching $ApoE^{-/-}$ females were chronically whole-body irradiated with γ-rays (20 mGy/d, cumulative dose of 3 Gy) for 150 days at the low dose-rate facility at the Institute of Environmental Sciences (IES), Rokkasho, Japan. This research investigated the impact of ApoE deficiency on the cellular composition of the dentate gyrus and adult neurogenesis, employing specific markers and explores the underlying molecular mechanisms. Our findings revealed that ApoE deficiency significantly disrupts the expression of miRNAs and their downstream neurogenesis-related target genes, as well as adult hippocampal neurogenesis in both unexposed and irradiated mice. Furthermore, ApoE deficiency impacts synaptic functionality and integration by altering specific miRNAs, leading to decreased expression of synaptic gene markers. Chronic radiation exposure had fewer effects compared to acute exposure, except for increased microglia-mediated neuroinflammation. Results of this research highlight the crucial role of ApoE in the hippocampus and its potential implications for developing therapies to mitigate radiation-induced brain injury.

NEUTRON BIOLOGICAL EFFECTIVENESS: TACKLING VARIATIONS AS A FUNCTION OF INCIDENT ENERGY AND DEPTH IN A HUMAN-SIZED PHANTOM

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Current neutron weighting (ICRP)/quality (U.S. NRC) factors might be insufficient for use in some radiation protection applications, because they do not account for depth. To support better-informed decisions for radiation protection in case of neutron exposure, we present new developments for an *ab-initio* model of the neutron Relative Biological Effectiveness (RBE) in inducing specific classes of DNA damage. RBE is evaluated as a function of the incident neutron energy in a wide energy range (from below the thermal energy of ≈ 25 meV and in the high-energy region, up to 100 GeV) and of the depth inside a human-sized reference spherical phantom. Reference depths representative of the position of organs at risk in a human subject are also derived from a set of dedicated Geant4 simulations with anthropomorphic mathematical phantoms (male and female). The model provides mechanistic insight into the origin of neutron biological effectiveness, and its predictions are successfully benchmarked with the currently adopted radiation protection standards when the depth information is not relevant (at the shallowest depth in the phantom or for very high energy neutrons). However, new RBE results demonstrate that great care is needed when applying weighting factors as a function of incident neutron energy only, not explicitly considering RBE variation in the target. Finally, exposure scenarios of interests are identified, including secondary neutrons generated in cancer therapy with particle beams, and those generated in space because of primary radiation interactions with space vessels or planetary atmosphere/soil/habitat walls. To facilitate the use of our results in all possible applications, we propose look-up RBE tables, explicitly considering the depth variable, and an analytical representation of the maximal RBE *vs* neutron energy.

TRANSCRIPTIONAL RADIATION REPONSE SIGNATURE OF HUMAN SKIN

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Blood sampling is a minimally invasive procedure which is successfully used for discovery and characterization of gene expression biomarkers for biological dosimetry purposes. However, as a downside, it is difficult to identify partial body exposures. Skin biopsies are easily accessible and could provide information on the localisation of the exposure; moreover, it offers a new source of gene expression biomarkers and its transcriptional response might be more persistent overtime than in blood. Therefore, the present study intends to determine the validity of the use of skin as a source of sample. For this aim, a time course experiment was performed in adult and infant human skin and in a 3D skin model where skin biopsies were exposed to a single 2Gy X-ray dose (0.5 Gy/min) and incubated for 1 to 7 days at 37ºC. At 24 hours time point, a dose response was performed at doses 0.1, 0.5, 1, 2, 5 and 10 Gy. Following the different incubations, RNA was extracted and reverse transcribed into cDNA for qPCR analysis or used for library preparation for nanopore long read sequencing. Sequencing analysis provided significantly differentially expressed up and downregulated genes which are associated with pathways involved in circadian rhythm, cancer, metabolic pathways and signalling pathways such as Wnt, hedgehog, notch and hippo. These pathways play an important role in cell proliferation, cell differentiation, apoptosis, epidermal and hair follicle development and controlling the function of differentiated skin cells. Comparing the differentially expressed genes identified by nanopore sequencing in the three different skin types, we observed a common expression signature which includes genes like ZMAT3, MARVELD2, TYMS, TRIAP1, APOBEC3C, SAA1, LTB4R and LINC00475. To conclude, this study has identified new gene expression biomarkers of radiation exposure in skin which we are further validating and characterizing. Currently inter-individual variability in response and *in vivo* exposure studies are being carried out. All together we identified a specific transcriptional radiation exposure signature of human skin.

IMPLEMENTATION OF THE CYTOKINESIS BLOCK MICRONUCLEUS ASSAY FOR BIODOSIMETRY PURPOSES AT NRPI

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Biological dosimetry aims to estimate the dose based on the analysis of biological materials, mostly blood samples obtained from irradiated persons. Apart from the dicentric chromosome assay, so called "gold standard" method, there are alternative biodosimetry techniques applicable for the dose estimates. Cytokinesis Block Micronucleus (CBMN) assay aims to determine the frequency of micronuclei within the binucleated cells obtained. Specifically, micronuclei are formed by acentric fragments generated upon the irradiation of the cell nucleus. Despite not being specific for ionising radiation, the CBMN assay is still a useful biodosimetry technique thanks to the potentially faster data analysis compared to the dicentric chromosome assay. In this study, blood samples from 16 healthy donors (5 donors younger than 25 years, 6 donors within 26-50 years and 5 donors over 50 years) with no previous radiation exposure were irradiated by various doses ranging from 0.1-5 Gy by the means of the linear accelerator with the 1.4 MeV X-ray beam located within the Motol University Hospital. Following irradiation, the blood samples were immediately transferred into the incubator set at 37°C and placed in there for 2 hours. The unirradiated controls were treated in the same way as the irradiated samples. Subsequently, the standard protocol of the CBMN assay was applied. The slides obtained were stained with DAPI and analysed by the automatic Metafer slide scanning system in order to determine the frequency of micronuclei within the samples in manual and semi-automatic mode. The aim was to analyse at least 2000 binucleated cells (for doses up to 0.5 Gy) or 1000 binucleated cells (for doses over 0.5 Gy) per donor for the presence of micronuclei. Therefore, the NRPI laboratory-specific calibration curves for the CBMN assay were obtained. Moreover, the implementation of the CBMN assay within the NRPI will be tested by the analysis of blood samples from 2 healthy donors irradiated *in vitro* by a priori blind doses. To compare the results and applicability of different biodosimetry techniques, the dicentric chromosome assay analysis of the samples will be utilized as well to obtain the dose estimates. Supported by the grant VK01020052 "Complex of methods of biological and physical retrospective dosimetry for radiation emergency" from the Ministry of the Interior of the Czech Republic.

LOW DOSE RADIATION BYSTANDER EFFECTS THROUGH IGFBP5, A COMPONENT OF THE SENESCENT CELL SECRETOME

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Low levels of radiation can significantly impact cellular function. People may encounter low levels of radiation either deliberately for medical treatments or inadvertently, such as through radiological terrorism or living near unlawful radioactive waste sites. We examined the effects of low-dose radiation on human bone marrow Mesenchymal Stromal Cells (MSCs). These cells include a subset of stem cells capable of differentiating into bone, cartilage, and fat, supporting blood cell formation, and maintaining body homeostasis.The primary consequence of low radiation exposure, aside from reduced cell proliferation, is the induction of cellular senescence and/or apoptosis. Senescence, characterized by a state of irreversible growth arrest, can induce senescence in neighboring cells through the release of factors collectively known as the Senescence-Associated Secretory Phenotype (SASP). The SASP comprises a variety of factors that regulate numerous functions, including the induction of secondary senescence, modulation of immune system activity, remodeling of the extracellular matrix, alteration of tissue structure, and promotion of cancer progression. Identifying key factors within the SASP is crucial for understanding the underlying mechanisms of senescence and developing effective strategies to counteract cellular senescence induced by radiation exposure. Our research has specifically focused on investigating the role of IGFBP5, a component of the SASP observed in various experimental models and conditions. Through our studies, we have demonstrated that IGFBP5 actively contributes to promoting senescence and can induce senescence in neighboring cells. We have gained valuable insights into the mechanisms through which IGFBP5 exerts its pro-senescence effects. These mechanisms include its release following genotoxic stress, involvement in signaling pathways mediated by reactive oxygen species and prostaglandins, internalization via specialized structures called caveolae, and interaction with a specific protein known as RARα. By uncovering these mechanisms, we have advanced our understanding of the intricate role of IGFBP5 in the senescence process.The significance of IGFBP5 as a pro-aging factor is further supported by an *in vivo* study we conducted on patients undergoing Computed Tomography analysis. In these patients, we observed an elevation in circulating IGFBP5 levels in response to low-dose ionizing radiation-induced organismal stress. Overall, our findings highlight the potential of IGFBP5 as a promising therapeutic target for combating the bystander effect induced by radiation exposure.

TRITIATED MICRO-PARTICLES: COMPUTATIONAL DOSIMETRY AND ANALYSIS OF RADIOBIOLOGICAL *IN VITRO* DATA

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Tritiated stainless steel and cement particles are produced in the µm-size range following mechanical operations in the dismantling of old nuclear power facilities. Their dispersion in the environment can lead to human exposure via inhalation, with a particular concern for workers. The genotoxic potential of such particles is investigated in the framework of the TITANS (ongoing) and TRANSAT (concluded) EU projects. In particular, *in vitro* measurements with epithelial cells and alveolar macrophages provided indications of DNA damage, both in case of administration of tritiated particles, as well as for the chosen control condition, *i.e.* the administration of non-radioactive hydrogenated particles, which can be attributed to chemical stress only. Of note, tritiated particles have been shown to transfer a significant percentage of their activity to the culture medium, presumably in form of tritiated water, which also adds to cell exposure. In all conditions, a thorough dosimetric assessment is challenging and requires the use of radiation transport codes to reproduce cell morphology and the possible spatial distribution of particles: indeed, as a consequence of the short range of β electrons emitted by tritium decays in biological tissues, the energy deposited to cell nuclei will vary substantially depending on the particle position. Also, cell exposure can be highly inhomogeneous, depending again on particle distributions at the cellular/subcellular level and on their concentration. In this context, we will present a computational approach for dosimetric reconstruction for *in vitro* experiments with tritiated particles, as well as new approaches to the analysis of radiobiological data that are necessary to tackle the possible inhomogeneity in the dose and to disentangle radiative from chemical stress. In perspective, this works aims at providing necessary information to build dose-effect relationship and improving radiation protection standards including scenarios of exposures to peculiar radioactive products leading to internal exposure.

EVALUATION OF DNA DAMAGE AND GENETIC INSTABILITY IN INTERVENTIONAL RADIOLOGISTS

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Ionizing Radiation (IR) at high doses is generally accepted carcinogen, which is able to induce DNA damage and genomic instability in human cells. Due to the enormous possibilities of using low doses of IR (≤100 mSv) in medical diagnostic procedures and chronic exposure of medical personnel, such as interventional radiologists, to this type of radiation, a question remains to answer whether such low doses of IR are carcinogenic. The aim of our work was to monitor DNA damage and genomic instability in peripheral blood lymphocytes from interventional radiologists and control workers from Slovak hospitals. Evaluation of DNA double-strand breaks was studied by quantification of fluorescently labeled residual 53BP1 (p53 binding protein 1) DNA repair foci. Analysis of Micronuclei (MN) and Chromosomal Aberrations (CA) were selected to detected genomic instability. The rearrangement in the MLL gene (Histone- lysine N-methyltransferase 2A), one of the most frequently mutated genes in leukemias, was examined using a break-apart probe by the fluorescence in situ hybridization. Using the RT-qPCR method, we also quantified the RNA of the blood cells for the presence of four Preleukemic Fusion Genes (PFG) typical for acute leukemias - MLL-AF4, MLL-AF9, AML1-ETO, BCR-ABL p190. Our result did not show a significant difference in the production of 53BP1 foci or incidence of any from examined PFG (MLL-AF4, MLL-AF9, AML1-ETO, BCR-ABL p190) between radiologists and controls. However, we found a significantly increased frequency of MN, CA (specifically: total CA, dicentrics, acentrics, ring chromosomes, chromatid gaps and fragments) and higher amplification of MLL gene segments in the radiology group compared to controls. Our findings suggest a possible effect of chronic low dose IR on genetic instability in radiology medical workers. Finally, these results could potentially help to increase safety limits and improve radiation protection in Slovak hospitals.
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CYTOGENETIC ANALYSIS IN PERIPHERAL BLOOD LYMPHOCYTES OF PATIENTS EXPOSED TO LOW DOSE IONIZING RADIATION IN FLUOROSCOPICALLY GUIDED INTERVENTIONAL PROCEDURES

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Purpose. The aim of the present study is to evaluate the cytogenetic effects of ionizing radiation in peripheral blood lymphocytes of patients underwent interventional radiological procedures.

Materials and Methods. Dicentrics, chromosomal fragments and total aberrations frequency was estimated in peripheral blood lymphocytes of 42 patients before and after medical procedure. Nineteen of them underwent coronary angiography and 23 – spinal surgery. A group of 19 healthy individuals from the population was used as a control to compare chromosomal aberrations levels with those in patients group before medical procedure.

Results. Our results show that chromosomal aberrations frequency in peripheral blood lymphocytes of patients, before the medical procedure is comparable to the same biomarkers evaluated in healthy individuals. The number of chromosomal fragments and the total number of chromosomal aberrations in the patients increased significantly after the both medical procedures, $p<0.01$. The frequency of dicentrics also shows statistically significant increase after the radiological procedures, $p<0.05$.

Conclusions. The significant increase in chromosomal aberrations frequency after the medical procedure is a result of an acute response to the examination performed under fluoroscopic control, but does not necessarily lead to an increased carcinogenic risk. Further studies involving a larger group of individuals and number of analyzed cells, as well as methods (fluorescence in situ hybridization) are needed to evaluate realized stable chromosomal aberrations - translocations, as a biomarker for carcinogenic risk.

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RADIATION SIGNATURE IN PLASMA METABOLOME OF TOTAL-BODY IRRADIATED NONHUMAN PRIMATES AND CLINICAL PATIENTS

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In the last decade, geopolitical instability across the globe has increased the risk of a large-scale radiological event, when radiation biomarkers would be needed for an effective triage of an irradiated population. Ionizing radiation triggers a complex response in the genome, proteome, and metabolome and hence can be leveraged as rapid and sensitive indicators of irradiation-induced damage. We analyzed the plasma of Total-Body Irradiated (TBI) leukemia patients (n=24) and Nonhuman Primates (NHPs; n=10) before and 24 hours after irradiation and we performed a global metabolomic study aiming to provide plasma metabolites as candidate radiation biomarkers for biological dosimetry. Peripheral blood samples were collected according to the appropriate ethical approvals, and metabolites were extracted and analyzed by liquid chromatography coupled with Quadrupole Time-Of-Flight Mass Spectrometry (QTOF-MS). We identified an array of metabolites significantly altered by irradiation including bilirubin, cholesterol, and 18-hydroxycorticosterone, which were detected in leukemia patients and NHPs. Pathway analysis showed overlapping perturbations in steroidogenesis, porphyrin metabolism, and steroid hormone biosynthesis and metabolism. Additionally, we observed dysregulation in bile acid biosynthesis and tyrosine metabolism in the TBI patient cohort. This investigation is to our best knowledge among the first to provide valuable insights into a comparison between human and NHP irradiation models. The results of this study could have practical implications for biological dosimetry.

DOSE-EFFECT RELATIONSHIPS OF DICENTRIC FORMATION DETERMINED BY FULLY- & SEMI-AUTOMATED DICENTRIC EVALUATION USING DIFFERENT DCSCORE CLASSIFIERS AFTER 3 H OR 24 H COLCEMID TREATMENT

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Purpose. To investigate if two different DCScore classifiers, available in the labortatories of BIR, are suitable without further lab-specific classifier training for cytogenetic triage on cytogenetic slides for dicentric (dic) analysis. Classifiers have been trained in two external laboratories >10 years ago to adapt them for lymphocyte cultures set up with short- (2-3 h; class I) or long-term (24h, class II) colcemid (col) treatment.

Methods. Comparison of dic induction in 3 h & 24 h col cultures using class I/II as well as fully- (no intervention except for elimination of non-metaphase (MP) images) and semi-automated dic scoring (exclusion of false pos dic by evaluator). Dose estimation of heterogeneous X-ray exposed (240kV, 1 Gy/min) blind samples after 24 h col treatment using both classifiers and scoring modes.

Results. 24h col treatment (final conc.: 0.08µg/mL) results in ~2-fold more MP than 3h col treatment (final conc.: 0.15µg/mL). The course of dic yields after short- and long-term col treatment is different, especially >1Gy. Class I (adapted to 2-3h col) detects more dic candidates as well as true positive dic, respectively, especially >2Gy / >3Gy after 24h/3h col, compared to class II (adapted to long-term col). False pos dic were more pronounced at low doses.

Conclusion. Col treatment of cell cultures for collecting reference data must not deviate from the way how unknown samples are analyzed. Thus, the applied col time has to be considered, especially when evaluating MP images after years or in another lab. For short-term col treatment, including very high doses (>4Gy) into the collection of reference data could introduce further uncertainty into dose estimation based on DCA due to saturation of dic formation at high doses, which has to be considered for calibration curve fitting. Intra-laboratory classifier training might further reduce false positive dic candidates to enable minimal human intervention in the course of (in the best case) the fully- but also semi-automated scoring method, as well as resulting in a more accurate dose assessment when applying the routine mode of dic analysis. Semi- as well as fully-automated analysis can be used for triage categorization.

OPUNTIA FICUS-INDICA EXTRACT AS POTENTIAL NATURAL RADIOPROTECTOR

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Natural products and extracts have emerged as promising sources of radioprotectors for their efficacy in mitigating ionizing radiation-induced damage in normal cells, with lower side effects and toxicity compared to synthetic radioprotectors. *Opuntia Ficus-Indica* (OFI) is an edible plant plant widely distributed worldwide and adapted to dry climatic conditions. The importance of OFI fruits and cladodes as a dietary source, rich in minerals, vitamins and antioxidants, has increased due to their potential nutraceutical properties. The use of extracts obtained from different parts of the plant, moreover, have been gaining interest due to their promising beneficial health effects. In this context, extracts obtained from OFI cladodes have been tested for their cytoprotective, antioxidant, antigenotoxic, antitumoral and anti-inflammatory activities, with the benefit to exploit OFI waste products for health protection applications. The current study aims to evaluate the possible radioprotective effect of OFI cladode extract in human Peripheral Blood Lymphocytes (PBLs) undergoing exposure to ^{60}Co γ-rays. OFI extract has been prepared by cutting the cladodes in cubic pieces and macerating in distilled water for 24 hours in the dark. Then, the macerated material was separated by different filtration stages and characterized by HPLC. Whole blood samples from healthy volunteers were pre-treated with different non-cytotoxic concentrations of OFI extract for 3 hours; after OFI incubation, the PBLs were exposed to ^{60}Co γ-rays (0.5 and 1 Gy). Radiation-induced chromosome damage was evaluated by the Cytokinesis-Block Micronucleus (CBMN) assay. Preliminary results are promising suggesting a potential protective effect of OFI extract against injury caused by ionizing radiation.

DICENTRICS AND INTERPHASE CELL SURVIVAL DOSE RESPONSE CURVES FOR CYTOGENETIC BIODOSIMETRY OF THERAPEUTIC EXPOSURE

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The methodology of cytogenetic radiation biodosimetry can find potential application in a specific branch of clinical radiobiology, focused on assessing the adverse radiation effects in radiotherapy patients. This may include *in vitro* dose response experiments to evaluate therapeutic potential of radiation beams, or *in vivo* studies to compare actual clastogenic impact of different radiotherapy techniques or dose fractionations, as well as *ex vivo* assays with irradiation of patients' cells to measure their individual chromosomal radiosensitivity. However, the irradiation of patients in most radiotherapy schemes is highly localised and thus inhomogeneous. To properly account for this partial body exposure in cytogenetic studies, appropriate modifications must be made to dose response calibration experiments. A dose-response curve (DRC) for cytogenetic biodosimetry by dicentric assay in human lymphocytes was constructed by irradiating *in vitro* blood samples with 6 MV X-ray photons from a medical LINAC. Irradiation setup, cell culturing and chromosome aberration scoring were in strict compliance with international requirements. In a parallel experiment, irradiated blood at each experimental point in the studied dose range was mixed 1:1 with unirradiated blood and processed further for dicentric analysis. By comparison of chromosome aberration yields in totally irradiated and 'mixed' cultures, the DRC for radiation interpahse cell survival was derived in addition to the classical DRC for radiation-induced dicentric frequency. A combination of these two DRCs was successfully validated in a 'blind' experiment *in vitro* with simulated total and partial irradiations, and also showed fairly good perfomace for the biodosimetric interpretation of dicentric data collected in cancer patients after their first radiotherapy fraction. Further implementation of this two-component DRC looks rather promising for *ex vivo* testing of patients cells by clastogenic-plus-cytotoxic sensitivity criterion, and also it will definitently be highly demanded for biodosimetry expertise in the scenario of accidental inhomogeneous or localized overexposure of radiotherapy patients. Several approaches can be proposed to improve the sensitivity and accuracy of this methodology, such as prematurely condensed chromosomes technique, or caffeine-modified dicentric assay, or pancentromeric FISH-labelling, but their effectiveness alone or in various combinations still needs to be assessed experimentally. A standardization of two-component DRC approach for practical application will require serious efforts by the international biodosimetric community.

Session 6B

Exposure of members of the public, workers and environment following a major nuclear or radiological accident or incident or malevolent nuclear or radiological act (I)

STRENGTHENING UKRAINE'S HEALTH SECTOR CAPACITY TO RESPOND TO NUCLEAR EMERGENCIES

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Since March 2022, the World Health Organization (WHO) has undertaken significant initiatives to enhance Ukraine's capacity to respond to nuclear emergencies, given the country's vulnerabilities due to past incidents like the Chernobyl disaster and ongoing military conflict. WHO's comprehensive strategy focuses on policy development, capacity building, technical support, and risk communication. To that regard, WHO collaborates with the Ukrainian government to refine and update existing public health policies and national guidelines pertainng to medical response to nuclear emergencies, as well as developing and translating WHO's guidelines to Ukrainian. Notably, WHO's capacity-building initiatives include extensive training programs for healthcare workers and emergency responders (both in-person and online), table-top simulation exercises, and resource allocation to ensure the health sector is equipped with necessary tools. Continuous technical support is provided through expert consultations and deployment of specialists to Ukraine. WHO connects Ukrainian authorities with international experts of the WHO REMPAN network to offer guidance on best practices and technological advancements. Public communication campaigns and community engaging programs are conducted by the Ukraine Ministry of Health with support of WHO to educate citizens about nuclear safety measures and emergency protocols. Mental health and psychosocial support initiative is rolled out to help individuals cope with the psychological impact of the ingoing war, displacement, and technological hazards, including potntial nuclear emergencies. Overall, WHO's multifaceted approach significantly enhances Ukraine's preparedness and resilience to nuclear emergencies, safeguarding public health and mitigating associated risks.

INTER-COMPARISON EXERCISE WITHIN THE NATO PROJECT *BIOPHYMETRE*

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The *BioPhyMeTRE* project, funded by NATO within the Science for Peace and Security (SPS) Programme, focused on the validation of innovative biological and physical dosimetry methods, employing inexpensive and rapid procedures that could be used in the triage categorisation of victims involved in R/N accidents. The novel biological protocol combines the two most standardised cytogenetic dosimetry methods (the dicentric and the micronucleus assays) into one, allowing the simultaneous scoring of dicentrics and micronuclei in the same slide. The method has been successfully automated using the *Metafer* slide scanning and imaging platform by a specifically created classifier combining three different search/analysis algorithms. In the proposed physical method, a low cost, portable mini photo-luminescence reader (OSL) that can be applied at the place of the incident for a rapid triage of civilians involved in a mass casualty event is applied for individual dose assessment by using personal objects, appropriately selected. A specific type of magnesium supplement was chosen as potentially usable fortuitous dosimeter. The two methods were previously validated through dose-response calibration curves. A blind inter-comparison exercise between the four laboratories participating in the project was performed to verify the reliability of the two methods for possible application in triage dose assessment (three categories of exposure) in case of R/N emergencies. Blood samples from two healthy donors and a common brand of magnesium supplement in tablets were blindly irradiated with ^{60}Co gamma rays (dose rate: 11.86 Gy/h) at the following exposure condition: unexposed, low exposed (0.5-1 Gy), medium exposed (1-2 Gy) and highly exposed (>2Gy) samples.

THYROID CANCER INCIDENCE RISK IN THE RESIDENTS AROUND THE SEMIPALATINSK NUCLEAR TEST SITE, KAZAKHSTAN

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The thyroid gland is one of the most radiosensitive human organs. Earlier, an NCI-led cross-sectional cohort study on ultra-sound detected thyroid nodules prevalence in the residents around the Semipalatinsk Nuclear weapon Test Site (SNTS), Kazakhstan, revealed a statistically significant linear dose response between prevalence of thyroid nodules and total absorbed thyroid dose (mean dose = 0.35 Gy). Thyroid nodules radiation-related risk was significantly associated both with external and internal (due to iodine-131, 133 ingestion with contaminated milk and dairy products) thyroid dose. We decided to perform a follow-up of the cohort screened in 1998 to assess the natural evolution of ultra-sound detected thyroid nodules, investigate the risk factors associated with possible transformation from benign to malignant nodule, and estimate thyroid cancer incidence risk in relation to the thyroid dose. The initial cohort included 3,000 people exposed to SNTS radioactive fallouts in the period of 1949-1962, at the age of exposure less than 21 years. The mean age at examination in 1998 was 56 years (ranging from 41 to 70 years). We expanded the initial cohort by inclusion of 240 new subjects mainly from the highly contaminated villages who underwent thyroid ultra-sound examination in 1999-2002. The total cohort comprises 3,240 individuals of both genders, ethnically heterogeneous, and at wide age range. During 26 years after the initial exam, 60% of the cohort has died. To identify thyroid cancer incident cases in the cohort, a linkage has been performed with regional population-based cancer registry and medical diagnoses registry of the regional diagnostic centre. An individual interview using study questionnaire and thyroid ultrasound examination were performed for each alive cohort member (n=1,099). Upon finalization of data quality and completeness checks, we will perform risk analysis to assess effects of ionizing radiation exposure on the incidence of thyroid nodules (both benign and malignant) in relation to time since exposure, gender, ethnicity, familial and individual history of thyroid diseases preceding the thyroid cancer diagnosis.

ASSESSMENT OF UNCERTAINTIES AND ERRORS IN POST-CHERNOBYL DOSIMETRY

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We assessed the uncertainties and errors in complex dosimetry systems that were developed to estimate individual doses in different post-Chernobyl (Chornobyl) radiation epidemiology studies among the general population and the cleanup workers. These uncertainties and errors are associated with (i) instrumental radiation measurements of humans and environmental samples, (ii) inherent uncertainties arising from the stochastic random variability of the parameters used in exposure assessment and from a lack of knowledge about the true values of the parameters, and (iii) human factor uncertainties due to poor memory recall resulting in incomplete, inaccurate, or missing responses during personal interview with study subjects conducted long after exposure. Relative measurement errors of ^{131}I thyroid activity associated with devices for measuring radioactivity in the thyroid reached up to 0.86 (coefficient of variation). The inherent uncertainty in estimates of individual doses varied between different studies and exposure pathways (GSD from 1.2 to 15 for model-based doses and from 1.3 to 5.1 for measurement-based doses). The human factor uncertainties can cause individual doses to be underestimated or overestimated by an average of 10 times for model-based doses and 2 times for measurement-based doses calculated for the general population and up to 3 times for doses calculated for cleanup workers. The sources of errors and uncertainties, especially the human factor uncertainties, should be carefully considered in dose assessment for radiation epidemiological studies, with particular attention to studies involving persons without instrumental radiation measurements. In turn, the potential impact of these errors on radiation-related risk estimates should be assessed. The approaches developed to quantify uncertainties and errors in exposure assessment can be applied to any other studies in radiation or occupational epidemiology, which are carried out a long time after the event of exposure.

RISK OF HAEMATOLOGICAL MALIGNANCIES IN GOMEL AND MOGILEV REGIONS OF BELARUS AFTER CHERNOBYL FALLOUT

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We used an ecological study design to investigate the radiation-related risk of Hematological Malignancy (HM) incidence in the residents of Gomel and Mogilev regions of Belarus, which were the most heavily contaminated regions after the Chernobyl nuclear power plant accident on April 26, 1986. HM incidence data (ICD-10 codes: C81-C96) were received from the national population-based cancer registry for the follow-up period from 26.04.1986 through 31.12.2018. For the same period, rayon-average age-specific annual absorbed doses to the red bone marrow (RBM) resulting from external irradiation and ingestion of long-lived radioisotopes of caesium (Cs-134, 137) and strontium (Sr-90) were estimated. Our study included 7,328 lymphoma, 9,476 leukaemia, and 2,003 multiple myeloma incident cases, and 90.8 million person years in the people who were born before the accident and whose attained age was 79 years or less. The mean (median) rayon-specific age-averaged RBM dose accumulated by 31.12.2018 was 14.2 (6.4) mGy with a maximum of 60 mGy. After adjustment for sex, attained, urban/rural status and calendar period effect, there was little evidence of association between two-year lagged accumulated RBM dose and risk of lymphoid (Hodgkin and non-Hodgkin, lymphoma), multiple myeloma, and haematological (lymphoid, myeloid leukaemia) malignancies. There was no significant variation of lymphoma, multiple myeloma, total leukaemia and lymphoid leukaemia radiation-related risk by the follow-up decades, sex, attained age, and age at the time of the accident. However, there was a suggestion of elevated risk of myeloid leukaemia in both sexes combined for the attained age group of 0-19 years based on a relatively small number of observations (n=63 cases) compared to the unexposed peers. As a next step we plan to perform similar risk analysis of HM incidence data in Ukraine to gain additional insight into possible effects of the Chernobyl radioactive fallout on HM risks in the residents of the most contaminated areas.

ATMOSPHERIC TRANSPORT AND DEPOSITION OF RADON-222 AND ITS PROGENY USING FLEXPART

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Precipitation routinely causes excursions in environmental gamma dose monitoring stations due to wet deposition of the progeny of airborne radon-222 (^{222}Rn). Since such stations are used to monitor the environment for signs of aberrant radioactivity, it is important to understand these excursions lest they be erroneously designated as anomalies. While their temporal evolution of such excursions can be theoretically explained using the Bateman equation, their magnitude is difficult to predict. The same precipitation intensity yields wildly varying dose excursions from one event to the next. Natural variations in the atmospheric concentration of ^{222}Rn are one possible reason for this. While varying meteorological conditions at the measurement site are often named as a reason for observed variations, we think that local meteorological information alone is not a good predictor. Owing to its 3.8-day half-life, ^{222}Rn can be transported over considerable distances through the atmosphere. If atmospheric conditions are at the root of the varying dose responses, one should instead consider atmospheric conditions over a much larger area. To investigate whether weather phenomena at the larger scale can account for these variations, we model the atmospheric transport of ^{222}Rn in Flexpart. Flexpart is a Lagrangian particle model to calculate long-range atmospheric transport of pollutants. In this work, we adapt Flexpart to deal with the dispersion of the parent nucleus (^{222}Rn) and its progeny (^{218}Po, ^{214}Pb and ^{214}Bi) in a single simulation under the assumption that parent and progeny are collocated in non-precipitating conditions. We prove that this collocation may be assumed despite the different dispersive properties that arise from the fact that only the parent is a noble gas. We present a case study using ECMWF reanalysis numerical weather data that covers the northern hemisphere for the year 2022. The entire land area of Europe is modelled as a heterogeneous plane source based on existing radon emanation data. We compare modelled to observed ^{222}Rn concentrations, and modelled deposition to environmental gamma dose observations. Observations come from Telerad, the Belgian radiological surveillance network and early-warning system. The results of this case study will help us understand whether excursions in environmental gamma dose can be explained with the proposed modelling setup and, if successful, will help to better interpret environmental gamma dose measurements.

Session 6C

Patient medical dosimetry

IMPROVING OUT-OF-FIELD DOSIMETRY IN MODERN RADIOTHERAPY: INSIGHTS FROM EURADOS WG9

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The growing complexity of modern radiotherapy techniques, such as Intensity-Modulated Radiotherapy (IMRT) and proton Pencil Beam Scanning (PBS), has led to significant improvements in cancer treatment. However, these techniques also generate complex secondary radiation fields, including scattered photons and neutrons that present radioprotection challenges. Since 2010, EURADOS Working Group 9 (Radiation Dosimetry in Radiotherapy) has focused on improving out-of-field dosimetry, particularly for pediatric patients. We conducted a series of studies on out-of-field radiation for realistic treatment scenarios for brain lesions and craniospinal irradiation, covering both photon therapies (3D-CRT, IMRT, VMAT) and proton therapy (PBS). Our experiments and Monte Carlo simulations maintained consistent target size and location to ensure a fair comparison between different treatment methods. The use of anthropomorphic phantoms of varying sizes, representing different pediatric age groups, allowed for an analysis of age-specific dosimetric variations. Recently, WG9 has initiated work on estimating out-of-field doses in pregnant patients, where accurate fetal dose assessment is crucial. Initially, efforts centered on developing and validating computational anthropomorphic phantoms for Monte Carlo (MC) simulations. The group's current work involves validating physical phantoms for in-phantom measurements, with the aim of providing reliable data on fetal dose exposure across different radiotherapy techniques. The findings from EURADOS WG9 highlight the importance of thoroughly validating Monte Carlo simulations, particularly for neutron dose assessments. Additionally, careful consideration of beam modifiers and treatment plan parameters is crucial when estimating out-of-field doses in radiotherapy. Proton Pencil Beam Scanning (PBS) potentially reduces out-of-field doses compared to conventional photon therapies, which is especially important for minimizing fetal exposure during pregnancy.

FEASIBILITY OF A NOVEL VIDEO FRAME INTERPOLATION ALGORITHM FOR RADIATION DOSE REDUCTION IN THE CATHETERISATION LABORATORY USING AI-GENERATED SYNTHETIC ANGIOGRAPHIC IMAGES

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Introduction. Artificial Intelligence (AI)-generated images present an opportunity to augment, in real time, sequences of radiation-acquired images, enabling the reduction of the acquisition rate. The aim of this paper is to evaluate a number of approaches to this process including RRIN (Residue Refinement Interpolation) and a RIFE (Real-time Intermediate Flow Estimation) algorithm which requires less training and has a lower computational burden.

Materials and Method. Anonymised DICOM coronary angiographic sequences for 30 patients were collected, with two sequences per patient (left and right coronary artery) from Allura 10 imaging system, (Philips Netherlands). Three sets of data were compared to each original sequence where every second image was replaced by a synthetic image using the three following algorithms: 1) linear interpolation 2) RRIN and 3) RIFE. Images were initially quantitatively evaluated with AI assessment metrics such as mean squared error and structural similarity index. Video sequences were then evaluated clinically and qualitatively by two consultant cardiologists on a dedicated work station.

Results. Both initial clinical evaluation and the AI-generated assessment indices showed that the RIFE and RRIN gave similar results, with both outperforming the linear interpolation model.

Conclusion. Video-frame interpolation through AI-based algorithms may allow us to reduce radiation doses for staff and patients while maintaining diagnostic capability.

EURADOS ROADMAP FOR INTERNAL DOSIMETRY IN RADIOPHARMACEUTICAL THERAPY: VISION TOWARDS DOSIMETRY-BASED PRESCRIPTION

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Personalised and optimized Radiopharmaceutical Therapy (RPT) aims to prevent overexposure of non-target healthy tissue and underexposure of the target tissue. The optimization principle is one of the fundamentals to use ionising radiation and is explicitly mentioned in the Council Directive 2013/59/Euratom. In 2020 the European Radiation Dosimetry Group (EURADOS) included a challenge on improving patient dosimetry in the strategic research agenda. This initiated a task to identify the knowledge gaps which hamper implementation of dosimetry guided prescription in RPT and to draw a roadmap to move towards dosimetry-based prescription. The results of this work, resumed in a forthcoming EURADOS report are summarized in this abstract. RPT needs to consider the radionuclide dependent nature of the emitted radiation, its associated dose rate, and the spatially heterogeneous distribution of radiopharmaceuticals at organ, tissue, sub-tissue, or cellular level towards an appropriate absorbed dose assessment with a direct impact on the biological effect. To this end, it is essential to have access to good quality data to gain knowledge that leads to optimized dosimetry workflows which could be adopted by the community by means of standardized and harmonised procedures.

The proposed roadmap considers three concerted areas:

1. Development of a repository to collect patient-specific dosimetry and outcome data to improve biokinetic modelling and dosimetry.
2. Translation of the gained knowledge to patient-specific-dosimetry-based workflows.
3. Collection of scientific evidence to foster the modelling of normal tissue complication probabilities and tumour control probabilities.

Like in external beam radiotherapy, we expect a synergistic process which will evolve and improve over time. Expanding the accessibility to reliable dosimetry data and the personalized dosimetry implementation is a key step in the optimization process.

ASSESSMENT OF EFFECTIVE DOSE CONVERSION COEFFICIENTS FOR CATEGORIES OF RADIOLOGICAL AND NUCLEAR MEDICINE EXAMINATIONS: AN ITALIAN MOH-ISS PROJECT

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According to article 64 of European Directive 2013/59, European States shall ensure that the distribution of individual dose estimates from medical exposure for radiodiagnostic and interventional radiology purposes is determined, taking into account, where appropriate, the distribution by age and gender of the exposed people. Italian Legislative Decree 101/2020, which transposed Directive 13/59, defined an information flow for the collection of patient dosimetric indicators for different categories of diagnostic examinations, at a regional and national level. In this context, a new research project funded by the Italian Ministry of the Health (MoH), led by the Istituto Superiore di Sanità (ISS) and involving four Health Physics structures distributed across the national territory, aims to define the proper Effective dose (E) conversion coefficients to be applied to patient dose indicators for large categories of medical examinations. The project involves a systematic review of existing E-coefficients, with a focus on results published over the last seven years. A total of 19 categories of examinations from the fields of conventional radiology, digital mammography, computed tomography, nuclear medicine and interventional radiology were considered. Technical aspects of data collection and synthesis were analysed, including recording and grouping of individual procedures. Numerical relevance and population dose impact of individual examinations within each category were also investigated. The feasibility of the developed methodological approach will be tested in the different diagnostic specialties of the hospitals involved in the project.

The project is conducted with the technical and financial support of the Italian Ministry of Health-CCM 2023. programme - "Approccio metodologico per la definizione dei coefficienti di conversione dei dati di esposizione in dose efficace, per le procedure di radiologia diagnostica e interventistica.".

AGE AND BIOLOGICAL SEX INFLUENCES THE BIODISTRIBUTION AND DOSIMETRY OF ^{131}I IN SPRAGUE DAWLEY RATS

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The knowledge of the radiobiological mechanisms following exposure to low doses of ^{131}I is still limited. To investigate these mechanisms in a controlled setting the use of animal models is necessary. Information of the biodistribution and biokinetics of ^{131}I in the model organism is therefore crucial to correctly assess the absorbed dose to the thyroid and other organs and relate that to observed biological changes. This study aims and to establish a dosimetry model that can be used for further experiments investigating the biological response to low-dose ^{131}I exposure in rats by determining the biodistribution of ^{131}I in male and female Sprague-Dawley rats of different age. Rats were exposed to 0.3-0.5 MBq (mean = 0.36 ± 0.06) ^{131}I at 5 or 17 weeks of age, corresponding to a young and an adult exposure group. The ^{131}I activity concentration in 16 tissues was measured at six different time points, ranging from one hour to six days after exposure. Absorbed dose calculations were based on activity concentration measurements. The thyroid showed the highest ^{131}I activity concentration in all groups, with a maximum concentration 18 hours after exposure in male rats and 24 hours after exposure in female rats. Significantly lower activity concentrations were found in all other organs analysed, with the stomach, intestines and kidney demonstrated the highest ^{131}I activity concentration in non-thyroidal tissue. In general females displayed higher absorbed doses compared to male rats. In addition, rats exposed at a young age exhibited higher absorbed doses compared to those exposed at an adult age. The mean total absorbed dose to the thyroid per unit of injected ^{131}I activity ranged from approximately 23 Gy/MBq for adult male rats up to around 103 Gy/MBq for young female rats. When comparing the different exposure groups, adult female rats had a three times higher thyroid absorbed dose than adult male rats, while young male rats had twice the thyroid absorbed dose compared to adult male rats. The results indicate a difference in the biodistribution and biokinetics of ^{131}I depending on age and sex, leading to a remarkable difference in the absorbed dose for a variety of different organs. Furthermore, a dosimetry model for rats of both sexes and two different age groups was developed, which can be used further, to investigate the radiobiological response after ^{131}I exposure in rats.

A MONTE CARLO CALCULATION OF CUMULATIVE RADIATION DOSE FROM MULTIPLE IMAGING MODALITIES IN PAEDIATRIC INTERVENTIONAL CARDIOLOGY

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Introduction. Paediatric patients face an increased lifetime risk due to radiation exposure, particularly those with Congenital Heart Diseases (CHD) undergoing Interventional Cardiology (IC) procedures. However, other imaging modalities such as CT, NM and radiography also contribute to radiation dose. This study aims to estimate the Cumulative Effective Dose (CED) and cumulative organ doses received from all imaging modalities by children undergoing multiple IC procedures at an Italian referral centre for CHD treatment. This is achieved through the use of three Monte Carlo (MC) simulation software: NCICT, NCINM and the recent NCIRF, all equipped with the same ICRP paediatric anthropomorphic phantoms.

Material and Methods. All paediatric patients who underwent at least two IC procedures between September 2018 and April 2024 were enrolled and their dosimetric indices were retrieved from RDSR. Organ doses and Effective Dose (ED) were calculated by simulating each irradiation event for IC procedures, all CT scans and all NM exams. Dose from chest radiography was obtained by simulating some "typical" radiography settings (different FOVs, AP/PA directions). In order to achieve accurate MC simulations, various reproducible methods were developed in collaboration with cardiologists. These methods included matching the ICRP phantom to each patient for each exam, optimizing isocenter placement for IC and RX, determining the scan range (start and end positions) for CT scans, matching beam quality (for both RF and CT, in different ways) and selecting the optimal number of histories. CED per patient was derived as the sum of the ED from all imaging modalities, and the same method was used to calculate cumulative organ doses.

Results. A total of 157 patients were enrolled, totaling 394 catheterizations, with an average of 2.5 IC procedures, 3.9 CT scans, 14 radiographies and 0.1 MN exams per patient. ED ranges from 0.037 mSv to 17.2 mSv per IC procedure and from 4 mSv to 14 mSv per CT scan, with the highest values on newborns. The simulated "typical" thoracic radiographies yield a mean ED of 0.025 mSv, ranging from 0.01 mSv to 0.1 mSv, with the highest values on newborns (mean 0.067 mSv). CED ranges from 0.08 mSv to 43 mSv, with the highest doses attributed to CT scans.

Conclusions. This study is one of the first on the subject to employ consistent anthropomorphic phantoms across all imaging modalities and specific methods to refine MC calculation, ensuring coherence and robustness in dose calculations.

A DOSIMETRIC EVALUATION OF GYNAECOLOGICAL CANCER PATIENTS UNDERGOING HDR BRACHYTHERAPY USING A COBALT-60 SOURCE

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Advances in Brachytherapy (BT) have increased the life expectancy of cancer patients over the years. Regardless, life expectancy after BT is still a major concern due to certain long-term side effects and in some instances, the development of secondary cancers after the procedure. One important advancement in BT is the use of sophisticated Treatment Planning Systems (TPS) to estimate dose distributions inside a patient's body and calculate doses to organs close to a target with high accuracy. However, the doses received by organs further away from an irradiated area or a target are not accurately calculated by most commercial TPS. This inaccuracy may lead to an underestimation of doses up to 40%. Additionally, dose calculations outside the irradiated area during BT are often restricted by limited anatomical coverage of Computed Tomography (CT) simulation images used for treatment planning. Monte Carlo N-Particle calculations in brachytherapy for dosimetry have become rife over the last decades due to the inability of the TPS to monitor doses outside the irradiated area accurately. This study seeks to propose a Monte Carlo (MC) approach to assess doses to organs outside the irradiated area during HDR brachytherapy (cobalt-60) for gynaecological cancer patients. Patient setup parameters were created using modelling and simulation software. The models were simulated to track photon particles to TLDs positioned in specific radiosensitive organs of 80 patients. The MC model was then validated with TLD-measured doses on the physical patients. The physical TLD measurements compared well with the simulated measurements. An average p-value greater than 0.05 ($p>0.05$) revealed an insignificant difference between measured and simulated doses. It is recommended that the verified MC models be used to develop an algorithm for organ dose estimation.

AN END-TO-END ITALIAN DOSIMETRY AUDIT FOR IMRT AND VMAT: RESULTS OF THE OPRORA PROJECT

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At the end of 2023, the five-year OPRORA (Optimization PROcesses in RAdiotherapy: clinical and dosimetric audits) project funded by the Italian Ministry of Health concluded its activity. The aim of the project was to develop a model of parallel clinical (CA) and dosimetry (DA) audits for IMRT and VMAT to be applied to 13 Italian Radiotherapy Centres (RTCs). In this work, the results of the end-to-end DA will be presented. Two types of DA were conducted, in reference conditions (DA-1) and in simulated treatment conditions (DA-2). The pathologies selected were prostate and head and neck carcinoma to be treated by VMAT and by IMRT, respectively. Both DAs were performed using 6 MV photons. Alanine, TLDs and EBT3 films, operating at ISS, were used. The dosimeters were calibrated in ^{60}Co at INMRI-ENEA. In total, 21 RTCs participated in the audit (including RTCs for model test and validation). For DA-1, RTCs were asked, using four small opposing beams, to deliver 10 Gy to a box-shape volume of a PMMA phantom, housing 3 alanine pellets and a piece of EBT3. For DA-2, two anatomical districts of a Rando-Alderson phantom were employed. The RTCs were provided with common contoured CT-scans of the Rando phantom. For the two pathologies, they were asked to create a personalized dose planning to be delivered according to the daily clinical practice. For both treatments, 7 positions for alanine pellets and TLDs, simulating target volumes and organ at risk (OAR) sites, respectively, were selected. Moreover, for dose distribution evaluation, large pieces of EBT3, sandwiched between two consecutive phantom slices at different tumor positions along cranial-caudal direction, were used. The results were expressed in terms of ratio of the Iss measured dose to RTC-stated dose. For DA-1, all RTCs results were within 3%. For both DA-2, except for two RTCs at one point (deviation of 6% and 8%), results were within 5% in all sites simulating target volumes. Deviations higher than 7% with respect to the measured dose were observed, for some RTCs, in a few sites simulating OARs, specifically, in those small volumes close to the targets, characterized by high dose gradients that are strongly affected by positioning errors.

Session 7A

PIANOFORTE - Building a collaborative future for RP: integrating community efforts and open call successes

PIANOFORTE - BUILDING A COLLABORATIVE FUTURE FOR RADIATION PROTECTION INTEGRATING COMMUNITY EFFORTS AND OPEN CALL SUCCESSES

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The PIANOFORTE Partnership (2022-2027) is committed to improving radiation protection for the public, patients, workers, and the environment in all exposure scenarios. Its overarching goal is to address barriers and challenges in human and environmental health risk research associated with ionising radiation, while promoting successes to inform radiation protection policies effectively. To achieve this, PIANOFORTE prioritises coordination and integration of the whole radiation protection community, and structured dialogue among stakeholders, ensuring that its research outcomes have a meaningful societal impact. By establishing a comprehensive pan-European scientific and technological foundation, PIANOFORTE aims to strengthen the radiation protection system and develop consolidated, science-based policy recommendations for decision-makers across diverse sectors that utilise ionising radiation, both energy and non-energy related. This effort encompasses all areas of radiation protection, such as, for example medical applications, deployment of innovative nuclear technologies, management of radiological or nuclear emergencies and recovery, etc. A key element of PIANOFORTE is its open call process, which co-funds research projects aligned with identified priorities. The success of its first competitive open call expanded the research community from 55 to 81 partners and enhanced global coordination of research efforts, integrating them into the research-to-application continuum. As a result, PIANOFORTE has been bolstered by nine newly granted research projects that began in early 2024. These projects are set to drive impactful advancements, including understanding radiation carcinogenesis at low doses/low dose rates, contributing to personalised diagnostic and therapeutic procedures, or adapting protection strategies to address emerging threats, as well as enhancing preparedness for disasters and armed conflict. In addition to promoting scientific excellence through research and embracing open science practices, PIANOFORTE is engaged in other initiatives, such as consolidating a network of infrastructures and developing education and training programs for the radiation protection workforce and young scientists.

HOW THE PROCESSES OF PRIORITISATION, SELECTION OF CALL TOPICS AND REVIEW OF PROPOSALS ARE DEVELOPING AND EVOLVING

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A major objective within the PIANOFORTE partnership is the organization of several open research and innovation calls. A task group was set up within PIANOFORTE to define the research priorities for these open calls. The calls must reflect a multidisciplinary and transnational approach, and priorities should integrate global EU policies and national research programs. The major input at the start came from the CONCERT Joint Roadmap for radiation protection research and the updated SRAs of the six platforms of MEENAS (MELODI, EURADOS, EURAMED, NERIS, ALLIANCE and SHARE). Through collaboration with the Stakeholder Advisory Board a continuous communication with radiation protection stakeholders was maintained during the each prioritization process. National POMs, the platforms and stakeholders were invited to actively participate in the prioritization process by expressing their opinion on the suggested research priorities and/or suggesting new ones. Up to now 2 such prioritization processes have been held, and the third one is on-going for the open call 3. An evaluation of the prioritization procedure of each call was performed after the close of each call procedure. In this talk, the procedures and results for each of the 3 calls will be explained, including the difficulties encountered during the process and the mitigation actions taken.

THE SONORA PROJECT: TOWARDS SAFE, OPTIMIZED AND PERSONALIZED RADIOLOGY AND RADIOTHERAPY PROCEDURES FOR PREGNANT PATIENTS (PIANOFORTE 2013-015)

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Introduction. In case of Diagnostic and Interventional Radiology (DIR) procedures and Radiotherapy (RT) treatments during pregnancy, the fetal dose must be assessed and optimized. However, the lack of harmonization of clinical practice results in large differences in fetal dose estimation. The SONORA project aims: 1. to develop phantoms of different pregnancy stages; 2. to investigate fetal doses and dosimetry methods for different DIR procedures, RT techniques and patient anatomies; 3. to identify the factors that affect the fetal dose estimations in methods used in clinical practice; 4. to develop and test a clinical tool for estimating the fetal doses in proton RT according to the individual pregnant patient's anatomy and clinical plan parameters.

Material and Methods. A consortium of 17 institutions (12 European countries) has been established and 5 Work Packages (WP) have been created to meet the aims of the project. WP1 investigates the state-of-the-art on practices, tools and methods for fetal dose assessment in DIR and RT, with advantages, limits and gaps. WP2 aims to develop physical phantoms and a library of computational phantoms at different stages of pregnancy considering differences both in patient anatomy and fetus position. In WP3, fetal doses in the most frequent DIR procedures will be determined through measurements in anthropomorphic pregnant phantoms and MC simulations on computational phantoms. The performances of dedicated tools for fetal dose estimation will be assessed thanks to comparison with measurements. WP4 studies fetal doses during breast cancer radiotherapy with photon and proton treatment techniques, including imaging dose. WP5 is dedicated to the communication and dissemination. In particular ethics workshop will be organized and empirically grounded patient communication will be developed.

Results. Activities are ongoing and preliminary results in WPs will be presented.

Conclusions. The project will provide a good practice guide to perform fetal dose estimation in pregnant or potentially pregnant patients from DIR or RT procedures. Fetal dose and associated risk data will be considered for their ethical aspects to increase the quality of risk-benefit communication with the patient.

DISCOVER: DISSECTING RADIATION EFFECTS INTO THE CEREBELLUM MICROENVIRONMENT DRIVING TUMOUR PROMOTION

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While radiation-induced carcinogenesis has traditionally been linked to DNA damage, recent insights into microenvironmental changes and epigenetic modifications challenge this view. The DISCOVER project aims to investigate the complex interplay between DNA damage, microenvironmental alterations, and epigenetic changes in radiation-induced carcinogenesis. The project will leverage our expertise of the *Ptch1*$^{+/-}$ radiation carcinogenesis mouse model to investigate the impact of low/moderate dose exposures (0.1 Gy *vs* 2 Gy) on the brain microenvironment. Various experimental systems, including mice, *ex vivo* cerebellum slices, and *in vitro* cerebellum cell cultures, will be used to assess the microenvironment's role in transmitting radiation signals for carcinogenesis. This advanced model system will be coupled with state-of-the-art multi-omics analysis methods and established bioinformatics pipelines to systemically investigate changes in the brain microenvironment and the role of extracellular vesicles and secretome in the development of radiation-induced carcinogenesis. Mechanistically, attention will also be drowned on the dose-dependency of above effects. By integrating DISCOVER animal data with publicly available human brain cancer data, the project aims to identify patterns or signatures indicative of medulloblastoma development.

The DISCOVER *project has received funding from the Euratom research and training programme 2022-2027 in the framework of PIANOFORTE under grant agreement No 101061037.*

SYNERGY BETWEEN IMMPRINT AND IMAGEOMICS PROJECTS TO IMPROVE BREAST CANCER PATIENT HEALTH AND SAFETY

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Molecular medical imaging is a new avenue in modern medical diagnosis, enabling early and personalized therapy for various diseases, especially cancer. However, existing *in vivo* medical imaging methods have limitations for molecular imaging in humans (low sensitivity to molecular processes, limited spatial and temporal resolution, or high exposure to ionizing radiation). To address these challenges, the technically oriented IMMPRINT project aims to develop a proof-of-principle demonstrator for *in vivo* 3D imaging, utilizing X-ray Dark-Field Imaging (DFI) and X-ray Fluorescence Computed Tomography (XFCT) as a novel hybrid tool for personalised tumor profiling, with a specific focus on Breast Cancer (BC). As a result of this approach, exposure to body-wide high ionizing radiation doses, as seen in nuclear medical imaging methods, can be confined to regions of interest, thus promoting patient safety. Distinct signatures of intra- and inter-tumor heterogeneity in BC will be identified, which are suitable for detection by specifically designed, functionalized and targeted nanoparticles (NPs). IMAGEOMICS relies on IMMPRINT and aims to improve benefit/risk ratio of BC patients by identifying patients with a predicted favourable response to combined Radiotherapy (RT) and immunotherapy and to develop new imaging modality with increased diagnostic potential and reduced ionizing radiation exposure. This project is biologically oriented and will investigate how RT influences immunogenic heterogeneity of BC cells of different molecular subtypes using *in vitro* and *in vivo* approaches; will test the applicability of NPs for XFCT to be used for the detection of BC heterogeneity. Furthermore the project aims to identify local and systemic signatures that predict patient benefit from combined RT and immunotherapy and test their clinical applicability trying to integrate experimental models and human studies with epidemiological data to build up a protocol for optimal patient stratification. The innovative aspects of the project rely on providing an integrative analysis based on *in vitro* (3D bioprints, organ-on-a-chip systems), *in vivo* and human studies on markers reflecting interactions between BC RT and immunotherapy as well as investigating the applicability of molecularly targeted NPs to be used in XFCT.

IMPROVEMENTS IN ATMOSPHERIC DISPERSION MODELLING AND PROTECTIVE ACTION STRATEGIES IN CASE OF NUCLEAR DETONATIONS – THE PREDICT PROJECT

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Since the invasion of Ukraine by Russia in February 2022, there has been ongoing concern over the threats of the use of tactical nuclear weapons. If such an event were to occur, radiation protection of the public could significantly help reduce health impacts in the fallout zone. Decision support systems/atmospheric dispersion models that are currently used in Europe, such as JRODOS, ARGOS and other national systems were primarily developed in the 1990s for responding to nuclear power plant accidents. The release and dispersion of radionuclides from nuclear detonations are in many ways different and pose specific challenges that must be met. Some European countries have recently engaged in assessments of the radiological impacts from nuclear detonations, but atmospheric dispersion models are not currently harmonised at the European level and input parameters require refinement based on up-to-date scientific understanding. The PREDICT project, funded by the 1st Open Call of the PIANOFORTE Partnership (co-funded by the European Union), is a consortium of twelve partners from seven European countries. It aims to fill in these gaps and improve current radiological assessment and decision-aid technological capabilities. The project started on the 1st of February 2024 and will run for 36 months. It is structured into six work packages, to determine the source term for specific explosive yields and types of bursts, improve the parametrisation of existing models, provide guidance for long-term model development, undertake model comparison and model validation (assessment of uncertainties) and develop corresponding protective action and communication

strategies as well as training materials to be used in courses and international exercises. The key results of PREDICT will be recommendations for protective actions as well as for pertaining dissemination strategies to the public. These recommendations will be based on the updated atmospheric dispersion models, which are expected to be state of the art at the end of the project.

LUTADOSE: PERSONALIZED DOSIMETRY TO IMPROVE THE CLINICAL OUTCOME OF PROSTATE CANCER PATIENTS TREATED WITH ^{177}Lu/^{225}Ac-PSMA TARGETED THERAPIES

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Prostate cancer is the second most frequent malignancy worldwide with metastatic Castration-Resistant Prostate Cancer (mCRPC) being very difficult to treat. A possible treatment of mCRPC is PSMA (prostate-specific membrane antigen) radioligand therapy (PRLT) to deliver a targeted high dose of ionizing radiation directly to tumour cells. However, current treatment schemes for 177Lu(Beta)-PRLT use fixed therapeutic schemes, resulting in a conservative tendency to undertreat patients and sacrificing efficacy for safety. As a result, complete response is still uncommon with about 30% of patients not responding to treatment. Meanwhile, 225Ac(Alpha)-PRLT has emerged as adjuvant therapy to improve efficacy and overcome the potential radio resistance to 177Lu-PRLT. However, 225Ac-PRLT can induce significant side effects such as salivary radiotoxicity, which has led patients to request treatment discontinuation. These side effects should be addressed before 225Ac-PRLT can be considered for earlier lines of treatment and not only for compassionate use. Therefore, the aim of LutADose is to increase the clinical applicability of tumour and organ dosimetry during 177Lu/225Ac-PRLT to allow individualized treatment schemes and move away from a 'one fits all' approach. This includes improved quantitative 177Lu/225Ac-SPECT imaging during therapy to better estimate the Pharmacokinetics (PK) of 177Lu/225Ac-PSMA ligands in tumours and Organs At Risk (OAR). For patients receiving 225Ac-PRLT as adjuvant therapy to 177Lu-PRLT, we will use 177Lu-PSMA PK information from the final 177Lu-PRLT cycle to better predict the absorbed dose of the subsequent 225Ac-PRLT cycle. In addition, we will revisit the Relative Biological Effectiveness (RBE) of 225Ac-PRLT *vs* 177Lu-PRLT for the salivary glands to better predict differences in radiotoxic effects between 225Ac-PRLT and 177Lu-PRLT. Meanwhile, small scale dosimetry will be considered for 225Ac-PRLT to better estimate the absorbed dose to OAR. Finally, we will evaluate the impact of the Recoil Daughter Effect (RDE) for 225Ac-PRLT and the potential renal toxicity caused by redistribution of free 213Bi. As a result, we will increase the clinical applicability of image guided dosimetry during 177Lu/225Ac-PRLT such that therapeutic doses can be tailored for each patient individually to achieve a better risk–benefit balance and improved efficacy. This work is supported by the European Partnership for Radiation Protection Research (PianoForte) as part of EU's "EURATOM" research and innovation program.

PRELIMINARY RESULTS FROM THE FIRST YEAR OF THE RESEARCH PROJECT PIANOFORTE: CITISTRA

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CITISTRA (Citizen measurements as complementary radiation monitoring strategy in threats due to armed conflict or natural disasters) is a project responding to the current geopolitical situation in Europe and the increased risk of threats related to radioactivity in connection with war and armed conflicts. The goal is to evaluate the possibilities of using citizen radiation measurements as a complementary strategy to traditional procedures. The project includes a sociological survey in the Czech Republic, Slovakia and Poland aimed at identifying suitable target groups suitable for carrying out citizen radiation measurements. As part of the project, 300 pieces of CzechRad detectors equipped with a Geiger–Müller tube, GPS and memory card recording will be produced and calibrated. Overall 500 portable CzechRad detectors will be loaned to selected volunteers in Poland, the Czech Republic and Slovakia for one year to perform measurements.. Users will also receive free tools to visualize field measurements on a map. Before the start of the measurement period, these chosen groups will be trained in radiation, detection, radiation protection and how to use CzechRad detectors. The data measured will be also available to the public. In addition to field measurements, attention will also be paid to the possibility of using the CzechRad device to measure the thyroid gland, food, feedstock, or objects of daily use. Various educational activities, informational materials and workshops are also a part of the project. The presentation will summarize the current status of the project, results obtained during the project's first year.

IN VIVO PATIENT-SPECIFIC REAL-TIME DOSIMETRY FOR ADAPTIVE RADIOTHERAPY (VERIFIED). WP1 - DEVELOPMENT OF ANTHROPOMORPHIC PHANTOMS (PIANOFORTE)

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Errors in radiotherapy can have significant consequences for patients and generate public concern due to misconceptions surrounding ionizing radiation. To enhance the safety and efficacy of radiotherapy, the implementation of *in vivo* dosimetry is crucial. The VERIFIED project aims to advance individualized therapeutic procedures by utilizing patient-specific information, real-time dose monitoring, and deep learning techniques in Adaptive Radiotherapy (ART). The primary objective of the project is to develop dynamic end-to-end methods that closely simulate real patient treatments. ART addresses the dynamic nature of radiotherapy targets, which can vary in position, shape, size, and biology over time. This variability necessitates continual adjustments to the treatment plan to ensure accurate dose delivery and minimize damage to adjacent critical structures. The WP1 from the VERIFIED project focuses on developing and characterizing anthropomorphic phantoms with movable and deformable inserts, specifically targeting lung and brain tumours for ART. These phantoms are essential for simulating realistic patient scenarios and conducting real-time patient-specific dosimetry studies. The dynamic phantoms developed in this project mimic patient anatomy and physiological motion, including breathing motion, tumour size, and organ position changes during and after each treatment fraction. This will involve expertise in medical imaging, 3D modelling, and additive manufacturing to create customized phantoms tailored to specific tumour types. Objectives within Work Package 1 include the design and fabrication of anatomically accurate phantoms for lung, bladder, and brain tumors; incorporation of mechanisms to simulate breathing motion in lung phantoms and volume changes in bladder phantoms; and implementation of adjustable tumor sizes and organ positions within all phantoms. These phantoms will be validated using imaging techniques and expert evaluation to ensure their anatomical fidelity. By leveraging real-time dosimetry, imaging, and deep learning, the VERIFIED project aims to enhance treatment efficacy, minimize toxicity, and reduce radiation-induced side effects. The integration of state-of-the-art deep learning methods with patient-specific real-time dosimetry in ART-VMAT and real-time position imaging in hfGKRS addresses several unmet needs in adaptive radiotherapy.

A VISION FOR "FAIR" DATA AND INFRASTRUCTURES IN RADIATION PROTECTION

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The European Commission's (ECs) Open Science policy is well established. Open Science is an approach based on open collaborative work and systematic sharing of data, knowledge, and tools as early and as widely as possible. To realise this vision, the EC has mandated the responsible FAIR (findable, accessible, interoperable and reusable) handling of project materials, including generating a data management plan and deposit in an appropriate data archive. Open access to data, infrastructures and publications supports reproducibility and accountability, promotes collaboration and guarantees the prevention of duplication. It facilitates the coordination and integration of projects and saves costs and resources for training and further education. Within the European Partnership for Radiation Protection Research PIANOFORTE, WP5 aims to promote development and establishment of a culture of FAIR exchange for all outputs, including data and infrastructures in radiation protection. The PIANOFORTE Data Management Plan (DMP) details the security, regulatory and ethical governance to ensure secure, transparent and efficient data storage, maintenance and utilization. The integration of DMPs into project planning and evaluation is an ongoing issue for PIANOFORTE. In the field of radiation protection, current efforts are focused on implementation of new approaches such as Artificial Intelligence (AI) and machine learning to improve data discovery, management and analysis. Sharing of large datasets supports the use of these techniques, but we are not yet in a position where >terabyte scale data can be readily archived and shared. Similarly, there are technical developments in database structure and querying, for example using Large Language Models (LLMs), where the technology is not yet sufficiently mature yet investment needs to be made in preparation. The radiation protection community must engage with stakeholders to address needs and concerns about data sharing, data repository architecture, interoperability and dual uses of data, ethical issues, and data management strategies employing AI and machine learning. This presentation deals with the promises and challenges of the growing culture and new technologies in support of FAIR data sharing in radiation protection.

Session 7B

Exposure of members of the public, workers and environment following a major nuclear or radiological accident or incident or malevolent nuclear or radiological act (II)

EVALUATE THE RADIOLOGICAL DISPERSION DEVICES' CONSEQUENCES THROUGH NUMERICAL SIMULATIONS

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Radiological Dispersion Devices (RDDs), commonly known as "dirty bombs," present a significant threat due to their potential to disperse radioactive materials over wide areas, causing both immediate and long-term consequences. This study aims to evaluate the potential impacts of RDDs using open-source numerical simulation software like HotSpot. By integrating various atmospheric dispersion models with radiological and health impact assessments, the research seeks to provide a comprehensive understanding of the consequences of RDD deployment. The methodology involves the use of models to simulate the dispersion of radioactive particulates following an RDD event. These models incorporate real-world variables such as weather conditions and population density to accurately predict the spread of contamination. Furthermore, the simulations assess the radiological dose distribution and potential acute and chronic health effects. High population density areas are particularly vulnerable to significant health risks, with the potential for both acute radiation syndrome and long-term cancer risks. The simulations also highlight the logistical challenges associated with population rescue procedures, emphasizing the need for effective emergency response planning. In conclusion, numerical simulations are a crucial tool in evaluating the consequences of RDDs, providing valuable insights for emergency preparedness and response strategies. The study underscores the importance of integrating radiological risk assessments with urban planning and public health policies to mitigate the impact of potential RDD attacks.

MODELLING THE EFFECT OF COUNTER-MEASURES ON RADIOLOGICAL ASSESMENT

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To allow for more realistic dose assessments for radiological accidents, we have included countermeasures such as sheltering to our atmospheric dispersion model. This knowledge allows us to more accurately implement a radiation-protection strategy for the surrounding areas of nuclear power plants and to determine precautionary areas. We study the effect of countermeasures on the reduction of distances which exceed dose thresholds related to accidental releases of radioactivity from nuclear power plants. We want our model to include countermeasures to validate and further develop our radiation-protection strategy. We implemented a mass/activity-balance equation into the NPK-PUFF atmospheric dispersion model to simulate air containing radioactivity penetrating into buildings. Using this model we can simulate the dose contributions arising from different exposure pathways incurred by a person while sheltering. The effectiveness of sheltering highly depends on the assumed scenario and conditions. To account for a wide range of meteorological conditions, we employ a statistical approach. We performed a thousand independent simulations spread out over a time span of 3 years and determined the distributions of maximum distances at which the imposed dose criteria are exceeded. This then allows us to determine precautionary area surrounding Nuclear Power Plant Borssele. We also use the statistical approach to examine the adequacy of the use of predetermined Dose Reduction Factors (DRFs) in relation to the application of counter-measures. These factors would greatly facilitate the study of average distances for a variety of reference levels for different source terms and scenarios. We will present sensitivity analyses and show that the validity of using predetermined DRFs varies greatly. The outcome is highly dependent on the air-exchange rate as well as on the indoor deposition velocity of the radioactive particles. We will show under which circumstances predetermined DRFs are safe to use, and when explicit calculation of the countermeasure dose is favourable. We observe a large difference in sheltering effectiveness between low and high air exchange-rate homes.

FRAMEWORK FOR LOCALIZATION OF ATMOSPHERIC CONTAMINATION SOURCE WITH NEURAL NETWORKS

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We present a practical framework for the localization of the continental atmospheric contamination source. This system can swiftly identify the unknown source parameters using the Artificial Neural Network (ANN). The ANN acts as a surrogate model for the atmospheric dispersion models typically used in stochastic event reconstruction frameworks. To achieve this, the ANN must be trained on suitable data to accurately reflect the rules governing the contaminant spread over a large terrain. In the absence of experimental datasets of sufficient size, the ANN was trained using the dataset generated by the JRODOS system. This scenario was accepted during the generation of the ANN's training dataset in the JRODOS-MATCH model. The adopted scenarios were based on the event in October 2017, when many European countries reported atmospheric detections of ruthenium Ru-106. We present the results of the dynamic localization using the Approximate Bayesian Computation (ABC) algorithm to obtain the posterior distribution of the probable source location coordinates. Thanks to the application of the ANN, the posterior distributions are updated dynamically by the data from sensors in subsequent time intervals. We also discuss the potential of the ANN trained on the specific scenarios data in other weather and wind field characteristics, inspiring further research and applications.

CHARACTERIZATION OF USING A PORTABLE OSL/IRSL READER FOR *IN SITU* DOSE ASSESSMENTS OF NaCl PELLETS

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Radiation dosimetry is central for the national radiation emergency preparedness and response system. An important objective is to develop methods allowing the estimation of individual absorbed doses to the general population after a Radiological or Nuclear (R/N) accident or release of radioactive substances after a malevolent attack. Knowledge of these doses allows the prediction of potential radiological health detriments to the individuals, contributing to the mitigation of negative health and societal consequences. In this study, Sodium Chloride (NaCl) pellets, made from household salt, have been evaluated for potential use as dosemeters readout *in situ* in connection with R/N emergency situations. Two dosimetry reading techniques were used: Optically Stimulated Luminescence (OSL) and Infra-Red Stimulated Luminescence (IRSL). OSL and IRSL dosimetric properties of the NaCl pellets were evaluated for one portable reader and two laboratory-based readers. The experiments show that, at least, five NaCl pellets are required in order to record sufficient signal with the portable reader for achieving comparable detection limits as with the stationary readers. Dose response tests (β^- and a γ sources) revealed a linear trend both for OSL and IRSL, within the applied dose range (0.6-487 mGy). The Minimum Detectable Dose (MDD) for NaCl pellets read in the portable reader was calculated at about 2 μGy for OSL, and between 43 and 72 μGy for IRSL depending on the radiation source. Residual signals after OSL and IRSL read protocols, were evaluated by two combined protocols were OSL-OSL and IRSL-OSL were measured respectively. The purpose was to identify if the first read-out can be used for rapid *in situ* assessment or screening of individual doses. Samples that exhibit a higher signal than a pre-established limit can be re-read a second time, using the residual signal for verification of the initial estimation and potentially more accurate dose determination. To evaluate the use of combined OSL/IRSL protocols, several aspects have been studied. The effect of various time delays between the two read-outs of each protocol on the second read-out was evaluated. The impact of the stimulation length of the first read-out on the signal recorded during the second read-out was also explored. The findings of the current study support the hypothesis that NaCl pellets can be used for *in situ* assessments of radiation absorbed doses using a portable reader during R/N situations.

BALANCING SMALL MODULAR REACTOR EMERGENCY PREPAREDNESS WITH THE IMPORTANCE OF TRADITIONAL FOOD CONSUMPTION IN THE CANADIAN NORTH

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The ongoing interest in implementing Small Modular Reactor (SMR) technology in remote and northern Canadian communities includes the need to explore potential community effects of radioactive release scenarios. In a post-release scenario, traditional food sources in areas beyond Emergency Planning Zones (EPZs) may lead to radionuclide uptake to individuals through ingestion. While the resulting radiation doses may be higher than normally permissible by Operational Intervention Levels (OILs) or other regulatory guidelines, preventing communities from partaking in these traditional food sources could lead to negative health effects that exceed the increased risk of stochastic effects from radiation dose. The relative nutritional contributions from traditional food sources in remote and northern communities should be weighed against the nutritional deficits associated with the replacement of nutrient-dense traditional and country foods with lower-nutritional value market foods. To this end, metrics such as Disability-Adjusted Life Years (DALY) can be used to reconcile potential negative health effects from these sources. Additionally, existing OILs for food consumption guidelines include pastureland-based food types that are not relevant for remote and northern communities. Consideration should be given for the implementation of new guidelines that include more appropriate food sources that are relevant in remote and northern communities. Overall, the topic of emergency preparedness response in remote and northern communities in the context of eventual SMR use includes food-consumption topics that are not seen elsewhere and should be given specific attention.

ENHANCING EPR THROUGH COMPREHENSIVE THEORETICAL AND PRACTICAL TRAINING PROGRAMS

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This study provides an in-depth analysis of a four-week training program designed to enhance Emergency Preparedness and Response (EPR) capabilities for handling emergency radiological events. The program effectively combined theoretical lectures with hands-on laboratory and field exercises, focusing on key Environmental Radioactivity Monitoring (ERM) and EPR strategies. To enhance EPR capabilities trainees were engaged in practical sessions covering personal protective equipment usage, dose rate measurements, on-foot and car-borne dose rate mapping, in-situ and gamma-ray spectrometry in mobile unit, emergency soil sampling, thyroid gland dose estimation, and the use of emergency communication tools and protocols. Hands-on training in stationary laboratories has strengthened knowledge and skills of key radioanalytical methods - high resolution gamma ray and liquid scintillation spectrometry, as well TLD and OSL dosimetry and calibration of portable dose rate and contamination survey meters. Sessions on Standard Operating Procedures (SOPs) were provided to reinforce quality assurance practices and enhance emergency management skills. Participants visited also key sites like the Krško Nuclear Power Plant, the Slovenian Nuclear Safety Administration's Emergency Centre, and the TRIGA reactor at the Jožef Stefan Institute, gaining insights into real-world radiological safety and response operations. The program demonstrated significant improvements in EPR, highlighting the effectiveness of combining theoretical knowledge with practical experience to prepare response teams for emergencies. These findings affirm the necessity of comprehensive training to ensure response teams are well-prepared, knowledgeable, and operationally ready for radiological emergencies.

THE HAZARD ASSESSMENT FOR THE ITALIAN NATIONAL PLAN FOR THE MANAGEMENT OF NUCLEAR AND RADIOLOGICAL EMERGENCIES

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The Italian national plan for the management of nuclear and radiological emergencies considers the possibility of a severe nuclear accident occurring at foreign nuclear power plant. The hazard assessment on which the plan is based was drafted in 2021 by the National Inspectorate for Nuclear Safety and Radiation Protection (ISIN). This assessment considers two accident scenarios. The first scenario involves an accident in a neighboring country (less than 200 km from national borders), while the second scenario involves an accident at a more distant NPP in Europe. The outcomes of the hazard assessment suggest that, for the first scenario, sheltering and administration of stable iodine should be considered as potential protective measures to be implemented in the northern regions of the country. Additionally, the expected ground contamination requires the implementation of a radiological monitoring program across large areas of national territory as far as food restrictions measures and protection of agricultural and livestock. For the second scenario, there is no need for direct protective measures, but the expected ground contamination still necessitates the implementation of a radiological monitoring program across large areas of the country, as well as possible food bans. Following the start of the Ukraine conflict, ISIN conducted an evaluation of the impact on Italian territory from accident scenario resulting from war events that may affect Ukrainian nuclear power plants. Moreover, an evaluation is still ongoing to assess the consequences of a potential tactical nuclear weapon explosion in Ukraine on national territory. Both studies show that the impact of these scenarios are compatible with the scenario 2 of the hazard assessment of the National plan.

RESCEU CBRN STRATEGIC RESERVE IN FINLAND

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Extreme weather conditions and emerging threats, such as the coronavirus, but also Chemical, Biological, Radiological and Nuclear (CBRN) incidents can overwhelm the ability of EU Member States to help each other, especially when several European countries face the same type of disaster simultaneously. The European Commission has upgraded the EU Civil Protection Mechanism and created rescEU to further protect citizens from disasters and manage emerging risks. Following the activation, rescEU provides an extra layer of protection and ensures a faster and more comprehensive response to disasters. During the years 2023-2026 the European Commission is allocating €305 million to Finland for the development of the rescEU Chemical, Biological, Radiological and Nuclear (CBRN) and medical strategic reserves. The Commission has already set up rescEU reserves for different areas across other EU Member States, such as the rescEU forest fighting airfleet and the rescEU medical stockpile of protective equipment and devices. Finland's CBRN reserve was the first dedicated to CBRN equipment and includes critical medical countermeasures, such as vaccines and antidotes, medical devices, personal protective equipment and measuring equipment to ensure better protection and response in the aftermath of CBRN events or in preparation for high-risk situations. The goal is to strengthen material preparedness and expertise in Europe and ensure sufficient capacities in high-impact events caused by different CBRN scenarios. The reserve of radiation measurement equipment includes personal dosimeters, dose rate and surface contamination monitors, portable devices for radionuclide identification, transportable radiation monitors for vehicles and personnel, thyroid monitors as well as foodstuffs monitoring systems. The rescEU reserves are 100% EU-financed and the European Commission maintains control of activation of the capacities in close cooperation with the countries managing the reserves. In an emergency, the rescEU reserves provide assistance to all EU Member States, Participating States to the Civil Protection Mechanism and can also be deployed to EU neighbouring countries.

METHODOLOGY FOR EVALUATING RADIOLOGICAL CONSEQUENCES FROM ATTACKS ON SPENT FUEL DRY CASKS

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Military attacks on nuclear sites can lead to major radiological release scenarios that would be otherwise impossible. When a civilian nuclear power production facility is outside of regulatory control due to the hostile actions of a foreign military, the current frameworks for guaranteeing safety are much more difficult to assure and may be subject to the strategic or tactical military priorities of the belligerents. The reactor, as well as wet and dry spent fuel storage, fresh fuel storage, and other radioactive sources may all be targets, with some being more vulnerable than others depending on how they are integrated into the facility. The focus of this study is on spent fuel in dry cask storage; although these systems are very robust in their design, they cannot claim to be completely resilient in the face of a targeted military attack. The explosive dispersal of spent fuel in dry cask storage is an example of this, and a methodology for assessing the consequences and protective action strategies are presented. The precise amount of material that is explosively dispersed, and therefore the magnitude of the radiological release, depends greatly on specifics of the attack that are impossible to know ahead of time. As such, the methodology that is presented aims to be part of an inverse modelling-based framework with measurement-informed protection strategies. Experience from past radiological dispersal device experiments are used to define the explosive aerosolization and subsequent atmospheric transport of the spent fuel particles. Amalgamated dose conversion factors are developed, based on the radionuclide inventory in aged spent fuel, that can be applied to any dispersion calculation with a unitary release. The high actinide content in the releases drive significant inhalation dose hazards during both the initial plume dispersal, as well as in the contaminated areas afterwards driven by particle resuspension. Operational intervention levels are developed that use Derived Airborne Concentration (DAC) limits for the actinides as the key measurement metrics for recommending evacuation or relocation of members of the public out of a contaminated area. The conflict in Ukraine has underlined the importance of considering the “beyond design basis threat” to nuclear facilities: where challenges are beyond what an on-site security force can be expected to defeat, and where the radiological consequences can be forced past (intentionally or unintentionally) the design basis accidents for the facilities. This study has been an effort to prepare for this new paradigm.

THEORETICAL STUDY ON PHYSIOCHEMICAL PROPERTIES AND DISPERSION OF RADIOACTIVE PARTICLES/AEROSOLS AND THEIR EFFECT ON MINIMUM DETECTABLE DOSE IN EXPOSED HUMANS FOR EUROPEAN SPALLATION SOURCE RELEASES

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The European Spallation Source (ESS) is a neutron facility under construction near Lund, Sweden. The facility will produce neutrons via proton-induced spallation reactions for various scientific applications. Under normal operation, many radionuclides will be produced and contained inside the tungsten target. However, in the scenario of the loss of coolant, it is predicted that these radionuclides can be spread into the ambient environment in the form of aerosol particles, potentially causing internal contamination in exposed workers and members of the public. There is little research into the possible detectability of members of the public contaminated with spallation source products in terms of Minimum Detectable Dose (MDD) and how this quantity varies depending on the measurement conditions. This study aims to examine the variability in MDD caused by the variability in particle physiochemical properties for selected dosimetrically important radionuclides such as ^{148}Gd (pure alpha emitter with a half-life of 84±4 y), ^{187}W, ^{172}Hf, ^{182}Ta and ^{125}I (gamma emitters, with half-lives of 23.7 h, 1.87 y, 114.4 d, and 59.49 d, respectively). Using an in-house Lagrangian dispersion model, we estimated parameters describing particle size distributions and spatial dispersions in a radius of 10 km from the ESS. The corresponding committed effective dose was calculated using gamma-ray spectra simulated with Nucleonica and ICRP's tabulations for occupational intakes of radionuclides. Variations in MDD at various distances from the ESS and over time after the accident were calculated using the Monte Carlo method. This project is part of ongoing efforts to design a methodology for internal contamination assessment from ESS radionuclides.

MAPPING RADIATION IN ITALY - AN INNOVATIVE MODEL FOR MONITORING AND ALARM

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The Italian National Fire and Rescue Service operates a network of over 1200 radiation detectors dispersed across the Italian territory. These sensors are strategically located to measure gamma dose rates in the air; however, they provide only localized readings. In the event of an accidental or deliberate radioactive release in areas outside the network's coverage, the detection of such incidents could be delayed, potentially leading to significant consequences. This research aims to develop an algorithm designed to integrate measurements from the existing network, enabling the estimation of gamma dose rates in regions without detectors. The objective is to provide near real-time estimates of the background environmental radiation across the entire country under standard conditions. Additionally, the developed algorithm can be integrated with other radiological assessment tools, such as HotSpot or GENII 2.0, to evaluate radiological risks to various environmental matrices and the local population in the event of a radiological release. Upon implementation, this system could serve as an effective tool for early warning in case of accidental or intentional radioactive releases, thereby supporting first responders and decision-makers in mitigating radiological threats.

EFFICIENCY ANALYSIS AND DETECTION LIMITS OF HPGE DETECTORS IN DRINKING WATER MONITORING

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Following a Radiological or Nuclear (RN) event near a drinking water source, it is crucial to monitor the drinking water in real time. In the early stages of nuclear fallout, quantifying radioiodine, especially I-131, is essential. Long-term monitoring should also include Cs-137 and Cs-134. Quantification is key due to EU's stringent concentration limits for liquid foodstuffs. This study simulates the use of two electrically cooled, low-maintenance HPGe detectors, Detective X (Ortec) and MicroGe (Mirion), to evaluate their efficiency in detecting gamma emissions from various water pipe configurations using the Monte Carlo tool VGSL. Preliminary calculations, based on in-situ background measurements with Detective X at a Swedish drinking water plant, indicate that the minimum detectable activities for Cs-137 and I-131 with a 1000-second measurement are 1.79 Bq/L and 2.47 Bq/L, respectively. These findings demonstrate the potential of these detectors for real-time monitoring and ensuring the safety of drinking water post-RN events.

OPENRADIATION: A COLLABORATIVE PROJECT FOR RADIOACTIVITY MEASUREMENTS IN THE ENVIRONMENT BY THE PUBLIC

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The OpenRadiation project offers to public the opportunity to perform dose-rate measurements in the environment at ground level or onboard aircraft using different types of dosimeters connected to a smartphone app. The challenge is to operate such a system on a sustainable basis in normal situations and being useful in a nuclear emergency. In normal situations, this project is based on a collaborative approach with the aim to get complementary data to the existing ones, to consolidate the knowledge about radiation background levels, to generate alerts in case of problem and to provide education and training for a clear understanding of measures for the public. In case of emergency, data will be available spontaneously from the field. Providing an opportunity for the emergency management and the communication with the public. Moreover, this is a powerful tool for populations to regain confidence about the daily living conditions. Such measurements have two major interests, on one hand, to enable everyone to assess his own risk regarding the radioactivity and, on the other hand, to provide "real time" data from the field at various locations, especially in the early phase of a nuclear emergency. The practical objectives are to develop i) an open access database centralizing measurement results, ii) a website providing dose-rate maps and offering dedicated areas for specific projects and iii) a dedicated smartphone app using different connected radiometers with an appropriate calibration factor depending on the use. This project is conducted within a partnership between organisms' representative of the scientific community and non-governmental organizations. The website is available since October 2017 and more than 750000 measurements have been performed by about 290 registered users. The number of measurements and the number of users is continuously increasing since the beginning of this project, demonstrating the interest of the public for such initiatives of citizen science.

STRENGTHENING THE EU CAPABILITY IN CBRN PROTECTION WITH THE DESIGN OF NOVEL LABORATORIES FOR RN IDENTIFICATION

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Member States of the European Union are more and more confronted with accidental and intentional actions threatening the general public and States' infrastructures, like CBRN events. Due to their high disruptive impact, protection against CBRN events has increased its priority level in the last decade for the EU, with the promotion of initiatives strengthening the long-term national and regional countermeasure preparedness. The latest Italian step in this direction is the EU-funded project rescEU-CBRN-DSIM-IT, involving several national entities and industrial partners putting together their expertise to build an innovative modular capacity composed of vehicles, personnel, and technologies covering the full spectrum of C, B, R and N threats. The modular solution adopted allows the rapid mobilization and deployment of resources in case of call, or preventive deployment for securing specific events. The capacity will provide operational support for the response to emergencies, thorough in-field CBRN Detection, Sampling, Identification and Monitoring (DSIM), and support in threat search activities, including the capability of custody of forensic evidence. The modular solution involves: several logistic vehicles, a DSM vehicle, a Chemical Laboratory (CLAB), a Biological laboratory (BLAB), and a Nuclear/Radiological Laboratory (NRLAB). ENEA and Nucleco are involved in designing the Nuclear/Radiological Laboratory within the rescEU-CBRN-DSIM-IT project, to be set up in a class 1C ISO 668 container able to be moved by road, air, and sea, and provided with an easy self-unloading system. The goal of the RN laboratory is to detect and quantify a wide range of radionuclides in many different matrices, while keeping as short as possible the time needed: most of the techniques involved, in fact, can determine several different radionuclides, and the sensibility of each technique can be "calibrated" according to the time available and a target minimum detectable amount of radioactivity. This work reports the functionalities and the project specifications of the RN Laboratory to be used in emergencies relating to the above areas.

NOVEL APPROACH TO MITIGATE THE SCANNING ORIENTATION EFFECTS IN RADIOCHROMIC FILM DOSIMETRY

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Accurate and practical dosimetry technique is crucial for the practices of radiological protection. Radiochromic films have been commonly used worldwide as a two-dimensional dosimetry tool in radiotherapy owing to their high spatial resolution and tissue-equivalent properties. On the other hand, commercial radiochromic films have the issues of scanning orientation effects that could bring about significant errors. To solve this problem and then widen the application of radiochromic film to other fields, such as emergency dosimetry, we investigate a novel approach using an Overhead Scanner (OHS) to mitigate the orientation effects as an alternative to the conventional Flatbed Scanner (FBS) for scanning and digitizing radiochromic films. Three types of popular radiocrhomic film: Gafchromic EBT3, EBT-XD, and EBT4, which were guaranteed for stable responses to different-quality radiations, were used. The films were shaped into hexagons with 5 cm sides and 120° internal angles to ensure uniform exposure and easy analysis. These samples were irradiated with X-rays (160 kV, 6.3 mA) at 0 to 10 Gy. To address the orientation effects, the films were scanned at 30° intervals using a commercial OHS (Aura, CZUR) and compared the results with those obtained from a traditional FBS (GT-X980, EPSON). By analyzing the consistency and accuracy of the color intensity readings from both scanners, we found that the OHS significantly mitigated the effects of scanning orientation effect compared to the FBS. In addition, it was confirmed that the OHS enables us to perform simpler and quicker dosimetry, which is required in an emergency situation. These results indicate a high potential of OHS for more reliable and practical tool for two-dimensional dosimetry. It is expected that the effectiveness of this novel technique will be tested in many occasions of radiological protection practices.

TL AND OSL DOSIMETRY WITH BOTH SINTERED AND UNSINTERED SALT DETECTORS

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Common salt (NaCl) is an alkali halide known as a Thermoluminescence (TL) and optically stimulated luminescence phosphor that has potential for dosimetry. Using grains of Alpine salt with iodine (Saline Reichenhall, Germany) purchased in a grocery, detectors in form of pellets (diameter of 4.5 mm, thickness of 0.9 mm) were made. They were sintered at temperatures of 400, 500 and 600°C. The luminescence measurements were performed by means of an automated Risø TL/OSL reader model DA-20 equipped with an inbuilt $^{90}Sr/^{90}Y$ beta source. Both TL and OSL dosimetry characteristics were investigated. It consisted in studying of sensitivity, reproducibility, Minimum Detectable Dose (MDD), dose response, energy response and fading of the luminescence signals. The resulting characteristic were compared with those obtained previously for unsintered salt detectors. The sintered detectors exhibited strong TL signals characterized with different TL curves specific for the used temperatures of sintration. The curves included stable high-temperature well reproducible peaks suitable for dosimetry. In contrast, unsintered detectors did not exhibit a strong high-temperature peak. MDDs for the sintered detectors were less than 0.1 mSv. Dose response of the TL signal was strongly supralinear for the sintered detectors. For all the detectors, a strong OSL signal was measured after irradiation and stimulation with blue light. However, in the case of the sintered detectors the signal was almost solely related to shallow unstable electron traps, which made it less usable for dosimetry. Moreover, the OSL signal of the sintered group exhibited significant changes in sensitivity in comparison with the unsintered detectors. Dose response was supralinear for OSL signals. Fading of both TL and OSL signals monitored within 3 months after irradiation was inverse for all types of detectors. Energy responses of the OSL signals were similar overestimating dose for photon energies less than 100 keV. In the case of OSL, unsintered detectors are more suitable for dosimetry. On the contrary, sintered detectors can be used for TL dosimetry provided that the strong supralinearity of the TL signal is appropriately corrected within the analytical protocol. Salt detectors are easily preparable and can be used in the case of a large-scale radiation monitoring in emergency situations.

A DIGITAL INCIDENT REPORTING SYSTEM FOR NUCLEAR MEDICINE THERAPY DEPARTMENTS

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This paper describes a digital incident reporting system developed for nuclear medicine departments. The purpose of reporting systems is to collect data to reconstruct the dynamics of an event (accident, near-miss, malfunction) and to assess its causes. It is a useful tool for implementing strategies and measures to correct and improve accident prevention procedures. Current reporting systems are often inaccurate, either because they are compiled and processed after the fact, thus with forgetfulness of details, or because of workers' lack of perception of the reporting usefulness or fear of the consequences. The system we developed aims to facilitate and speed up incident reporting and subsequent data processing, and consists of a mobile application, a dedicated database and a dashboard. The innovative aspect of the project was the involvement of staff and managers to gather experiences, specific needs and feedbacks on possible solutions. This was seen as a necessary step to increase the perceived usefulness of reporting and to reduce the fear of repercussions. The application has a mobile version accessible to operators, Radiation Protection Officers (RPOs) and Risk Management Officers (RMOs) to create and fill reports, and a desktop dashboard-based version reserved for RPOs and RMOs for report management, approval and resolution and for data visualization. The application collects data using both menu-driven questions and free text and images: the former allows RPOs and RMs to quickly visualize graphs and statistics; the latter requires a more complex taxonometric analysis, but it is potentially richer in information. The system is now under test in in patients protected rooms of radiometabolic therapy departments. Preliminary examples of data collected by incidents and near miss will be described. As a future action, is it foreseen to share the system among several Hospitals is foreseen to allow aggregation of data for statistical purposes and to promote harmonization emergency procedures.

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INTERLABORATORY COMPARISONS IN BIOLOGICAL DOSIMETRY: NATIONAL AND INTERNATIONAL COLLABORATIVE EFFORTS

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The threat of large-scale exposures to the public from accidental events or terrorist activities has led to an intensive study of potential emergency dosimetry techniques, particularly Dicentric Chromosome Assay (DCA) and Cytokinesis Block Micronuclei assay (CBMN). A critical aspect of the clinical application of biodosimetry is the standardization of techniques and the unification of approaches to data interpretation. This necessitates interlaboratory comparisons of various methods in controlled experiments and harmonization of protocols. Interlaboratory comparisons are key to achieving this standardization, highlighting the necessity of harmonizing protocols and validating methods through controlled experiments. The study presents the evaluation and results from our institution, focusing on two biodosimetry methods, DCA and CBMN. It includes proprietary calibration curves and the outcomes of retrospective dose assessments of blind samples. A significant part of the study examines the influence of different storage conditions of whole blood samples and culture parameters, highlighting the crucial role of the culture medium. These findings underscore the importance of standardized procedures and robust calibration to ensure reliable dose estimation. The interlaboratory comparisons were performed in cooperation with National Radiation Protection Institute from Czechia and two German laboratories - Federal Office for Radiation Protection (BfS) and Bundeswehr Institute of Radiobiology (BIR). Harmonization efforts are essential to enhance the accuracy and reliability of biodosimetry techniques, ultimately contributing to better preparedness for radiation emergencies. This study details interlaboratory comparisons in biological dosimetry at the national level involving three national institutions under project Bifydos: "Complex of methods of biological and physical retrospective dosimetry for radiation emergency" and two national institutions in collaboration with an international partner under Project Medirabi: "Interlaboratory comparison of the dicentric chromosome assay for radiation biodosimetry". Additionally, it discusses recent interlaboratory comparisons within the European Network of Biological and retrospective Physical dosimetry (RENEB).

IMPROVED DATA EXCHANGE IN EMERGENCY PREPAREDNESS APPLICATIONS

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With the support of the EU Civil Protection Mechanism UCPM (Prevention and Preparedness), STUK is currently working on a project called IDEAMETA (Improvements for Data ExchAnge of eMErgency daTA). The project consists of developing a geospatial software platform, data exchange and smartphone application for radiological field measurements. The focus of this paper is to present the data exchange work package where the aim is to improve the communication between the systems for dedicated use. The solution to this problem is to create software based on REST web technology. The benefits of RESTful architecture include interoperability, flexibility, scalability, security (with tokens) and ease of use (for developers). STUK has several information systems that support emergency preparedness. This project will implement the REST interfaces for three different systems. These systems are TIUKU, JRODOS and USVA. The client software for communication with systems using advanced GIS platform (ArcGIS Enterprise) will be implemented. The modularity of the REST application makes it easy to add other systems in the future. The USVA system manages the results of the automated early warning radiation monitoring network. The TIUKU information system is used to manage emergency situations. It is used to perform and display dose and dispersion calculations, to make recommendations for protective measures in the event of an accident. The JRODOS decision support system is used for dose and dispersion calculations and for assessing the effectiveness of protective measures. Together with field measurements, this provides a technical basis for decision making in emergency preparedness. The ArcGIS Enterprise platform will be the first end-user of the REST software. It will be used to deploy data collection, analysis and presentation of collected measurement data to provide accurate and timely situational awareness data. There will be applications for data collection, analysis and presentation that use automated procedures to reduce the user's workload. The project products will improve STUK's situational awareness in emergency situations. This will be achieved by having all the necessary data available through a single application interface. The software allows for future scalability to new services and is technically designed to have a long life cycle.

EMERGENCY SITUATIONS: SAFETY AND REMEDIATION

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In emergency situations it is necessary to intervene as soon as possible to make the area and the contaminated material safe, so as to avoid possible dispersion of the materials, with a consequent increase in undue exposure of workers and the population. This work shows 3 different scenarios in emergency situations, where the contamination appears to have been Cesium-137, Americium-241 and Radium-226. The intervention, safety, measurement and effective dose activities for workers involved in safety and population activities will then be illustrated, even in the event of an accident scenario. In particular, the results of the safety activities for ash from abatement of fumes contaminated by cesium-137, dust and processing residues contaminated by Americium-241, and processing waste from lead recovery contaminated by Radium-226 will be shown. In all cases, it is highlighted how the resolution of the emergency allowed the resumption of the production process without limitations and the design of areas for temporary warehouses for the safe storage of materials. This is economically the best solution. To these situations is added the description of a heterogeneous material characterization operation preparatory to the final remediation, carried out with advanced technologies, developed specifically for contamination by Cesium-137.

Session 7C

Reducing scientific and societal uncertainties related to radon and NORM

ADVANCES IN RISK MANAGEMENT OF RADON & NORM THROUGH THE RADONORM PROJECT

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The RadoNorm project aims to reduce scientific, technical and societal uncertainties in the assessment of risks from radon and Naturally Occurring Radioactive Material (NORM). Significant headway has been made in occupational protection against radon, investigating the exposure scenarios in underground workplaces and assessing the functionality of radon monitors. Through a survey, a method for identifying and classifying NORM-involving industries was created, and a list of these industries in Europe was developed. For one such industry, operational values could be elucidated for sludge (frequently containing NORM) resulting from water treatment facilities to be used as fertiliser, thereby ensuring compliance with radiation protection requirements and encouraging circular economy. Moreover, radioecological studies have revealed exciting possibilities for bioremediation and biorecovery of NORM from contaminated sites. The most climate-friendly and efficient radon mitigation systems and techniques have been ascertained. Together with a new prototype for measuring radon diffusion coefficients in building materials and research into the barriers and facilitators of NORM-containing alternative cementitious binders, these achievements should support the construction industry in ensuring better radiation protection compliance. Looking at dosimetry, radon dose to the lungs and other organs has also been assessed showing interesting dynamics in combination with other stressors, such as smoking. The quantification of radon dose distributions in lungs will go on to aid in the assessment of *in vitro* experiments. Biokinetic models, especially for pregnant women, are also being finished. Moreover, substantial progress has also been made in improving diagnosis of radon-induced lung cancer. Meanwhile, considering societal aspects, the public perception towards radon, including radon spas, is being mapped. Combined with research on communication strategies, these results will help regional authorities design more effective anti-radon campaigns. Through numerous citizen science projects, education & training initiatives, and a diverse stakeholder network, RadoNorm has substantially enhanced protection against radon & NORM in society.

RADONBIOLOGY - PAST, PRESENT AND FUTURE

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Radon biology, the study of the effects of radon gas and its progeny on biological systems, has developed significantly over the past century. Historically, the recognition of the health risks of radon dates back to 1567, when Paracelsus described "Schneeberger disease", later recognised as lung cancer in miners. Epidemiological studies of miners and radon-exposed residents, identified radon as a major environmental carcinogen for lung cancer. Early research in radiation biology has therefore focused on understanding the mechanisms of radon-induced lung cancer in causing DNA damage and its error-prone repair, leading to cytogenetic aberrations and genetic mutations in genes such as TP53. *In vitro* experiments end of the 1990s highlight the role of bystander effects of alpha particle exposure. Brenner and Sachs and others emphasize its role in the observed inverse dose-rate effect in miners and in contributing to residential radon risk. In the present era, radon biology involves a comprehensive investigation of the molecular and cellular effects of radon exposure, particularly after chronic low exposure. RadoNorm uses advanced technologies such as high-throughput sequencing to elucidate the pathways involved in radon-induced carcinogenesis and to identify radon signatures in lung tumour tissue from exposed mice, miners and residential lung cancer cases. Technically sophisticated *in vitro* broncho-epithelial cell studies are investigating the combined effects of tobacco smoke and radon. The nematode Caenorhabditis elegans is a sophisticated model system for identifying radon-induced biological mechanisms, such as epigenetic effects. Another major project, GREWIS, has contributed to our knowledge on biological effects, particularly on inflammatory and immunomodulatory responses to chronic low-dose radon exposure. Current radon research also focuses on genetic susceptibility to radon exposure, identifying specific gene mutations and polymorphisms that increase individual radon-related? Risk for lung cancer. There is a growing interest in biological mechanisms underlying potential radon-related carcinogenic effects other than lung cancer and non-carcinogenic effects like cardiovascular and neurological diseases. Looking towards the future, radon biology is poised to make significant advancements with the integration of radon biobanks and cutting-edge technologies from genomics, epigenetics, immunology and cancer research embedded in interdisciplinary research approaches of dosimetrists, epidemiologists and biologists. A holistic understanding of radon-induced biological effects in humans modulated by age, sex and combined exposure to environmental noxes will allow to understand the implications on public health and therefore refine preventive measures and radiation protection strategies.

LUNG CANCER MORTALITY ATTRIBUTABLE TO RESIDENTIAL RADON IN GERMANY

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Radon is one of the most important risk factors for lung cancer after smoking. An illustrative way of describing the lung cancer risk of residential radon is to give the number of so-called population-attributable lung cancer deaths caused by radon in homes, since this indicator can help policy makers and the public to understand the health impact of radon exposure. In 2006, it was calculated that around 1,900 lung cancer deaths per year are attributable to radon in homes in whole Germany. Some of the data used to calculate the number of attributable deaths have changed since then. Thus, the talk presents the Population-Attributable Fraction (PAF) and the number of lung cancer deaths attributable to residential radon in Germany per year using updated data and an advanced method of calculation. Data on lung cancer mortality (2018-2022), smoking behavior (2017), and the estimated distribution of radon concentrations in homes in Germany (based on a radon measurement survey from 2019 to 2021) are used. The considered risk model is derived from the pooled European residential radon study, the so-called Darby study, which indicates that the excess relative lung cancer risk is increased by 16% per 100 Becquerel per cubic meter long-term radon concentration. In contrast to the PAF approximation formula mostly used in the literature, which only takes into account the average radon exposure in a population, we applied an approach, which incorporates the entire distribution of radon exposure and leads to more accurate results. Compared to the results from 2006, the current analyses give a slightly higher PAF (6% versus 5%) and a substantially higher number of radon-induced lung cancer deaths in Germany. The slightly higher PAF is mainly due to the improved knowledge about the residential radon distribution in Germany, which yielded higher radon values (63 versus 49 Bq/m³ mean value). The higher radon levels as well as the increase in annual number of lung cancer deaths over time in Germany lead to an increase in the number of radon-attributable lung cancer deaths. Most radon-attributable lung cancer deaths are current smokers and ex-smokers. However, a considerable proportion is also found among never smokers. The results confirm that radon in homes is a relevant risk factor for lung cancer and emphasize the importance of protection measures against radon in Germany for all population groups.

PATHOGENIC TIMELINE AND RADIATION RISK IN RADON-EXPOSED RATS FOR LUNG CANCER AND ITS HISTOLOGICAL TYPES FROM MULTI-STAGE CLONAL EXPANSION MODELS

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Lung cancer risk from radon exposure has been analysed with biologically-based models of carcinogenesis in cohorts of uranium miners and in experimental animal datasets since the late 1990s. Recent insight in differential molecular landscapes and radiosensitivity of histological types has prompted a renewed interest in a histology-specific analysis of historic data sets of radon-exposed rats. In RadoNorm Task 4.6.2 we apply multi stage clonal expansion models to analyse a dataset of 4276 rats from the Pacific Northwest National Laboratory (PNNL) in the U.S. The dataset describes for each rat the exposure, which ranges from 0 to 10000 Working Level Months (WLM), and exposure rate, up to 1000 Working Level (WL), together with information on the presence of lung tumours, and on their histology. First analysis showed that the age-risk patterns of Adenocarcinoma (AC) and Squamous Cell Carcinoma (SCC) show strong differences depending on exposure. To analyse these differences, we studied the exposure responses of the two carcinogenic processes. The risk models with the preferred carcinogenic mechanisms were selected based on goodness-of-fit. In particular, the preferred model for AC shows both radiation-induced initiating mutations and clonal expansion of tumour initiating cells, while for SCC radon exposure mostly accelerates clonal expansion. Our preferred conceptual model is obtained by extending a two-stage clonal expansion model by a third stage describing tumour growth. This allows us to estimate the duplication rate of tumour cells expressed as latency time, which is defined as the time between the first appearance of a malignant cell and the clinical discovery of the tumour. The estimated lag time is longer in AC compared to SCC, due to the detected faster tumour growth rate of the latter. The onset of the Excess Relative Risk (ERR) per WLM after the end of exposure is determined by the lag time. The mechanism of radiation-induced growth acceleration (promotion) for preneoplastic lesions on cancer incidence and risk is discussed in radiobiology intensely. We illustrate the conditions under which the impact of this mechanism on lung cancer incidence after protracted radon exposure can be detected. We show how the age-exposure patterns of Kaplan-Meier estimators are driven by the underlying cell-based processes of radiation-induced initiation and promotion. We describe the presence of an “inverse dose rate effect” as an inversion of the ERR at constant cumulative exposures and increasing exposure rates. The inversion occurs for exposure rates higher than 30 WL for SCC respectively 200 WL and less significantly for AC, possibly as a consequence of the underlying mechanisms leading to the development of AC or SCC, respectively. In contrast to risk estimates from state-of-the-art ERR models, estimates from biologically-based models reflect the impact of radiation-induced carcinogenic processes. If available, our models allow the integration of information on preneoplastic lesions and on molecular landscapes of tumour tissue for model development and parameter estimation.

THE EFFECT OF ASTHMA AND COPD ON THE RADIATION BURDEN OF THE BRONCHIAL AIRWAYS

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Radon progeny inhalation is the second most important cause of lung cancer worldwide, so it is necessary to determine how much energy is absorbed in different parts of the lungs from their decay. The aim of our study was to simulate how asthma and Chronic Obstructive Pulmonary Disease (COPD) influence the radiation burden of the bronchial airways. For this purpose Monte Carlo simulations were used. First, the airway deposition of ^{218}Po, ^{214}Pb and ^{214}Pb was simulated, and as the next step, the probability of the alpha-decays of ^{218}Po and ^{214}Po was calculated in every bronchial airway tube. The deposition distribution of the unattached and attached progeny was determined with the Stochastic Lung Model (SLM). Using these data, the alpha and beta decays during mucociliary clearance were simulated with a self-developed clearance and dosimetry model. In asthma only the bronchial airways are contracted, but in COPD, in addition to this, the partly alveolated conducting airways are also narrower and the alveolar structure is damaged. The breathing pattern of a subject with asthma or COPD is also quite special. For these lung diseases, as the health status gets worse, more and more air is inhaled and the breathing becomes asymmetric. These changes have a considerable effect on both the progeny deposition rate and the dose rate originating from their decay. In asthma and COPD, the altered mucociliary clearance (thicker and slower mucus) needs also to be simulated. The bronchial deposition fractions (deposited/ inhaled progeny number) of the unattached and attached progeny are much higher for COPD class I-II than for a healthy man. This is due to the synergistic effect of the higher inhaled air volume (helping the inhaled particles to penetrate deeper into the lungs), and the contracted airways (enhancing deposition by diffusion and sedimentation). As COPD gets worse, for Class III, the difference between the healthy and the diseased subject gets even bigger. The dose rates in the nuclei of radiosensitive basal and secretory cells are also much higher for a subject with COPD. This is caused by the higher progeny deposition rate and the contraction. Due to the smaller airway diameter, the target cells get closer to the alpha-emitters, so more of the emitted alphas can reach them. For a diseased subject, the mucus layer is thicker, which some shielding effect, but our calculation has clearly showed that this cannot compensate for the above mentioned dose elevating effects. According to our results, health status of the subject is very important in radon dosimetry. To investigate this, a flexible particle deposition and clearance+dosimetry model is needed with airway generation specific resolution. The Stochastic Lung Model and the connected radon progeny clearance and dosimetry model are unique tools to simulate the effect of age, height and health status on the radiation burden.

PARAMETER UNCERTAINTY ANALYSIS OF THE EFFECTIVE DOSE FOR INTAKE OF RADON PROGENY IN UNDERGROUND MINES USING INTDOSKIT TOOL

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Radon presents significant health risks due to inhalation of its short-lived progeny. The organ at risk from the inhalation of radon progeny is the lung. This is because about 95% of the effective dose from inhalation of radon progeny is attributed to this organ. For intakes of radon, evaluation of the effective dose is crucial for assessing the potential health risks from radon exposure such as lung cancer. This study therefore focused on the parameter uncertainty analysis of the effective dose coefficient from radon progeny inhalation in mines. Dose calculation using INTDOSKIT an inhouse software developed in the R programming language were done using the latest models published by the International Commission on Radiological Protection (ICRP) for the Human Respiratory Tract Model (HRTM), Human Alimentary Tract Model (HATM) and the systemic models for polonium, lead and bismuth. Probability distributions for the model parameters were obtained from published literature sources and Monte Carlo simulations with random sampling performed to derive frequency distributions of the doses per unit exposure to radon progeny. The parameters considered in the Monte Carlo simulations included the aerosol parameters, subject related parameters and absorption rates for radon progeny. The calculations were performed for two exposure scenarios i.e., wet drilling with good ventilation (job type 1) and dry drilling with poor ventilation (job type 4). Results showed that the doses for job type 4 are higher than those for job type1 by about 40%. This can be attributed to a higher equilibrium factor for job type 4 compared to job type 1. For the global uncertainty analysis, the effective dose for job type 1 followed a lognormal distribution with a geometric mean of 5.67 mSv/mJhm-3 and geometric standard deviation of 1.5. The Uncertainty Factor (UF) for this job type was 2.44 while for job type 4, the effective dose distribution was characterized by a lognormal distribution with a median value of 8.86 mSv/mJhm-3 and GSD of 1.5. UF for this job type was 2.25. Hence, the uncertainties were greater for job type 1 as opposed to job type4. This can be attributed to the differences in aerosol characteristics for the two job types. Sensitivity analysis results show that it is the uncertainty on the aerosol parameters that influences most the calculated effective dose coefficient.

Session 8

Round table: situation in Ukraine

DISINFORMATION AS THE MAJOR THREAT IN NUCLEAR AND RADIATION RESEARCH: UKRAINIAN EXPERIENCE DURING THE FULL-SCALE INVASION OF RUSSIA

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In wartime, the need for quick responses becomes paramount when the information landscape is oversaturated. There is often no time for thorough analysis, and the race to counter disinformation is won by those who can react swiftly and take control of the narrative. Russia has repeatedly exploited this by spreading disinformation about Ukraine's nuclear capabilities and intentions. For instance, Russian propaganda has falsely accused Ukraine of developing "dirty bombs" or attempting to sabotage the Zaporizhzhia Nuclear Power Plant (ZNPP). These narratives aim to sow fear and confusion, both domestically and internationally, and shift blame for potential nuclear incidents. To effectively counter such disinformation, it is crucial to cultivate new leaders who can engage with the public, act as influencers, and work closely with journalists. This leadership development is key to building a proactive communication strategy, rather than just reacting to false claims. One effective measure would be to involve young people in the nuclear field by popularizing science and offering retraining programs for graduates of physics and mathematics faculties. The nuclear industry already faces a shortage of qualified specialists, amplifying the vulnerability to misinformation. Educational outreach is another vital component in countering disinformation. Engaging communities - particularly influential groups like doctors and teachers who often serve as hubs of information dissemination - is essential. These individuals can become trusted voices in the countering against disinformation and misinformation. Ukrainian society generally has a high level of trust in its experts, but there is growing skepticism toward international institutions, especially due to their perceived inaction in addressing nuclear risks posed by Russia. This frustration extends to doubts about the international expert community and even erodes faith in the rule of law, particularly concerning the de-occupation of the Zaporizhzhia NPP. A critical step forward is ensuring that communication is consistent and continuous, not just during moments of heightened threats. This effort must span across all platforms - books, articles, podcasts, videos - and target all audiences, from the general public to industry experts. It is important to emphasize that nuclear weapons are not a solution or a defense mechanism. Russia's aggression against Ukraine goes far deeper than just the nuclear question, and understanding this complexity is essential to resisting simplistic narratives propagated by disinformation campaigns. By focusing on comprehensive, proactive communication, we can build resilience against disinformation in the nuclear field and foster greater public understanding and trust in both national and international experts.

Session 9

Beyond the silo: Union programmes and priorities that intersect with Radiation Protection research and how to put synergies into practice

ERPW: CONNECTING RADIATION PROTECTION RESEARCH. PLATFORM SESSION ON EU FUNDING/ PROGRAMME SYNERGIES

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The session is dedicated to the presentation and discussion of overlaps between radiation protection R&I funding, i.e. EURATOM Fission, and other European programmes and initiatives. Which are the most relevant areas for cooperation and mutual benefit? How can the radiation protection community engage in or cooperate with certain Horizon Europe domains, EU missions, or European Partnerships? The inputs should shed light on the prospects for interdisciplinary collaboration while highlighting the needs for radiation research in Europe as a whole. Thus, the speakers for the event will discuss their agendas for the programmes and their thoughts on the possibility of creating synergy. In addition to highlighting future strategies for enhancing communication and teamwork, the panel discussion will outline the state of cooperative contacts between the various programmes and disciplines.

Session 10A

Debate on skin dosimetry

TOWARDS AN IMPROVED COMPUTATIONAL PHANTOM FOR SKIN DOSIMETRY: CURRENT STATUS AND FUTURE DIRECTIONS OF EURADOS TASK GROUP 6.3

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The skin is the largest organ in the body, and vulnerable mainly to weakly penetrating radiation. For exposures from widespread contamination to beta particles or low energy photons, there could be large parts of the skin that are highly exposed, but the doses will likely be fairly uniform across those regions, so typically may be evaluated by considering dose averaging at 70 μm depth over a 1 cm2 area. Exposures from small particles of radioactive material (so-called "hot particles") in contact with the skin are very different, however, because even near the exposure site, dose gradients will be steep. In an effort to explore some of the issues, Task Group 6.3 of EURADOS Working Group 6 ("Computational Dosimetry") has initiated a pilot study to develop computational phantoms aimed at providing improved dose mapping within the skin. Specifically, high-resolution voxelized phantoms have been studied to consider energy deposition distributions on microscopic scales: the prototype models feature macroscopic volumes (1 cm3) of skin resolved into ~10×10×10 μm3 sub-volumes, i.e. comparable to the sizes of typical skin cells. A number of alternative tallying approaches have also been considered, including bulk dose and single-event energy depositions, using different Monte Carlo codes (MCNP6, FLUKA, and GEANT4 + GEANT4-DNA). Focus so far has been on idealized electron sources, with plans to extend the work to incorporate real radionuclide emission spectra from microparticles of realistic shapes and compositions. The research is still a work in progress with many questions still to be investigated. These include: what are the optimum physical quantities of interest, what are the optimal outcomes from the work, and how can the findings best contribute within the overarching framework of radiological protection?

Session 10B

Biological effects of low dose exposure during medical applications

MOLECULAR MARKERS FOR BIOLOGICAL DOSIMETRY IN RADIATION PROTECTION, CANCER RISK ASESSMENT AND OPTIMIZING RADIOTHERAPY

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Our group elaborates effects of ionizing radiations on genetic instability in human cells. DNA damage response, gene and chromosome rearrangements, and apoptosis are the main endpoints studied by automated fluorescent and imaging microscopy, DNA repair foci and comet assays, chromosomal aberrations, micronuclei, FISH, RT-qPCR, DNA cloning and sequencing, standard and imaging flow cytometry, and cell sorting. In order to optimize evaluation of DNA repair foci, we have elaborated step-by-step protocol for optimization of classifier spot count using METAFER Slide Scanning System. This optimization was proven by comparison with enumeration of 53BP1 and γH2AX foci using manual analysis with JCountPro software. We analysed effect of low dose ionizing radiation on DNA repair foci in human lymphocytes to the aim of potential biodosimetry and possible extrapolation of high-dose H2AX/53BP1 effects to low doses and compared kinetics of DSB and IRIF. No significant difference was observed between data obtained by γH2AX residual foci evaluation in cells that were irradiated by low doses and data obtained by extrapolation from higher doses. We found that 53BP1 foci induced by low-dose radiation remain longer at DSB loci than foci induced by higher doses. Using these techniques along with evaluation of micronuclei we assessed individual radiosensitivity of breast cancer patients. Increased level of *in vitro*-induced γH2AX/53BP1 DNA repair foci suggested impairment of early stages of DNA repair process in radiosensitive patients. We have analysed DNA damage response and preleukemic fusion genes induced by radiation in human hematopoietic stem/progenitor (HSPC) cells and found that CD34+ HSPC are: (i) extremely radio-resistant showing delayed time kinetics of apoptosis compared to lymphocytes; (ii) accumulate lower level of endogenous DNA damage/early apoptotic γH2AX pan-stained cells; (iii) have higher level of radiation-induced 53BP1 and γH2AX/53BP1 co-localized foci. Within CD34+ HSPC we identified CD34+CD38+ progenitor cells as a highly apoptosis-resistant population, while CD34+CD38− (HSC/MPP) was sensitive to radiation-induced apoptosis. Irradiation with low dose of IR (≤50 cGy) induced very low level of BCR-ABL but not TEL-AML1, MLL-AF4, and AML1-ETO Preleukemic Fusion Genes (PFG). We then analysed PFG responsible for the genesis of AML: RUNX1-RUNX1T1, PML-RARα, and KMT2A-MLLT3 induced by the low dose of γ rays in sorted and expanded HSPC populations. Our data did not reveal cell population with a higher sensitivity to the formation of radiation-induced PFG. We found higher accumulation of

chromosomal damage in the radiological workers in comparison to the control group. In addition, long-term low-dose exposure to IR resulted in amplification of the MLL gene segment what could potentially contribute to malignant transformation.

This work was supported by the Research and Innovation Authority (VAIA 09I03-03-V04-00466), (VAIA 09I03-03-V04-00456) and VEGA 2/0082/23, VEGA 2/0079/23 and VEGA 2/0012/23.

BIOLOGICAL EFFECTS OF RADIATION EXPOSURE IN PATIENTS TREATED WITH X-RAY-GUIDED ENDOVASCULAR AORTIC REPAIR

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Background. Endovascular Aortic Repair (EVAR) exposes the patient to significant doses of radiation. Studies have suggested a higher incidence of cancer in these patients compared with those having open surgical repair of aortic aneurysms, but evidence linking this observation to radiation is insufficient. We investigated biological sequalae of radiation exposure, including markers of genomic instability, in patients after EVAR.

Methods. Lymphocytes were isolated from patients after complex (branched/fenestrated) EVAR and non-irradiated controls. Dicentric Chromosomes (DC), chromosomal aberrations caused by irradiation, were enumerated. γ-H2AX, a marker of acute DNA damage/repair, was measured by immunofluorescence after *ex vivo* irradiation of 0.2 and 1 Gy. Expression of radiation-responsive genes (FDXR, CCNG1, P21 and PHPT1) was measured by RT-qPCR following irradiation of blood samples.

Results. Seventeen patients (82% male, age 73 range [59-85 years]) and sixteen controls (56% male, age 68 range [53-83 years]) were recruited. The mean incidence of DC was 3.782, 95% CI[3.13, 4.43] and 0.898, 95% CI[0.48, 1.32] per 1,000 cells for patients and controls, respectively ($p<0.0001$). Patients had higher background of γ-H2AX foci than controls, (0.7056, 95% CI[0.3163, 1.095] *vs* 0.2413, 95% CI[0.0774, 0.4051]) per cell, ($p<0.05$). FDXR was the most radio-responsive gene ($p<0.0001$), but no statistically significant difference was found between the two groups.

Conclusion. We have shown an increased frequency of chromosomal aberrations in patients after complex EVAR. A higher background DNA damage/repair activity was also found in this cohort, observed as an increased baseline expression of γ-H2AX. The link between DNA damage and clinical effects remains unclear, However, these findings support the theory that increased cancer incidence after EVAR may be related to radiation exposure.

EVALUATION OF ONCOGENIC RISK AND CUMULATIVE DOSE FROM RADIOLOGICAL INVESTIGATIONS IN INTENSIVE CARE UNIT PATIENTS: VARIABILITY BETWEEN BEIR VII *vs* RADRAT *vs* ICRP 103 *vs* US EPA MODEL RISKS

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Purpose. To compare Additional Oncogenic Risk (AOR) related to radiation exposure according to different risk models including Biological Effects of Ionizing Radiation seventh report (BEIR VII), Radiation Risk Assessment Tool (RadRAT), International Commission on Radiological Protection (ICRP) 103, and U.S. Environmental Protection Agency (EPA) risk models in Intensive Care Unit (ICU) patients.

Methods and Materials. This was an IRB-approved observational retrospective study. 150 patients (45 F; 105 M, mean age 63.2±27 years) admitted to intensive care multivisceral transplant unit (MTU, 44 patients) or cardiac surgery unit (CSU, 106 patients), who underwent x-ray radiological examinations between April and June 2023, were included. For each patient, the cumulative effective dose during one single hospital admission was calculated and AOR for all cancer and leukemia were estimated according to the risk models.

Results. All cancer risks was lower according to ICRP 103 *vs* BEIR VII *vs* U.S. EPA *vs* RadRAT (20±105 *vs* 40±226 *vs* 41.88±254 *vs* 47.5±346 $p < 0.001$), while it was higher in male patients according to BEIR VII (male *vs* female median ± IQR, 58.6±279 *vs* 18.6±112), RadRAT (77.2±456 *vs* 24.2±130), ICRP 103 (20±121 *vs* 15.94±64) and U.S. EPA (69.40±329 *vs* 20.59±125). Leukemia risk was higher in the U.S. EPA *vs* BEIR VII *vs* RadRAT *vs* ICRP 103 *vs* (7.75±41 *vs* 7.6±37 *vs* 7.27±42 *vs* 1.8±13, $p < 0.001$), while it was higher in male patients both according to all the models: BEIR VII (male *vs* female median ± IQR, 9.5±52 *vs* 2.12±11), RadRAT (9.94±50 *vs* 2.03±12), ICRP 103 (2.17±18 *vs* 0.92±4) and U.S. EPA (9.83±51 *vs* 2.34±12).

Conclusions. The ICRP 103 risk model estimated a lower radiation-induced cancer risk for all cancer risks. The U.S. EPA estimated an increased radiation-induced leukemia risk compared to BEIR VII, U.S. EPA and RadRAT.

DEVELOPMENT OF NOVEL PIPERAZINE DERIVATIVES AS ENHANCED RADIOPROTECTIVE AGENTS

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The use of Ionizing Radiation (IR) in medical treatments and the potential for nuclear incidents necessitate effective radioprotective solutions to mitigate associated risks. Current radioprotectors like amifostine offer limited application due to severe side effects and logistical constraints in administration. This study aims to develop and evaluate novel piperazine derivatives with improved efficacy and safety profiles as potential Radioprotective Agents (RA). We synthesized a series of novel 1-(2-hydroxyethyl)piperazine derivatives and assessed their radioprotective efficacy and cytotoxicity *in vitro*. These compounds were evaluated for their cytotoxicity using a panel of human cell lines, and their ability to mitigate DNA damage was determined by the Dicentric Chromosome Assay (DCA). The enhancement of MOLT-4 cell viability after irradiation by our substances was assessed utilizing the Annexin V/propidium iodide assay. The leading compounds were compared with amifostine for their protective effects against gamma radiation. Among the synthesized derivatives, compounds 3 and 6 emerged as promising candidates, showing significant radioprotective effects with minimal cytotoxicity across tested cell lines. They demonstrated a favorable balance between lipophilicity and efficacy, suggesting a potential for higher clinical applicability. Compound 3 displayed potent radioprotective effects, particularly in reducing the formation of dicentric chromosomes, indicating effective mitigation of DNA damage. The novel piperazine derivatives presented in this study hold substantial promise as safer and more effective RA. Their enhanced safety profiles and significant efficacy in protecting against IR-induced damage make them suitable candidates for further development and possible future clinical evaluation. These findings contribute to the broader efforts in developing next-generation radioprotectors to safeguard human health against the adverse effects of IR.

INDIVIDUAL RADIOSENZITIVITY OF BREAST CANCER PATIENTS

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Breast cancer is the most frequently diagnosed malignancy in women worldwide. Along chemotherapy, Radiotherapy (RT) is one of the most widely used treatment strategies. Despite significant advances in RT planning and radiation techniques, approximately 1-5% of patients experience serious side effects. Great effort is made to study potential biomarkers of individual radiosensitivity and to detect Radiosensitive Patients (RS) before the start of treatment. The analysis of DNA damage, apoptosis, Chromosomal Aberrations (CA) and Micronuclei (MN) are the most studied techniques mainly for their reliability and affordability. The aim of our work was to verify the analysis of γH2AX and 53BP1 DNA repair foci, apoptosis, CA and MN in detection of RS patients. In this study, we analyzed 50 patients before, during (after 10 Gy RT) and after the end of RT (month and year after RT). Our results showed an increased amount of DNA repair foci before RT in RS (n=5) patients compared to patients with Normal RS (NOR), but this method was not sensitive enough to determine RS at the individual level. The number of DNA repair foci was also affected by Chemotherapy (CHT), which was given to about half of the patients before RT. In patients treated with CHT, we observed an increased level of DNA repair foci before RT. *In vitro* experiments showed an increased level of 53BP1 and γH2AX/53BP1 DNA repair foci in RS patients in comparison to NOR patients, but repair kinetics was the same in both groups. The level of radiation-induced apoptosis was the same in both groups of patients. We also observed an increased level of CA and MN during and after the end of RT. During the entire therapy, a trend of a higher number of MN was observed in RS patients compared to the NOR patients, but the amount of CA did not differ. For all biomarkers, we observed individual variability between patients, which precludes the individual use of these methods in the assessment of RS, but their combination could be a promising approach in the future.

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IMPLEMENTATION OF A THERANOSTIC SYSTEM FOR NUCLEAR MEDICINE APPLICATION: PRELIMINARY BIOLOGICAL DATA

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The actual main challenge in radiotherapy is to reduce the radiation adverse effects in the healthy tissue, at the same time a massive development of nanotechnology and in particularly of nanomaterials for radiopharmaceutical's drug delivery has began. In effect, combining gold nanorods (AuNRs) with Technetium-99m (^{99m}Tc) could generate a theranostic radiopharmaceutical that could be delivered to the tumor site: gamma photons from the ^{99m}Tc decay irradiate AuNRs that will emit low energy x-rays and electrons (i.e. Auger electrons) in the area where the radiopharmaceutical is delivered. Also, AuNRs irradiated by photons with a specific energy, can emit the same kind of electrons. Inside tumor cells, Auger electrons cause a dense deposition of energy increasing the radiobiological efficiency, thus allowing the use of a lower therapeutic irradiation dose resulting in the sparing of healthy tissue. In this framework, the SEGNAR project, founded by INFN, fits in and in which one of the aims is to assess *in vitro* the radio-induced damage at cellular and/or molecular level following irradiation with photon beam in T98G cells, thus mimicking the labelled ^{99m}Tc used in clinical settings. The following preliminary data collected during the first period of this work are focused on radiobiological effect and mitochondrial damage in T98G cells with and without treatment with different concentration of AuNRs and photon irradiation. The next step planned in the project is to functionalize AuNRs with a peptide capable of addressing them to the tumor cell nucleus to maximize and increasing the radio-induced damage.

IN VITRO STUDY OF RADIOSENSITIVITY IN COLORECTAL CANCER CELL LINES ASSOCIATED WITH LYNCH SYNDROME

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Lynch syndrome patients have an inherited predisposition to cancer due to a deficiency in DNA Mismatch Repair (MMR) genes which could lead to a higher risk of developing cancer if exposed to Ionizing Radiation (IR). This pilot study aimed to reveal the association between MMR deficiency and radiosensitivity at both a CT relevant low dose (20 mGy) and a therapeutic higher dose (2 Gy). Human colorectal cancer cell lines with (dMMR) or without MMR deficiency (pMMR) were analysed before and after exposure to IR using cellular and cytogenetic assays i.e., clonogenic, Sister Chromatid Exchange (SCE), ɣH2AX foci and apoptosis assays. The advantages and limitations of these assays were assessed *in vitro*, and their applicability and feasibility investigated for their use in further studies using clinical samples. Results from the clonogenic assay indicated that the pMMR cell line (HT29) was significantly more radio-resistant than the dMMR cell lines (HCT116, SW48, and LoVo) after 2 Gy X-irradiation ($p \leq 0.04$). Both cell type and radiation dose had a significant effect on the yield of SCEs/chromosome ($p < 0.001$). When the yield of SCEs/chromosome for the irradiated samples (2 Gy) was normalized against the controls, no significant difference ($p = 0.349$) was observed between the cell lines. For the ɣH2AX assay, 0, 20 mGy and 2 Gy were examined at post-exposure time points of 30 min, 4 and 24 h. Statistical analysis revealed that HT29 was only significantly ($p < 0.05$) more radio-resistant than the *MLH1*-deficient cells lines, but not the *MSH2*-deficient cell line. Apoptosis analysis revealed that HT29 was significantly ($p < 0.05$) more radio-resistant than HCT116, albeit with very few apoptotic cells observed. Overall, the study showed radio-resistance of the MMR proficient cell line in some assays, but not in the others. All methods used within this study have been validated; however, due to the limitations associated with cancer cell lines, the next step will be to use these assays in clinical samples to understand the biological and mechanistic effects of IR in Lynch patients; as well as the risks of IR in this patient population.

INTERLABORATORY COMPARISON OF THE DICENTRIC CHROMOSOME ASSAY WITHIN THE MEDIRABI PROJECT

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The Dicentric Chromosome Assay (DCA), i.e. the detection of aberrant dicentric chromosomes in human peripheral blood lymphocytes, is regarded as the gold standard biodosimetry method due to its high specificity for ionizing radiation. However, DCA is time-consuming, and its final evaluation is subjective, leading to a potential variability across different biodosimetry laboratories. Therefore, the interlaboratory comparisons are essential to maintain high-quality standards in DCA-based dose estimates. Following this, an interlaboratory comparison of the Dicentric Chromosome Assay (DCA) was conducted between two Czech biodosimetry laboratories (the National Radiation Protection Institute and the University of Defence) and two German biodosimetry laboratories (the Federal Office for Radiation Protection and the Bundeswehr Institute of Radiobiology). Specifically, blood samples from two healthy donors with no prior radiation exposure were irradiated with three different doses using a 1.4 MeV X-ray beam generated by a linear accelerator at Motol University Hospital. Following irradiation, the blood samples were incubated at 37°C for two hours, then distributed at room temperature to each participating laboratory. Each laboratory performed DCA-based dose estimates using their internal protocols and calibration curves. The results were compared with the reference doses and among the laboratories to identify potential pitfalls and areas for improvement in the implementation of DCA for biodosimetry purposes.

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BONE MARROW-DERIVED EXTRACELLULAR VESICLES FROM IRRADIATED MICE ARE ABLE TO INDUCE SENESCENCE IN THE HEMATOPOIETIC MICROENVIRONMENT

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Ionizing Radiation (IR)-induced genomic instability, immune system alterations and senescence have a key role in developing malignant processes, especially in the context of cancer patients treated with radiotherapy. Low- and high dose IR can induce several alterations in the Bone Marrow (BM) and their stromal microenvironment which might lead to serious defects in the hematopoiesis. Extracellular Vesicles (EV) have a key role in the intercellular communication, particularly mediating radiation induced-bystander effects. We have set up an *in vivo* model system to better understand IR-induced processes potentially involved in leukaemogenesis and the role of EVs in this process. Male 9-12 week-old mice were (I) directly irradiated with 0.1 Gy or 3 Gy X-rays; or (II) injected with BM-derived EVs isolated from directly irradiated animals; or (III) both irradiated and injected with EVs. Long bones were isolated 3, 6 and 9 months after treatment. Single cell suspensions were prepared separately from the BM and bone. Major phenotypical changes of subpopulations within the bone and BM and B-gal staining indicative of cellular senescence in the respective cell subpopulations were investigated by flow cytometry. Direct 0.1Gy treatment did not cause senescence in the radiosensitive lineage negative compartment in the BM, while EV treatment with EVs isolated from 0.1 Gy treated mice resulted in an increased level of cellular senescence in the stem cell compartment in the recipient mice. Irradiation with high dose (3 Gy) induced cellular senescence in specific BM and stromal cell subpopulations 3-9 months after treatment (long-term haematopoietic stem cells, multipotent progenitors). EV treatment resulted in an increased level of cellular senescence in the mesenchymal stem cells and endothelial cells in the stromal compartment. Our studies demonstrate that not only ionizing radiation can cause abnormalities and trigger senescence in specific BM and stromal cell types, but also BM-derived EVs isolated from directly irradiated (both at low and high doses) animals can induce bystander effect in certain BM and stromal subpopulations in the recipient mice. We showed that intercellular communication has a strong influence in hematopoietic microenvironment changes after IR exposure.

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CONFOUNDING INFLUENCE OF INTER - AND INTRA - INDIVIDUAL VARIATION IN γH2AX FOCI FOR BIOLOGICAL DOSIMETRY ESTIMATES

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Inter- and intraindividual variability during sampling for γH2AX foci analysis can impact on baseline and spontaneous foci. Such sampling confounders could contribute to an overall increased in DNA damage and potentially leading to unreliable dose estimates in clinical or accidental exposure cases. In this study, we aim to investigate the effect of intra- and interindividual variation on radiation-induced DNA repair response from a cohort of healthy volunteers and analyse the inter-and intra-individual variability of DNA repair response of the volunteers (n=10). Samples will be taken from UKHSA volunteers at two time points within the same day. Samples will then be *ex vivo* irradiated with X-rays (0.5 Gy at 0.5 Gy/min) and incubated for 30 minutes, after which the DNA damage/repair response will be compared against unirradiated controls. DNA repair activity will be assessed using the γH2AX immunofluorescence assay to determine the relative frequencies of DNA repair biomarkers (γH2AX and 53PB1). During this initial pilot study, study participants will donate peripheral blood samples twice on the same day, on 3 separate occasions over a period of 6 weeks. In total, 120 samples will be analysed. These samples will be irradiated at a single dose (0.5 Gy), before a short incubation period (30 mins). The γH2AX foci will be scored using the automated Metafer 4 system, with a comparison between the automated and manual scoring to investigate the sensitivity of each method. From this group, we will be able to demonstrate inter- and intra-individual variability between radiation dose response and changes in spontaneous/baseline foci frequencies.

CONSTRUCTION OF THE FIRST CALIBRATION CURVE "DOSE - RESPONSE" IN KAZAKHSTAN FOR ASSESSING INDIVIDUAL QUANTITATIVE DOSE BY BIODOSIMETRY METHODS

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Radiation dosimetry is crucial for Kazakhstan due to the activities of the Semipalatinsk Test Site (1949-1989) and Kazakhstan's leading position in uranium reserves, mining, and export. These factors, along with the growth of nuclear medicine and the use of radioactive sources, underscore the need for precise dose assessment methods to ensure radiation safety and emergency preparedness. Dose sorting and monitoring are essential for minimizing health impacts, saving lives, and maintaining the population's psycho-emotional well-being. *In vitro* experimental work conducted using a ^{60}Co gamma source (Therabalt K02) with an average energy of 1.25 MeV. Peripheral blood lymphocytes were cultured using the classical cytogenetic method (dicentric, DIC) and Fluorescent In Situ Hybridization (FISH) with whole-chromosome DNA probes for chromosomes 1, 4, and 12 (MetaSystems, Germany). Chromosomal Aberrations (CA) of unstable and stable types were identified, manually sorted, photo-archived, and analyzed for dose distribution using a cytogenetic platform based on the AxioImager Z2 microscope (Carl Zeiss) and Metafer 4, MSearch (MetaSystems), ICAROS, and ISIS (MetaSystems Software, license No. 2250047) software. The obtained results of dose-dependent yields of radiation-induced unstable chromosomal aberrations formed the basis for constructing a calibration curve from 0 to 5 Gy for acute exposure scenarios: $Y = 0.0015 (+/- 0.0010) + 0.0150 (+/- 0.0039) \times D + 0.0176 (+/- 0.0020) \times D^2$. Using the FISH method, a dose-dependent calibration curve of stable radiation-induced chromosomal aberrations - translocations at various dose points up to 1 Gy was obtained: $Y = 0.0003 (+/- 0.0002) + 0.0110 (+/- 0.0029) \times D + 0.0073 (+/- 0.0042) \times D^2$. The experimentally determined coefficients of the linear-quadratic equations are key parameters, the use of which allows for reliable personalized dose assessment in acute and chronic exposure scenarios. Validation of the calibration curve through blind exercises demonstrated results, which characterized as informative and representative. The obtained results open new horizons for the practical application of cytogenetic dose assessment and build the foundation for further scientific and practical developments in the field of radiation safety in Kazakhstan and the Central Asian region as a whole.

CANCER MORTALITY AND OCCUPATIONAL EXPOSURE AMONG KOREAN RADIATION WORKERS

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Numerous studies have documented the effects of exposure to ionizing radiation, especially in populations exposed to moderate-to-high levels. The Korean Radiation Workers Study (KRWS) was initiated to establish a cohort of Korean radiation workers and evaluate the health effects of chronic low-dose radiation exposure. This study aims to determine whether prolonged exposure to low doses of ionizing radiation is associated with cancer mortality. The KRWS cohort comprised 196,379 radiation workers registered in the National Dose Registry (NDR) and their radiation doses was linked to the National Vital Statistics Registry (1992-2020). We estimated the association between external penetrating ionizing radiation and cancers, modelling the Excess Relative Risk of cancer per Gray (ERR/Gy) using Poisson regression. The cohort predominantly comprised men (83.5%) and nuclear power plant workers (32.4%), with 61.1% of the workers were born before 1980. The average cumulative colon dose (standard deviation) for all workers was 4.10 mGy, higher in men (4.67 mGy) than women (0.55 mGy). A total of 1548 workers (0.8%) died from cancer during the follow-up period, with liver cancer (22.7%), lung cancer (19.4%), stomach cancer (15.0%), and pancreatic cancer (6.8%) being the most common types. No statistically significant risk associated with ionizing radiation was observed in the dose-response analysis. The ERR/Gy for all cancers was 2.57 (95% CI -2.05 to 7.18), for stomach cancers 7.69 (95% CI -7.12 to 22.50), for colorectal cancer 0.70 (95% CI -13.41 to 14.82), for pancreatic cancer 5.68 (95% CI -15.18 to 26.54), and for lung cancer 6.35 (95% CI -5.62 to 18.31), indicating an increasing trend but not statistically significant. Further studies are required to investigate the dose-response relationship, considering more diverse confounders such as smoking habits, alcohol consumption, and social economic status. Additionally, given the relatively young age of this cohort and the limited duration of follow-up, continued monitoring is crucial to investigate the health risks associated with radiation exposure.

HERITABILITY OF TRANSCRIPTIONAL RESPONSE TO IONIZING RADIATION

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Health risks following Ionizing Radiation (IR) exposure vary among individuals. Understanding the impact of genetic and environmental factors on IR sensitivity variance is fundamental in radiation oncology and radiation protection. Gene expression in response to IR has been widely studied in human blood. We analyzed blood sample-derived primary T-cell cultures from 16 monozygotic, 38 dizygotic pairs and 19 pairs of unrelated donors, to quantify the contribution of genetics to response variance, i.e., heritability in 9 previously identified radiation-responsive genes. To this aim, structural equation methodology was applied to expression data. Heritability was estimated for the best-fitted models incorporating the genetic factor. Transcriptional phenotype similarity increased with genetic relatedness. Only *CCNG1* and *CDKN1A* had a significant heritability level, respectively 71.4% and 74.1% at the endogenous level. When exposed to IR, the heritability was significant for *CCNG1* (69.3%), *CDKN1A* (74.6%), *FDXR* (73.4%), *BBC3* (81.1%) and *ATF3* (67.2%) expression. Radiation exposure thus better revealed the genetic impact. The positive correlation between additive genetic effects at baseline and after irradiation further indicated a larger genetic effect on transcription variance for *CCNG1* (r_A=0.95) and *CDKN1A* (r_A=0.69). Overall, the study quantified for the first time the human genetic contribution to IR transcriptional response variance which is significant, albeit gene dependent. Results highlight the complexity of genetic regulatory effects in DNA damage response and the potential of further similar studies to enhancing the understanding of individual response, including identification of radiotoxicity markers.

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CELLULAR RESPONSE VARIATIONS AFTER X-RAY IRRADIATON WITH DIFFERENT ENERGIES

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Introduction. Radiation dose, measured in Gray (Gy), is the "gold standard" for developing any treatment plan for clinic patients and plays a role in radiation protection to minimize health risks for exposed occupational groups. In studies, irradiation of patients or biological materials with the same dose but different devices, sometimes leads to divergent effects. Given that, we sought to determine whether device properties such as energy, which is typically overlooked, might be responsible for these variations and could influence cellular responses to ionizing radiation. Consequently, we investigated Macrophage (MPH) plasticity and functionality as well as alterations in Osteoclasts (OCs) *ex vivo,* following irradiation with 0.5 Gy in an energy-dependent (eV) approach.

Methods. Healthy wildtype C57BL/6 mice of both sexes were used to isolate monocytes from bone marrow. OCs were generated using RANK-L, M-CSF and optionally TNF-α. Differentiation into different MPH subsets was induced via M-CSF (M0), GM-CSF, LPS and IFNγ (M1) or M-CSF and IL-4 (M2). Irradiation was conducted using X-rays at a uniform dose of 0.5 Gy, with 120 keV, 250 keV and 6 meV, respectively. Osteoclast differentiation was analysed via TRAP-staining and MPH surface marker expression was examined via flow cytometry. Further, ROS levels of both cell types were assessed.

Results. MPH surface marker expression was stable for M1 except for CD206 which significantly decreased at an energy of 250 keV and 6 MeV. On M2 MPHs, PD-L1 was significantly upregulated at 6 MeV, while MHC-II was downregulated with 250 keV and 6 MeV. ROS analysis indicated a significant decrease of ROS in M1 MPH following irradiation with 250 keV and 6 MeV, but not 120 keV. In contrast, ROS levels of osteoclasts were only variable in an inflamed milieu (+ TNFα) with a slight increase at 120 keV and a decrease at 6 MeV.

Conclusion. Irradiation of MPHs and OCs with the same dose, but with different energy levels, results in disparate effects, especially in terms of oxidative stress levels. Here, further research on cell death and additional cellular functions would be of interest. Nonetheless, these results emphasize the importance of inclusion of irradiation qualities into dosimetry and the potential necessity for a re-evaluation of risk assessment.

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IMMUNOFLUORESCENT VISUALIZATION OF CENTROMERES IN METAPHASE CHROMOSOMES OF LYMPHOCYTES: POTENTIAL IMPROVEMENT IN DOSE ESTIMATION ACCURACY OF DICENTRIC ASSAY

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The dicentric chromosome assay using blood lymphocytes has been one of the most accepted and frequently used cytogenetic techniques for retrospective biodosimetry since the mid-1960s. In this method, dicentric chromosomes are scored from cytological preparations of chromosomes in metaphase. Giemsa cytological stain or DAPI fluorescent stain are commonly used for chromosome visualization. However, these stains do not specifically mark centromeres, making the recognition of dicentric chromosomes challenging. The accuracy of identification depends heavily on the quality of the preparation and the experience of the evaluator, making dose estimation susceptible to human error. For instance, artificially crossed chromosome arms arising during preparation can be mistakenly identified as centromeres. Improved visualization of centromeres would significantly refine dose estimates. This study tested the usability of immunofluorescent detection of the centromere protein CENP-C, a centromere marker, on human metaphase lymphocyte preparations. Blood samples from volunteer were gamma-irradiated with doses up to 5 Gy. Post-irradiation, the samples were incubated at 37°C in a CO_2 incubator. The irradiated blood was then added to RPMI medium containing fetal bovine serum and PHA-M (Thermo Fisher Scientific) and cultured in TK25 cultivation flasks for 50 hours. Two hours before the end of cultivation, colcemid was added at a concentration of 267 ng/ml. After cultivation, the blood culture was centrifuged, and the blood cell pellet was resuspended in a hypotonic KCl solution, incubated at 37°C for 15 minutes, and centrifuged again. The cells were then fixed with a methanol/acetic acid mixture (3:1), a step repeated three times, before the lymphocytes were dropped onto Super Frost Plus slides. A heat-mediated epitope retrieval technique was applied by boiling the preparations in 98°C EDTA buffer with a pH of 8.5 to reduce chemical modifications of proteins caused by the fixative. To prevent non-specific antibody binding, samples were incubated in a 5% bovine serum albumin solution. The samples were then incubated with primary anti-CENP-C antibody (Abcam) at 37°C for two hours. For signal visualization, a secondary fluorescent antibody Alexa 568 was used. DAPI was employed to visualize the entire chromosomes. The immunofluorescent detection of the CENP-C protein in the centromere region of metaphase lymphocytes was successful, indicating that this method can reduce dose estimation errors caused by human factors.

Session 10C

Cosmic radiation

LONG-TERM RADIATION SIGNAL PERSISTENCE IN URINE AND BLOOD: A TWO-YEAR ANALYSIS IN NON-HUMAN PRIMATES EXPOSED TO AN ACUTE 4 GY TOTAL BODY GAMMA RADIATION DOSE

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National security concerns regarding radiological incidents, accidental or intentional in nature, have increased substantially over the past few years. A primary area of intense planning is the assessment of exposed individuals and timely medical management. However, exposed individuals who receive survivable doses may develop delayed effects of acute radiation exposure many months or years later. Therefore, it is necessary to identify such individuals and determine whether their symptoms may have been initiated by radiation, requiring complex medical interventions. We previously developed early response metabolomic biosignatures in biofluids from Nonhuman Primates (NHPs) (up to 60 days) exposed to a single total body gamma radiation dose of 4 Gy. A follow-up of these animals has been ongoing with samples consistently collected every few months for up to 2 years after exposure, providing a unique cohort to determine if a radiation signal persists longer than 2 months. Metabolic fingerprinting in urine and serum determined that exposed animals remain metabolically different from pre-exposure levels and from age-matched controls, and the pre-determined biosignature maintains high sensitivity and specificity. Significant perturbations in tricarboxylic acid intermediates, cofactors and nucleotide metabolism were noted, signifying energetic changes that could be attributed to or perpetuate altered mitochondrial dynamics. Importantly, these animals have begun developing diseases such as hypertension much earlier than their age matched controls, further emphasizing that radiation exposure may lead to accelerated aging. This NHP cohort provides important information and highlights the potential of metabolomics in determining persistent changes and a radiation-specific signature that can be correlated to phenotype.

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BIOLOGICAL EFFECTS OF CHRONIC LOW DOSE RATE EXPOSURES OF NEUTRONS ON PLANTS

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The exposure of biological organisms to cosmic rays during future space missions to the Moon and Mars is a well known problem. The presence of plants on future space missions will have a dual purpose, the production of fresh food (through microgreen growth) for the astronauts and the production of oxygen. This work focuses on the study of the damage and behavior of plants under flux of neutrons produced as secondary radiation by primary cosmic rays. Dose rates derived from bibliographic data, measurements and simulations are in the order of 15 to 40 microSv/h. Seeds of two cultivars of *Raphanus sativus*, Rioja and Daikon, have been irradiated at the ENEA-NUC-INMRI neutron laboratory at Cr-Casaccia for a few weeks to several months, at low dose rates comparable to those foreseen for the above missions. The laboratory contains a room in which several shielded neutron sources are stored, some of which have energy spectra partly similar to those of cosmic neutrons. After neutron exposure of seeds, the effects on germination and seedling growth were evaluated by morphological, flow cytometric and metabolomic analyses. First results will be present

SPACE RADIATION DOSIMETRY IN AEROSPACE

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Due to its characteristics, space radiation has an unfavourable effect on the crew and passengers in the aircraft. One of the methods of protecting both workers and customers from the effects of cosmic rays is the monitoring of in situ radiation levels. According to ISO 20785-3:2023 (Dosimetry for exposures to cosmic radiation in civilian aircraft, Part 3: Measurements at aviation altitudes), calculations of dose rates should be validated by measurements. Astronauts in space are exposed to higher doses of radiation and Solar Particle Events (SPE's) and Galactic Cosmic Rays (GCR's). This presentation is a review of methods actually used and a method studied at the Institute of Optoelectronics at Military University of Technology. Traditional dosimetric methods use Thermoluminescent Detectors (TLDs) attached to the crew's clothing. Their main advantages are small size and independence from power supply. Nowadays, active types of measurements, such as silicon detectors, are more popular. They allow continuous monitoring of the radiation dose in space. In aerospace, the most common method is mathematical calculations to estimate the amount of dose accumulated by a person. Dose assessment is based on data from satellites and theoretical models of the atmosphere and space weather. Experimental studies such as the Radiation Dosimetry Experiment (RaD-X), the European Space Agency Active Dosimeter (EAD) and the Matroshka AstroRad Radiation Experiment (MARE) are improving and validating computational dose assessment methods. One of the experiments that investigated the risks caused by space radiation in aviation was the Radiation Dosimetry Experiment (RaD-X) flight mission conducted by NASA in 2015. It collected data from a stratospheric balloon, supporting aircraft flights, and provided an estimate of the exposure of aircraft crews to primary and secondary cosmic rays using the four different types of dosimeters. Latest improvement in personal dosimetry on the International Space Station (ISS) is the implementation of the European Space Agency Active Dosimeter (EAD). It consists of different types of detectors that allow for the most accurate dose assessment possible. For space stations it is especially important to know the current dose because of unpredictable events like SPE's and GCR's. Based on the need to research active methods for space radiation detection, the IOE has started to work on personal dosimeter for aircraft crews. The Silicon PhotoMultiplier (SiPM) and other semiconductor detectors have been used for experiments to check which one is the most suitable for personal dosimetry. Testing and modification of the research setup will allow improvement of the device and enable it to be used in the future. Some of the results will be presented at the conference.

RADIOBIOLOGICAL EFFECTS OF PROTONS OR GAMMA RAYS AND UVB RADIATION ON HUMAN CELLS: IMPLICATIONS FOR RADIATION PROTECTION

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Radiation from cosmic and solar sources constitutes a significant environmental factor influencing human health on Earth. While cosmic radiation originates mainly from the outer space, solar radiation emanates from the Sun, both contributing to the complex radiation environment experienced by living organisms on our planet. Although studies have traditionally examined the effects of cosmic and solar radiation individually, emerging research suggests that their combined (mixed beams) exposure may induce synergistic effects, altering cellular responses and potentially impacting human health in ways yet to be fully understood. This work aims to delve into the intricate interplay between cosmic radiation and solar radiation at the cellular level, focusing on their synergistic effects on human cell biology. Through a multidisciplinary approach we explored key aspects of synergistic interactions, including cell viability, DNA damage, and finally genomic instability. To assess the impact of the combined exposure, normal human cell lines (skin fibroblasts, keratinocytes, etc.) were exposed to gamma rays and protons (simulating muon radiation) followed by UVB. Cellular, molecular and cytogenetic biomarkers of radiation exposure were utilized, such as DNA damage response proteins (γH2AX and 53BP1) and dicentric chromosomes. The MTT assay was applied in co-exposed samples to determine cellular metabolic activity as an indicator of cell viability, proliferation, and cytotoxicity. Preliminary results have revealed elevated levels of persistent unrepaired DNA Damage in co-exposed samples compared to samples exposed to ionizing radiation only, using the γH2AX foci biomarker. Towards this direction, the experimental approaches used in the present study aim to comprehensively investigate the effects of the combination of solar UV and cosmic radiation in order to evaluate their radiobiological consequences on human cells. Our findings may eventually contribute to the advancement of our understanding of the complex radiation environment on Earth and its potential implications on human health for radiation protection purposes.

CHARACTERISTICS OF CANCER INCIDENCE AMONG WORKERS IN THE KOREAN AVIATION INDUSTRY

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Flight attendants experience prolonged exposure to cosmic radiation while performing their duty at high altitudes. Considering these characteristics, flight attendant represents an important study group for investigating the health effect of cosmic radiation exposure. Despite previous study on the health effect of flight attendants, notably concerning cancer, the precise association is unclear. The aim of this study is to define workers in the aviation industry workers including cabin crew and pilot, using Korea national registry-based health database and to evaluate the cancer incidence risk. We constructed a cohort consisting of aviation industry workers by utilizing data from the Korea National Health Insurance Service(K-NHIS) spanning 2002 to 2021. The K-NHIS databases, derived from insurance data covering 97% of the Korean population, comprises a Qualification Table (QT) containing demographic characteristics and a treatment (20T) and diseases table (40T) where diagnosed diseases codes can be verified. We identified aviation industry workers by using job coded outlined in the QT. Cancer incidence was determined using ICD-codes in 20T and 40T, and age- and sex-specific Standardized Incidence Ratios (SIRs) with 95% Confidence Intervals (CIs) were calculated based on the cancer incidence rate of the general population from 2002 to 2019. The cohort encompassed a total of 37,011 workers, including 23,400 (63.3%) male and 13,611 (36.7%) female. Most workers were born post-1980, and a significant portion commenced their work after 2015, resulting in a short tenure, typically <5 years. Approximately 5% of the cohort had been diagnosed with cancer. The SIR for all cancers combined was lower compared to the general population in Korea. However, notably higher SIRs were observed for nasopharyngeal cancer (SIR, 3.21; 95% CI, 1.71-5.48) and non-Hodgkin lymphoma (SIR, 1.57; 95% CI, 1.02-2.32) in males, as well as for masked reporting (SIR, 1.51; 95% CI, 1.34–1.70) and thyroid cancer (SIR, 1.25; 95% CI, 1.05-1.47) in females. Our results revealed a significant healthy worker effect in all cancers combine; however, several types of cancer exhibited higher incidence rates compared to the general population. To better understand the association with cosmic radiation exposure beyond comparison of incidence rates, further investigation through dose-response assessment using radiation dose is essential. Also, flight attendants frequently travel across multiple time zones, they are at a higher risk of experiencing circadian rhythm disruptions. Thus, in further study, conducting a thorough investigation that consider additional information concerning potential confounding factors like smoking, alcohol consumption, and shift work would aid in comprehensively understanding the association.

Session 11

Revolutionizing Radiation Protection with AI

AI IN DOSIMETRY

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AI is becoming deeply integrated into many aspects of society, transforming industries from healthcare to finance. As AI continues to evolve, its influence on daily life and the global economy is expanding, reshaping the way people work, communicate, and live. Artificial Intelligence (AI) is also starting to play a role in radiation protection. Of course there are many applications being used and coming up in the medical field. In other fields of radiation protection AI is less used, but it is emerging. This became clear in a recent workshop that was organized by PIANOFORTE. The participants discussed current and future artificial intelligence implementations in various sectors of radiation protection that include medical applications, radiation dosimetry, radiobiology, radioecology, emergency preparedness, response and recovery. This talk will focus on the potential future role of AI in dosimetry. Results from a literature review will be presented which shows that AI has the potential to revolutionize dosimetry of ionizing radiation. Traditional dosimetry methods often rely on physical detectors, but AI can also aid in the development of new dosimetric technologies, such as camera-based systems or advanced wearable sensors, providing continuous, real-time dose monitoring in diverse settings. By integrating AI with simulations, such as Monte Carlo methods, it becomes possible to predict radiation doses more precisely, considering various environmental and biological factors.

AI-DRIVEN DOSIMETRY: PERSONALIZING PATIENT RADIATION SAFETY

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Artificial Intelligence (AI) is rapidly transforming the field of medical dosimetry, particularly in enhancing patient safety and personalization in radiation exposure. AI-driven dosimetry uses advanced algorithms and machine learning models to predict and optimize radiation doses in diagnostic X-ray imaging. Several recent studies have explored innovative approaches to replace traditional Monte Carlo (MC) dose simulations. MC simulations are the gold standard for accurate dose calculations. However, these simulations can be time-consuming, making them less practical for real-time clinical applications. To overcome this limitation, scanner-specific and patient-specific MC simulations have been performed to calculate organ doses and use these as the "ground truth" for machine learning models. A notable advancement in this area is the development of neural networks, especially those based on the U-Net architecture, to delineate radiosensitive organs automatically. By employing U-Net-based neural networks, researchers have been able to segment organs and accurately predict radiation doses across multiple organs, such as the lungs, liver, kidneys, and thyroid. This approach is particularly useful in clinical settings where rapid dose calculation is critical. In addition, the ability to incorporate patient-specific data, such as anatomical variations, into these models makes them highly personalized, aligning with the growing trend toward individualized medicine. Overall, these advancements in AI-driven patient dosimetry represent a promising shift from traditional methods, offering faster, yet accurate, dose predictions. As AI continues to evolve, its role in dosimetry will expand, integrating more advanced predictive models and facilitating greater collaboration between medical physicists, radiologists and clinicians. By personalizing radiation safety, AI-driven dosimetry not only protects patients from unnecessary radiogenic risks but also enhances the overall effectiveness of medical imaging, ushering in a new era of precision medicine.

AI-ENHANCED IMAGE RECONSTRUCTION AND IMAGE QUALITY IN MEDICAL IMAGING

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The use of artificial intelligence is increasing in many fields and, also in medical applications. Most of the current medical applications are dealing with therapy assistance. However, there is a growing number of approaches for medical imaging evaluation or optimization. While segmentation and classification are classical tools for image evaluation and are partly used to foster sometimes also AI driven clinical decision support systems, image optimization mainly focusses on advanced image denoising and image reconstruction. Image processing with respect to image denoising and image reconstruction in the medical field has to be evaluated and verified very well as it has to be avoided that relevant structures are suppressed, or signs of diseases are introduced into the images by means of the AI based approaches. Thus, AI based image processing methods has to be validated to produce clinically equivalent images regarding the diagnostic outcome. This paper discusses the various actual existing methods for image denoising in X-ray based imaging as well as in nuclear medical imaging and various approaches investigated or proposed for image reconstruction. It will show approaches including also applications like producing super-resolution images, artefact reduction and proposed use for exposure reduction. Potential problems will be shown on examples as well as studies having shown significant potential. In addition, various approaches to determine the quality of the image processing, and the generated images again based on classical approaches as well as on AI approaches will be presented and discussed. This discussion will be based on what the quality measures determine, how they cover potential relevance to diagnostic procedures, how they relate to clinical evaluations where available. Evaluation studies for the methods proposed and described as indicated above will be presented and their results will be discussed as well. Finally, a number of suggestions will be given for prerequisites to develop relevant and useful image processing tools and how such tolls could be quality assured in a meaningful way.

ETHICAL AND REGULATORY CONSIDERATIONS FOR AI IN MEDICAL APPLICATIONS

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The introduction of Artificial Intelligence (AI) in medical applications is mostly driven by private initiatives that use proprietary algorithms. Given the significant impact that AI-guided diagnostic and therapeutic systems can have on patients, and considering the known issues of bias and representativeness in data-driven systems, it is essential to exercise caution in matters of radiation protection. The work of SHARE within the strategic research agenda of EURAMED (https://roccnroll.euramed.eu/deliverables/ (see Deliverable 6.1) and the Ethics guidelines for trustworthy AI of the European Commission (https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai) have especially remarked the need for transparency, diversity (as opposed to unfair bias) and benefit for all human beings, including future generations. These three conditions, which are meant to spread the use and increase the acceptance of AI among patients, are currently lacking in most algorithms that are daily used in innovative clinics. One potential solution is offered by adhering to the "FAIR Guiding Principles for scientific data management and stewardship" (https://www.go-fair.org/fair-principles/). The FAIR data management enforces the Findability, Accessibility, Interoperability, and Reuse of digital assets and emphasizes secure, transparent, and efficient data practices, addressing security, regulatory, and ethical issues. The ethical issues are a challenge for regulatory agencies, which are also considering the technical challenges and opportunities regarding AI technologies (https://roccnroll.euramed.eu/deliverables/ (see Deliverable 6.1). There is a need to apply novel quality assurance methods for machine-learning-based tools, such as denoising algorithms in radiology. The potential of AI-tools is being used to support regulatory activities, for instance looking for patterns in dosimetry (big) data, which can help prevent incidents or detect imaging protocols that are especially successful. Coordinated efforts between research, industry, public bodies, and patient involvement at the European level are crucial for the proper development of AI in medicine. A perspective that can be addressed by the recently adopted EU AI Act (https://artificialintelligenceact.eu/), which aligns with existing regulations on data governance, ethical use and coordination between science, policy and funding agencies.

AI-DRIVEN FRAMEWORK FOR INTERNAL DOSE ASSESSMENT IN RADIOLOGICAL EMERGENCIES: INTEGRATION OF MULTIPHYSICS, BIOKINETICS, DOSE RECONSTRUCTION, AND *IN VIVO* ANALYSIS

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Introduction. Precision estimation and reconstruction in internal dosimetry is critical in radiological emergencies to effectively mitigate health risks associated with radiation exposure. Traditional methods may be limited due to their reliance on uniform Particle Deposition Profiles (PDPs) in source term definition, with further limitations in accounting for individual anatomical and physiological variability from inhalation of source terms during nuclear security exposure events. A unique methodological framework will demonstrate an innovative integrated computational-experimental methodology, incorporating Computational Fluid and Particle Dynamics (CFPD), biokinetic modeling, Artificial Intelligence (AI), and *in vivo* assay triage to refine internal dose coefficients.

Materials and Methods. The study harnessed a large dataset of de-identified CT scans to create detailed 3D models of Human Respiratory Tracts (HRTs), capturing the anatomical variability of the non-reference population (age, sex, and morphometry-specific) influencing PDPs. CFPD simulations were conducted on these models to track aerosolized particles across diverse demographic clusters, using a log-normal particle size distribution (mean = 0.42 μm, GSD=3.5). These simulations generated personalized dose deposition factors integrated into dose estimation models established by the International Commission on Radiological Protection (ICRP). Stochastic biokinetic models were expanded, considering radionuclide inventory, particle size, solubility, and clearance rates from inhaled sources. A novel dose coefficient computational tool developed at Georgia Tech, called REDCAL, was created to enhance statistical coupling for uncertainty analysis, providing a personalized approach to dosimetry in nuclear security events. Additionally, *in vivo* lung counting efficiency assessments were conducted using anthropomorphic phantoms and Monte Carlo simulations, accounting for Chest-Wall Thickness (CWT) and Body Mass Index (BMI) variations. A novel approach to this study involved translating data from historical animal studies to conduct dose reconstruction from acute administrations of internal emitters. Animal data from the Inhalation Toxicology Research Institute and the Northwestern University Radiobiology Archive were selected to inform AI-driven dose reconstruction models of body burden using variables of sex, age, skeletal burden, and excreta. This included preprocessing and normalizing historical data, simulating biokinetic behaviors, and optimizing AI algorithms for intake reconstruction.

Results. CFPD simulations produced high-fidelity PDPs, revealing significant individual differences in particle deposition, critical for accurate radiation dose assessment from inhaled radionuclides. The experimental component demonstrated improved lung counting efficiencies, with clear correlations between CWT, BMI, and morphological differences. The REDCAL computational code provided enhanced statistical coupling, validated against traditional dosimetry models, and integrated with experimental measurements. Investigating animal data from acute internal emitters using a series of AI-models identified the limitations of candidate network architectures, while creating a figure-of-merit, demonstrating the potential to reduce dosimetric uncertainties for prospective human dose predictions.

Conclusions. The integration of CFPD, biokinetic modeling, AI-driven machine learning, and *in vivo* assays presents a robust framework for personalized internal dosimetry in radiological emergencies. Moving beyond deterministic models to more individualized dosimetric calculations will significantly aid in the administration of medical countermeasures during nuclear security events, exposure scenarios involving military warfighters, and post-exposure triage for members of the public. Future work will focus on refining dosimetry models further using AI techniques on expanded datasets.

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EVALUATING THE ROBUSTNESS OF AI-BASED MODELS FOR PATIENT DOSE OPTIMIZATION IN MEDICAL IMAGING

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When using ionizing radiation in medical imaging, it is crucial to maintain diagnostic accuracy while keeping patient exposure as low as reasonably achievable. In this direction, task-oriented metrics based on human observers have gained more relevance than traditional indices (e.g., SNR, spatial resolution) in image quality evaluation. As these studies are costly and time-consuming, Model Observers (MOs) have been used as convenient surrogates for physicians in optimization protocols, closely matching human decision in the same task. The latest MOs rely on Convolutional Neural Networks (CNNs), a widely used AI tool for image-based tasks due to their impressive predictive performance. However, several studies have shown that these models still lack the robustness of the human visual system to various forms of image corruption. These include adversarial attacks, small perturbations of the input images imperceptible to humans, but that can mislead the model, causing a misdiagnosis and limiting their use in safety-critical environments, such as clinical settings. In this context, we are developing a framework analysis prototype exploiting Adversarial Perturbations (APs) on a use case derived from a CNN-based MO for the automatic quality evaluation in phantom CT images, in terms of detection and localization of low-contrast inserts. The aim is to provide quantitative estimates of the robustness of the model and to identify the phase space of the input data which guarantees a given level of performance. Some common APs are being investigated, and the deviation of MO prediction from that on the unperturbed images is being computed for different levels of perturbation and image parameters (e.g., insert size and contrast, image reconstruction technique, MO prediction). Furthermore, APs can be related to irrelevant features in the image that the MO should not rely on when making predictions. We are then studying quantitative features (e.g. radiomics) in both unmodified and perturbed images, to investigate approaches to AP detection and possibly explain how the model works, thus giving hints on its interpretability. The ultimate goal is to determine the extent to which MOs can be used as reliable tools for defining protocols that minimize

patient dose without loss of diagnostic potential. Once their feasibility as robustness testing and analysis tools has been verified, these methods can also be extended to other AI-based devices supporting decision-making in clinical practice.

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