UCD DUBLIN

Programme and Book of Abstracts

ERPW2023

7th European Radiation Protection Week

9th-13th October 2023 | UCD, Dublin

www.ucd.ie/ERPW2023

erpw2023@ucd.ie

Platinum Sponsors

Health Research Board

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

Gold Sponsors

Fáilte Ireland

UCD School of Medicine
Scoil an Leighis UCD

Platform Sponsors

MELODI

EUROPEAN RADIOECOLOGY ALLIANCE

EURAMED
European Alliance for Medical Radiation Protection Research

NERIS

SHARE
Social sciences and Humanities in ionising radiation REsearch

EURADOS
European Radiation Dosimetry Group

Other Sponsors

Tracerco
Insight through innovation

ORTEC®
AMETEK

Southern Scientific
EXPERIENCE & EXPERTISE

DOSEMONITOR®
By PACSHealth

scientaenvinet

Committees

Local Organising Committee:

Jonathan McNulty (Chair / UCD)
Nadin Abualroos (UCD)
Christopher Burbidge (UCD)
Brenda Byrne (MMUH)
Sean Cournane (UCD / SVUH)
Andrew England (UCC)
Shane Foley (UCD)
Paddy Gilligan (MMUH / UCD)
Isabelle Gunn (UCD)
Luis Leon Vintro (UCD)
Fiona Lyng (TUD)
Anna Matuszak (UCD)
Brendan McClean (SLH / TCD)
Shauna Murphy (UCD)
Simon O'Toole (EPA)
Louise Rainford (UCD)
Smaranda Sava (UCD)
Veronica Smith (EPA)
Margaret Tiuchta (UCD)
Rachel Toomey (UCD)

Scientific Committee:

Shane Foley (Chair / UCD)
Jonathan McNulty (LOC Chair / UCD)
Nadin Abualroos (UCD)
Boris Brkljacic (EURAMED)
Christopher Burbidge (UCD)
Brenda Byrne (MMUH)
Sean Cournane (UCD / SVUH)
Pascal Crouail (NERIS)
Andrew England (UCC)
Paddy Gilligan (MMUH / UCD)
Christoph Hoeschen (EURAMED)
Nathalie Impens (MELODI)
Olivier Isnard (NERIS)
Luis Leon Vintro (UCD)
Fiona Lyng (TUD)
Brendan McClean (SLH / TCD)
Boguslav Michalik (ALLIANCE)
Shauna Murphy (UCD)
Pawel Olko (EURADOS)
Simon O'Toole (EPA)
Tanya Perko (SHARE)
Ivica Prlic (ALLIANCE)
Louise Rainford (UCD)
Veronica Smith (EPA)
Rick Tanner (EURADOS)
Yevgeniya Tomkiv (SHARE)
Rachel Toomey (UCD)
Andrzej Wojcik (MELODI)

Welcome Message

Dear ERPW 2023 Delegates,

We are delighted to welcome you all to European Radiation Protection Week (ERPW) 2023 here in University College Dublin, Ireland. ERPW 2023 unites the global radiation protection community at this annual, multidisciplinary event which brings together experts and addresses current and emerging topics related to radiation protection. Under the Consortium of European Radiation Research Platforms (MEENAS Group), ERPW aims to:

- promote the integration and the efficiency of European research and development in radiation protection to better protect humans (public, patients and workers) and the environment;
- advance scientific excellence in radiation protection;
- maintain and develop European radiation protection research capacity;
- encourage scientific education and training and foster key research infrastructures in the field of radiation protection;
- foster international collaboration, including collaboration with sister organisations and networks, in a non-exclusive manner by open interaction with the wider radiation protection research community and stakeholders (inclusive of patients and the public).

The ERPW meeting series was initiated in 2016 in Oxford (UK) and is supported by key international organisations including, from the MEENAS Group: MELODI, EURADOS, EURAMED, ALLIANCE, and SHARE; together with expertise from PIANOFORTE, the IAEA, the ICRP, and the WHO.

ERPW 2023 is being hosted by University College Dublin, a member of EURAMED, and will have a strong focus on medical applications of ionising radiation and the associated radiation protection of patients, staff, and the public. For ERPW 2023, there will also be a strong focus on outreach and engagement (with patients and the public) linked to medical applications and environmental applications (e.g., radon gas) in radiation protection research.

We are delighted to be welcoming over 300 delegates to ERPW 2023 and we hope that all travelling to Dublin will also be able to use this as an opportunity to explore the city and enjoy Irish culture, social activities, and hospitality; especially our ERPW 2023 Main Social Event: Taylors Irish Night for Irish food, drinks, music, and dancing!

The Scientific Committee have put together a fantastic programme encompassing all areas of radiation protection across plenaries and special sessions, scientific sessions, a poster exhibition, and a range of satellite sessions on the Monday and Friday. We look forward to meeting you in Dublin!

Jonathan McNulty

Chair, ERPW 2023 Local Organising Committee

(on behalf of the ERPW 2023 Local Organising Committee)

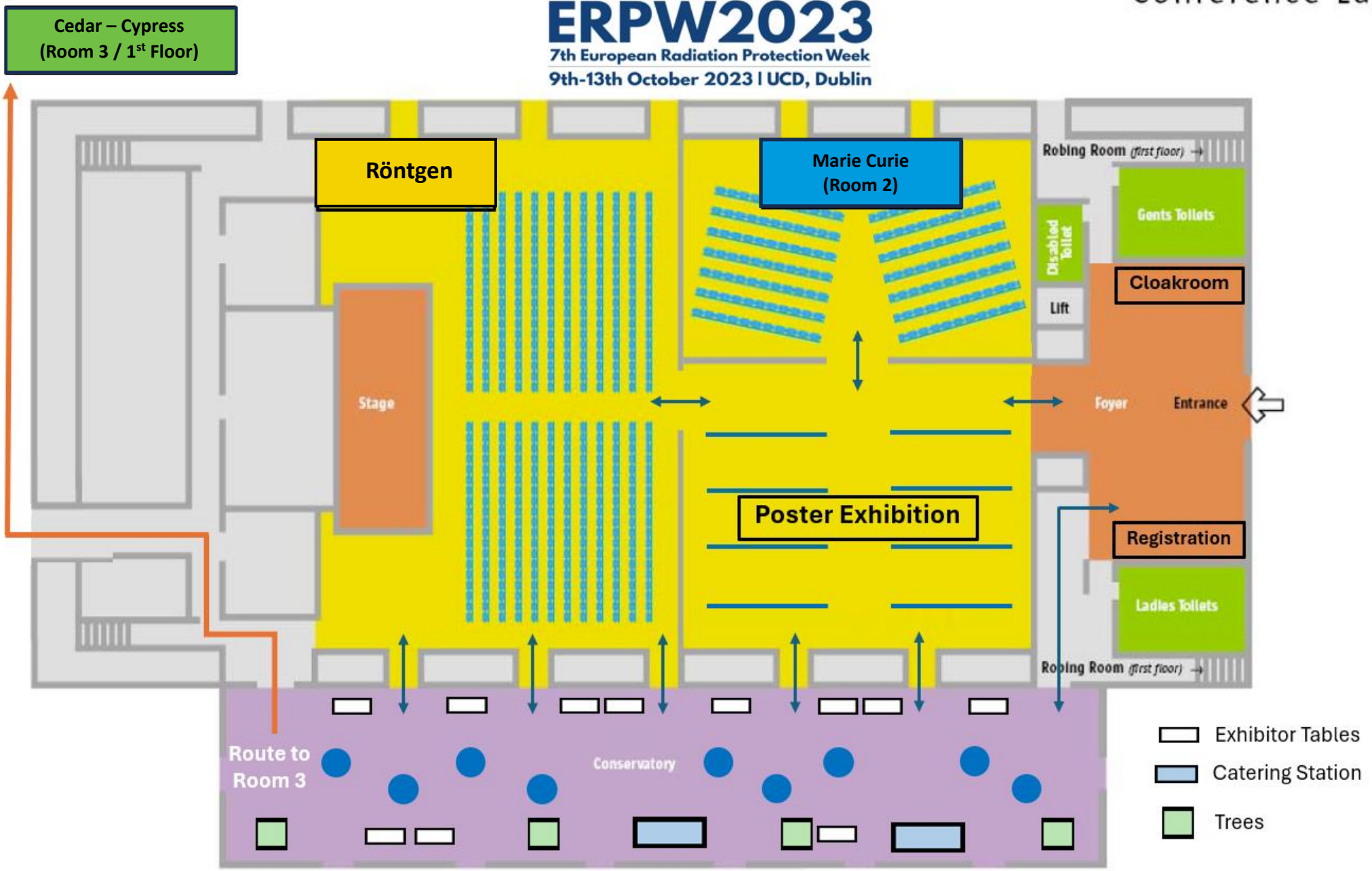
Conference Programme Outline

	Platform Meetings / Sessions *Monday, October 9th*	ERPW 2023 Main Conference *Tuesday, October 10th*	ERPW 2023 Main Conference *Wednesday, October 11th*	ERPW 2023 Main Conference *Thursday, October 12th*	Platform Meetings / Sessions *Friday, October 13th*
08:30	ALLIANCE General Assembly *(Ardmore Boardroom 2, UCD Ardmore House)* NERIS Workshop *(Cedar-Cypress Room, UCD Club)* RENEB General Assembly *(Robing Room, UCD O'Reilly Hall)*		Plenary: Public and Patient Involvement in Radiation Protection Research	Plenary: Post-Accident Management	MELODI Gen. Assembly *(Beech-Birch Room, Club)* PIANOFORTE Meetings RadoNorm WG2: Industry Interest Group Meeting *(Cedar-Cypress Room, UCD Club)*
09:00		Opening Plenary Welcome / Keynote on the Future of Radiation Protection Research			
09:30					
10:00			Coffee Break	Coffee Break	
10:30		Coffee Break	Scientific Session 4A: NERIS: Emergency Preparedness and Response Scientific Session 4B: Medical Radiation Protection Scientific Session 4C: Low Dose Research	Plenary: PIANOFORTE Special Session	
11:00		Plenary: Radioecology and Environment Scientific Session 1A: Medical Radiation Protection			
11:30					
12:00			Lunch Break	Lunch Break	
12:30		Lunch Break			
13:00					
13:30		Plenary: Communicating Radiation Benefits and Risks	Plenary: Variability of individual response to exposure to ionising radiation	Artificial Intelligence in Radiation Protection Scientific Session 5A: Radioactivity Control and Monitoring Scientific Session 5B: Education, Training, and Citizen Science	
14:00	EURAMED RnR Workshop *(Beech-Birch Room, UCD Club)*				
14:30		Scientific Session 2A: NERIS: Biodosimetry in Emergency Preparedness and Response Scientific Session 2B: Computation and Modelling for Radiation Protection and Dosimetry Scientific Session 2C: Occupational Radiation Protection	Plenary: Navigating Radiation Protection: Policy, Legal Requirements, Harmonisation, and Implementation Plenary: Medical Applications of Radiation Protection	Poster Session	
15:00					
15:30		Coffee Break	Coffee Break	Coffee Break	
16:00		Plenary: EURAMED Advancing Medical Radiation Protection and Patient Care: The Latest on European Collaborative Efforts Scientific Session 3A: Radioecology and the Environment	Plenary: Innovative approaches to Radiation Protection Education & Training Student Session: Ask the Experts (Roundtable Discussion)	Plenary: Equality, Diversity, and Inclusion and Cultural Issues in Radiation Protection	
16:30	EURAMED GA *(Beech-Birch Room, UCD Club)*				
17:00			ERPW Awards	Plenary: Closing	
17:30		Welcome Reception			
18:00			ERPW 2023 Social Event *(Taylor's Irish Night, Departing UCD O'Reilly Hall at TBC)*		

Röntgen (Main Room)
Marie Curie (Room 2)
Cedar – Cypress (Room 3)

O'Reilly Hall
Conference Layout

ERPW2023
7th European Radiation Protection Week
9th-13th October 2023 | UCD, Dublin



ERPW 2023

Main Conference Programme

Tuesday, October 10

Opening Plenary / Keynote on the Future of Radiation Protection Research

(Moderators: Jonathan McNulty / Boguslaw Michalik)

9:00	Welcome to ERPW 2023	Jonathan McNulty
9:10	The ICRP vision of the future of radiation protection	Werner Ruhm
9:40	Strategic research agenda and roadmaps for EURAMET's European Metrology Network for Radiation Protection	Joao Alves
10:05	Medical radiation protection from vision to action: creating a research roadmap	Christoph Hoeschen

10:30 Coffee Break

Plenary: Radioecology and Environment

(Moderators: Chris Burbidge / Nele Horemans)

11:00	Ecosystem services in environmental radiological protection	Deborah Oughton
11:30	Tribute to Professor Nick Beresford	Hildegard Vandenhove / Rodolphe Gilbin
11:45	Factors controlling radon distribution in natural and built environments	Quentin Crowley
12:15	Panel Discussion	

Scientific Session 1A: Medical Radiation Protection

(Moderator: Sean Cournane / Nadin Abualroos)

11:00	Spectral biomarkers of normal tissue toxicity in prostate cancer patients following radiotherapy	Dinesh Medipally
11:09	The impact of filtration in dose optimisation in large-size patients	Saeed Alqahtani
11:18	Radiation protection requirements for a new state-of-the art paediatric hospital	Louise Bowden
11:27	The impact of an Irish "Absolute Confidence" judicial ruling concerning cervical screening on radiologists opinion regarding clinical audit	A. J. Coffey
11:36	Centres of Excellence as a network of infrastructures to support the EURAMED rocc-n-roll strategic research agenda and roadmap development: Impacts on future research programmes including digitalisation, artificial intelligence and ethics aspects	Jean-Michel Dolo
11:45	Radiation protection impacts in the era of digital PET	Eamon Loughman
12:54	Case study: calculation of skin dose after contamination with PET isotopes	Sarah Meaney
12:03	How can we best care for our transgender patients? Combining the patient perspective with radiation safety	Naoise Donohue
12:12	Automated vetting of radiology referrals: exploring natural language processing and traditional machine learning approaches	Jaka Potočnik

12:21	Assessment of biological effects upon ϒ-irradiation of cells treated with G4-DNA binders as radiosensitizers for chemo-radiotherapy	Ana Belchior

12:30 Lunch Break

Plenary: Communicating Radiation Benefits and Risks *(Moderator: Rachel Toomey)*

13:30	Risk communication in radiation protection - a psychologist's view!	David Hevey
13:50	Benefit-risk communication: strategies for effective engagement with patients, caregivers and comforters	Jonathan Portelli
14:10	Lessons learned from the Covid-19 pandemic for radiological emergencies and risk communication	Tanja Perko

Scientific Session 2A: NERIS: Biodosimetry in Emergency Preparedness and Response
(Moderator: Florian Gering)

14:30	Chair's Lecture	Florian Gering
14:50	The applicability and limitations of PCC methods in biodosimetry	Mingzhu Sun
15:00	Surface model for possible triage applications in emergency dosimetry	Monica Pujol-Canadell
15:10	Usefulness and limitations of various detector systems for estimation ofI-131 activity in humans after an RN event	Martin Hjellström

Scientific Session 2B: Computation and Modelling for Radiation Protection and Dosimetry
(Moderator: Chris Burbidge)

14:30	Biokinetic modelling of Rn-219 gas exhalation and its progeny from patients undergoing Ra-223-dichloride therapy	Lena Katzdobler
14:40	Concepts of association between cancer and ionising radiation and the role of biological mechanisms	Markus Eidemüller
14:50	Simulation of radon and thoron inflow and behaviour inside a closed space	Krystian Skubacz
15:00	Geochemical modelling for the prediction of NORM scaling in geothermal installations using GRE	G. de With
15:10	Development of graphical user interface (GUI) program for dose assessment of skin contamination in radiation accidents	Seung Je Lee

Scientific Session 2C: Occupational Radiation Protection
(Moderator: Boguslaw Michalik)

14:30	Comparison of organ activity estimates based on bioassay monitoring with post-mortem tissue analyses	Martin Šefl
14:40	The use of personal dosimeters by veterinary practitioners during portable equine radiography	Shauna Daly
14:50	Measurement of the 177 Lu spectral γ-ray transmission to assess the efficacy of X-ray aprons and lead screens for use by staff carrying out PRRT administrations	Danielle Maguire
15:00	Radiation exposure of clinical staff during nuclear medical treatment of castration-resistant prostate cancer: results from the ExperT project	Kerstin Hürkamp
15:10	Radiation safety of our employees during the COVID-19 pandemic in nonhuman primate research	Niels Beenhakker

15:30 Coffee Break

Plenary: EURAMED Advancing Medical Radiation Protection and Patient Care: The Latest on European Collaborative Efforts *(Moderators: Boris Brkljačić / Graciano Paulo)*

16:00	Shaping the future of medical applications of ionising radiation in Europe: the EURAMED rocc-n-roll strategic research agenda (clinical perspective)	Katrine Riklund
16:15	Shaping the future of medical applications of ionising radiation in Europe: the EURAMED rocc-n-roll Strategic Research Agenda (policy perspective)	Christoph Hoeschen
16:30	Justification of CT examinations: presentation of the EU-JUST-CT project	Boris Brkljačić
16:45	Mitigating radiation exposure in lymphoma and brain tumour management (SINFONIA project): novel web-based tools for the estimation of patient doses from X-ray examinations	John Damilakis
17:00	Transforming oncological imaging for improved patient safety and cancer care: results from the i-Violin Project	Christoph Hoeschen
17:15	Enhancing patient safety in medical imaging through learning from incidents and near misses: an overview of the MARLIN Project	Colin Kelly

Scientific Session 3A: Radioecology and the Environment
(Moderator: Ivica Prlić)

16:00	Chair's Lecture	Ivica Prlić
16:20	Population transcriptogenomics highlights impaired metabolism and small population size in tree frogs living in the Chernobyl Exclusion Zone	Olivier Armant
16:30	Two- and three-dimensional models of radionuclide migration from a subsurface repository	Cristiana Carvalhal
16:40	Long term consequences to chronic low dose radiation exposure: do plants adapt?	Nele Horemans
16:50	Effects of ionizing radiations across multiple generations: learning summary from non-human biota ICRP TG121 meeting subgroup	Sandrine Frelon
17:00	The new age of radium use: transferring risk into benefits	Hubert Makuła
17:10	The winner takes it all: is the Baltic or the Irish sea higher contaminated with Cs-137	Pedro Nogueira

Wednesday, October 11

Plenary: Public and Patient Involvement in Radiation Protection Research

(Moderators: Tanja Perko / Jonathan McNulty)

8:30	Top tips for implementing public and patient involvement in your research	Emma Dorris
8:45	Successful involvement of patients and public in RP research	Erik Briers
9:00	How best to engage patients in research and beyond	Siobhan Freeney
9:15	Panel Discussion	

10:00 Coffee Break

Scientific Session 4A: NERIS: Emergency Preparedness and Response

(Moderators: Damien Didier / Antony Bexon)

10:30	ICRP Task Group 120 on radiological protection for radiation emergencies and malicious events	Zhanat Carr
10:50	Radiological hazard assessment of the ARPANSA Yallambie site	Blake Orr
11:00	Building geometry input for urban atmospheric dispersion modelling	Dana Lüdemann
11:10	Continental-scale Atmospheric contaminant dispersion modelling by the artificial neural network based on the event of release Ru-106	Anna Wawrzynczak
11:20	Voluntary radiation measurement team to enhance the radiation measurement preparedness in Finland	Maarit Muikku
11:30	A citizen monitoring network: a Croatian pilot project proposal	Ivica Prlić
11:40	European metrology network for radiation protection: education and training activities	Oliver Hupe

Scientific Session 4B: Medical Radiation Protection

(Moderator: Paddy Gilligan)

10:30	Overall risk of cancer incidence attributable to adult CT examinations: impact of a 7 years dose optimisation program	Natalie Heracleous
10:40	Global noise level as noise metric for low-dose chest CT in lung cancer screening	Kwinten Torfs
10:50	Total out-of-field dose distribution in Hodgkin lymphoma patients receiving proton therapy	Maite Romero-Expósito
11:00	Peripheral organ doses from volumetric modulated arc therapy (VMAT) for Hodgkin lymphoma	Mona Azizi
11:10	Noradrenergic agonists attenuate microglial inflammation and impairments in hippocampal neurogenesis induced by whole-brain irradiation	Rafi Benotmane
11:20	Practical and regulatory radiation protection experience in the delivery of the first Radioligand Lutetium PSMA therapy doses to patients in Ireland	Dara Murphy
11:30	Possible impact of diagnostic reference levels on administered activity in nuclear medicine	Anja Almen
11:40	Domain specific language models for enhanced training in radiation protection	Niki Fitousi
11:50	EFOMP Malaga Declaration 2023: an updated vision on Medical Physics in Europe	Brenda Byrne

Scientific Session 4C: Low Dose Research

(Moderators: Fiona Lyng / Andrzej Wojcik)

10:30	Age- and sex-specific differences after low-dose radiotherapy of human TNFα tg mice	Lisa Deloch
10:40	Late effects of chronic low dose rate total body irradiation on the heart proteome of ApoE-/- mice resemble premature cardiac ageing	Omid Azimzadeh
10:50	Differential outcomes of co-exposure to low-dose irradiation and inhalation of tungsten particles on brain toxicity parameters in rat	Chrystelle Ibanez
11:00	Multigenerational effect of gestational exposure to uranium on the metabolic profile of rat spermatozoa	Stéphane Grison
11:10	A mathematical formulation of Elkind recovery	Takahiro Wada
11:20	Study of potentially renal cancerous effect of uranium in genetically-engineered mouse models: UKCAN project	Laurie De Castro
11:30	Investigating transcriptional and translational responses to low-dose ionising radiation: towards an integrated low-dose response model	Guillaume Vares
11:40	Dose rate-dependent cellular effects of low doses in AHH-1 lymphoblasts	Milagrosa Lopez-Riego
11:50	Mathematical modelling of low dose hyper-radiosensitivity and induced radioresistance	Szabolcs Polgár
12:00	Use of intestinal organoid models to study low-dose radiation effects	Holly Laakso
12:10	Use of multi-lineage differentiating stress enduring cells (MUSE cells) in an irradiated mouse model treated with senolytic agent	Domenico Aprile
12:20	Viewpoint on the use of the Linear No-Threshold (LNT) model in radiological protection	Dominique Laurier
12:30	Effects of low doses of gamma irradiation (137-Cesium) on the development of cardiovascular pathologies in the heart-lung axis	F. Saliou

Plenary: Variability of individual response to exposure to ionising radiation

(Moderator: Fiona Lyng)

13:30	Dealing with human variability in response to ionizing radiation in earth and space	Rafi Benotmane
13:50	Future of Radiation Protection: cardiovascular/neuro effects	Simone Moertl
14:10	Variability in radiation response: the COVID effect	Stanislav Polozov

Plenary: Navigating radiation protection: policy, legal requirements, harmonisation, and implementation *(Moderators: Veronica Smith / Louise Rainford)*

14:30	Implementing and harmonising radiation protection in a federal system: DRW and orientation values in Germany	Augusto Giussani
14:45	An Irish regulator's perspective on the opportunities and challenges in harmonising practice in radiation protection	Lee O'Hora
15:00	Role of the EFRS in harmonising radiation protection across Europe	Altino Cunha
15:15	Panel Discussion	

Plenary: Medical applications of radiation protection

(Moderator: Brenda Byrne)

14:30	ICRP TG 108 outcomes: optimisation of radiological protection in digital radiography, fluoroscopy, and CT in medical imaging	Irene Hernandez-Giron
14:50	Current occupational radiation protection challenges in the medical context	Susan Maguire

15:10	Clinical applications of low dose CT: can we replace projectional radiography?	Mark McEntee

15:30 Coffee Break

Plenary: Innovative approaches to radiation protection education and training
(Moderators: Nathalie Impens / Shauna Murphy)

16:00	Virtual reality education possibilities in radiation protection	Louise Rainford
16:20	Best practice in radiation protection education	Michèle Coeck
16:40	Promoting education and training to build nuclear competencies	Roberta Cirillo

Student Session: Ask the Experts (Roundtable Discussion)
(Moderators: Jaka Potočnik / Ciara Hickey)

16:00 – 17:00 **Expert Panel:** Boguslav Michalik (ALLIANCE), Christoph Hoeschen (EURAMED), Andrzej Wojcik (MELODI), Pascal Crouail (NERIS), Tanja Perko (SHARE)

ERPW Awards session *(Moderators: Jonathan McNulty / Christoph Hoeschen / Andrzej Wojcik)*

17:00 – 17:30

Thursday, October 12

Plenary: Post Accident Management

(Moderator: Pascal Crouail)

8:30	Research and development on retrospective dosimetry in support of radiation emergencies under the European Radiation Dosimetry Network (EURADOS)	Liz Ainsbury
8:50	The WHO's work in the area of mental health and psychosocial support in radiological and nuclear emergencies	Zhanat Carr
9:10	NEA Framework for post-accident recovery/preparedness	Thierry Schneider
9:20	RENEB: Network's contribution to emergency preparedness and response	Ursula Oestreicher
9:40	Panel Discussion	

10:00 Coffee Break

Plenary: Pianoforte Special Session

(Moderator: Jean Christoph Gariel)

10:30	Interrelation between research platform works under the MEENAS umbrella and the PIANOFORTE partnership	Christoph Hoeschen
10:40	Priority setting for the 2nd pianoforte open call for research projects	Filip Vanhavere
10:50	Benefits and impacts of PIANOFORTE in Europe	Catherine West
11:00	Broadening perspectives: guidelines for integrating social sciences and humanities in radiation protection research	Catrinel Turcanu
11:10	Stakeholder Outreach: the PIANOFORTE electronic survey and further plans	Florian Rasuer / Jelena Popic
11:20	Proton therapy and radiation protection: an update on PIANOFORTE activities	Florian Rauser / Pawel Olko
11:30	Enhancing the competence in radiation protection: E&T activities of Pianoforte	Andrzej Wojcik
11:40	Infrastructures and FAIR data management	Liz Ainsbury / Omid Azimzadeh
11:50	Communication, dissemination and impact creation by PIANOFORTE partnership	Marie Davidkova

12:00 Lunch Break

Plenary: Artificial Intelligence in Radiation Protection

(Moderator: Christoph Hoeschen)

13:30	AI applications in radiation therapy	Alberto Traverso
13:55	AI applications in medical radiation protection	John Damilakis
14:20	Panel Discussion	

Scientific Session 5A: Radioactivity Control and Monitoring

(Moderator: Boguslaw Michalik)

13:30	Chair's Lecture	Boguslaw Michalik
13:50	Dose assessment of the radiation effects of liquid discharges from the Krško NPP supported by the 3D	

	numerical modelling	Benjamin Zorko
14:00	Latest developments and highlights from the research project RadoNorm	Warren John
14:10	Characterisation of a novel calibration chamber for radioactive aerosol detectors	Shamil Samanta Galvez Febles
14:20	Radon hazards. Validation of dose conversions based on measurements in Polish operating and show underground mines	Krystian Skubacz

Scientific Session 5B: Education, Training, and Citizen Science

(Moderators: Deborah Oughton / Paulo Nunes)

13:30	Building European nuclear competence through continuous advanced and structured education and training actions	Michèle Coeck
13:40	Educating the people for understanding radiation risk: the impact of dose-response models	Radu Vasilache
13:50	Radiography and medical student perceptions of radiation protection teaching using three-dimensional virtual reality simulation	Jaka Potočnik
14:00	Education and training in radiation protection in Europe: results from the EURAMED Rocc-n-Roll project survey	Graciano Paulo

15:30 Poster Presentations and Coffee Break

Plenary: Plenary: Equality, Diversity, and Inclusion and Cultural Issues in Radiation Protection

(Moderators: Simon O'Toole / Rachel Toomey)

16:00	Transgender and EDI issues in radiation protection	Marie-Louise Ryan
16:20	Representation in the RP community / context	Susan Molyneux Hodgson
16:40	Effect of race and ethnicity on risk of radiotherapy toxicity	Catherine West

17:00 ERPW 2023 Closing Remarks **Jonathan McNulty**

Scientific session 1A: Medical Radiation Protection

Spectral biomarkers of normal tissue toxicity in prostate cancer patients following radiotherapy

Fiona M. Lyng[1], Dinesh Medipally[1]*, Isha Behl[1], Jade Monaghan[1], Francois Paris[2], Chris Talbot[3], Aidan D. Meade[1],
[1] Technological University Dublin, Dublin, Ireland
[2] University of Nantes, Nantes, France

Purpose: Late radiation toxicity can continue years after completion of radiotherapy and is generally irreversible. Known causes of radiation toxicity include dose volume parameters, co-morbidities such as diabetes, intrinsic radiosensitivity and concurrent chemotherapy, but there is a large patient-to-patient variability in response which is intrinsic to the patient. Currently, it is impossible to predict before treatment which patients will experience these long-term side effects. To date, no markers of tumour response to radiotherapy or predictors of normal tissue toxicity are in routine clinical use.

Cell based predictive assays may not be easy to translate to routine clinical use due to intrinsic variability and labour intensive protocols and genomic assays can be expensive. A new approach based on optical spectroscopy has advantages in terms of minimal sample preparation, speed and cost. This study aims to develop an assay based on spectral biomarkers for the prediction of radiation toxicity.

Materials and Methods: Plasma samples were obtained from prostate cancer patients (n=143) enrolled on the EU funded REQUITE study (www.requite.eu) through a collaboration with the University of Leicester. The patients were followed up to 24 months following radiotherapy and toxicity was recorded using the National Cancer Institute Common Terminology Criteria for Adverse Events (CTCAE) v4.0 grading system. Spectra were recorded from plasma samples using Raman spectroscopy and ATR-FTIR spectroscopy. Sphingolipidomic analysis was carried out using LC-MS/MS.

Results: After pre-processing and multivariate analysis, plasma samples from prostate cancer patients with no/minimal radiation toxicity (grade 0-1) could be differentiated from those with severe radiation toxicity (grade 2-3) with >85% sensitivity.

Conclusions: Prediction of radiation toxicity could allow stratification of cancer patients according to risk and could guide the selection of treatment modality to reduce this risk in high-risk patients or allow dose escalation in low risk patients to improve tumour control.

The impact of filtration in dose optimisation in large-size patients

Saeed J. M. Alqahtani [1,2]* , Karen M. Knapp [1], Jude R Meakin [1]
[1] Exeter University, Exeter, United Kingdom
[2] Najran University, Najran, Kingdom of Saudi Arabia

Purpose: The aim of the current study is to investigate the impact of added filtration on image quality and radiation dose of lumbar spine projection radiography for different sizes phantom.

Materials and methods: Five different phantoms, range in Body Mass Index between 18.3 and 46 kg/m2, were used to image lumbar spine in Anteroposterior view. Multi Fusion Max Siemens Unit (Siemens Healthcare, Germany) and a flat panel detector made of Amorphous Silicon with TFT/PIN diode technology with a conversion screen Czl, DRZ+ was used (PaxScan4336W,Varian Medical Systems, Salt Lake City, UT, USA). The detector area is 35 x 43 cm2 with a pixel matrix of 3072 (v) x 2.476 (h) and pixel pitch of 139 µm . Added filtration were used (0.0, 0.1,0.2,0.3 mm of Cupper) and the radiation dose were recorded in the form of Dose of Area Product (DAP) using . The image quality was tested objectively (SNR, CNR) and subjectively (2 reporting radiographer). Data were analyzed using Minitab software.

Results: Added filtration showed a substantial impact on the radiation dose reduction across all phantom (p: 0.0005). With regards to image quality, the added filtration impacted positively on all phantoms except the morbidly obese due to reach of cut off point for the machine.

Conclusion: Added filtration can be considered as a valuable measure to be used when imaging large-size patient, however, this should be practiced with caution in morbidly obese patients.

Radiation Protection Requirements for a new state-of-the art Paediatric Hospital

Louise Bowden [1]*, Colm Saidléar [1,2]
[1] Children's' Health Ireland, Dublin, Ireland
[2] National Paediatric Hospital Development Board, Dublin, Ireland

The use of ionising radiation in a medical environment is key for any diagnostic or interventional procedure. However, to ensure the safety of staff, patients and public from radiation sources, protective measures need to be in place. The most significant one being the radiation shielding installed in physical boundaries. The new Children's Hospital, currently under construction in Dublin, Ireland will have over fifty areas where radiation shielding is installed.

To assess the shielding installed, the Radiation Protection Adviser (RPA) first reviewed the technical submittals provided by the lead-installers and provided recommendations on door overlaps, penetration shielding, etc. The RPA was then provided with samples of the lead, concrete and fire stopping material which were to be used in the shielding. Tests using a radioactive source were carried out to assess the attenuation of each material. Next the RPA undertook site visits to visually assess the installation of the lead. During these visits, discussions on the best way to shield large penetrations caused by the high level services, were had between the RPA and lead-installer. Theses visits were photographed and documented using a software package, Autodesk. Finally an assessment of the integrity of the lead installed was carried out using a radioactive source.

The initial technical submittals were useful for reviewing the lead installation plans while the final assessment with the radioactive source provided a reasonable picture of the integrity of the lead installed. However, the RPA found the continuous monitoring and engagement onsite, before and after lead installation, provided the most benefit in assessing the shielding. Seeing the lead wraps and shelves around the penetrations, before walls and ceilings were closed up, gave confidence in what shielding was actually being provided. Associated pictures provided a record which was able to support the risk assessments required for the EPA licence application.

The impact of an Irish "Absolute Confidence " judicial ruling concerning cervical screening on radiologists opinion regarding clinical audit

A. J. Coffey [1,7*] , F. D. M. Dineen ,[1,2], A. Ahmed [3] , P. Gilligan [4,7], P. Cunningham [5,7], C. Glynn [6,7.]
[1] Cork University Hospital, Cork, Ireland, [2] Mercy University Hospital, Cork, Ireland, [3] University Hospital Limerick ,Ireland [4] Mater Misericordiae University Hospital , Dublin, Ireland [5] Our Ladies Hospital, Navan, Ireland, 6 University Hospital Galway, Ireland , 7. Faculty of Radiologists and Radiation Oncologists, Dublin, Ireland

Purpose: Clinical audit is a useful tool that is mandated under EU directive 59/13. Some barriers have also been identified in the QUADRANT project. The role of clinical audit has received further attention in Ireland in recent years, due to a cervical cancer screening controversy. This survey briefly examines Irish radiologist's views on clinical audit post this controversy, and subsequent judicial rulings suggesting that 'absolute confidence' should be the standard in screening results, and the response of medical bodies.

Materials and Methods: A short survey was disseminated amongst radiologists in Ireland, aiming to identify opinions towards audit, and whether the Cervical Check controversy and judicial ruling had impacted their likelihood to engage in audit.

Results: A total of 35 responses were obtained, approximately 40% consultants and the remainder radiology trainees. A minority (23%) are engaged in cancer screening imaging. 92% of respondents have engaged in audit within the last 2 years, the vast majority as standalone projects, rather than part of a larger hospital-wide audit programme.

Approximately two-thirds of respondents indicated that the controversy has not impacted their likelihood of conducting a future audit. Understanding of the Justice Cross report was substantially less pronounced, but similar impact on likelihood of future audit was noted, with a significant minority of one-third indicating they are less likely to engage in audit as a result. Royal College of Radiology audit templates are a popular audit resource, particularly amongst trainees. ESR guidelines have been used by 17% of respondents. Only 7% of respondents have utilised formal Health Service Executive (HSE) audit training programmes.

Conclusion: Reflections from the Cervical Check controversy, mirrored to an extent in the survey conducted for this project, suggest that a fear of professional or legal repercussions may negatively impact on a culture of audit for some.

Centres of Excellence as a network of infrastructures to support the EURAMED rocc-n-roll Strategic Research Agenda and Roadmap development: Impacts on future research programmes including digitalisation, artificial intelligence and ethics aspects

Jean-Michel Dolo[1]*
[1]Mission Head, CEA, French Alternative Energies and Atomic Energy Commission ("Commissariat à l'énergie atomique et aux énergies alternatives") France

We report here a synthesis of the work done in the framework of the EURAMED rocc-n-roll project Work Package 4 (Infrastructures, digitisation and digitalisation: approaches and ethics). The work serves as in input to the EURAMED rocc-n-roll Strategic Research Agenda and associated Roadmap, which will impact future research programmes in medical applications of ionising radiation and its related radiation protection aspects.

Our work includes the development of a SWOT analysis approach to identify potential networks of centres of excellence (CoE). The approach is based on shared criteria to address possible priority research themes summarised in the SRA and the Roadmap. Moreover, digitalisation and artificial intelligence are analysed as a strong impact in healthcare optimisation for medical applications of ionising radiation and its related radiation protection aspects for patients and medical staff.

The opportunities, challenges and caveats of these points are reported in connection to the need to address ethics and data protection issues in future research projects. These aspects are essential to realise a global patient-centred approach with increasingly personalised medicine including monitoring, diagnosis and therapy.

Radiation Protection Impacts in the era of digital PET

Eamon Loughman [1]*, Caroline Banahan [1], Maria Dooley [2], David Caldwell [2], Paddy Gilligan [2], Martin O'Connell [1, 2], Susan Maguire [1*]
[1] Mater Private Network, Dublin, Ireland
[2] Mater Misericordiae University Hospital, Dublin, Ireland

Purpose: Historically PET-CT has been considered a higher dose modality, in terms of patient and occupational dose. Digital PET has the potential for a reduction in injected activities. This can also result in lower overall activity delivered to the PET-CT facility, saving on dose to the operators. This study examines the use of lower injected activities of FDG and the impact on occupational dose and the potential for increased patient throughput and cost reduction.

Materials and Methods: Average injected activity was compared pre and post installation of a digital PET-CT (Biograph 450, Siemens, Erlangen). Patient surface dose-rates were measured for whole-body FDG scan patients (n=30) on the digital PET-CT. Patient dose-rate was measured at head, chest and abdomen at 1m. Results were compared to TG-108 methodology for shielding of PET facilities [1].

Results: Average patient injected activity of FDG has been reduced from 350MBq per patient to 190MBq (54% reduction) with the introduction of a digital PET-CT scanner and replacement of the analog scanner (Biograph 16, Siemens, Erlangen). Median patient dose-rate at 1m, 60 minutes post injection at patient abdomen were measured to be approximately 13 µSv/h. This is comparable to published external dose-rates from nuclear medicine bone scan patients of 13.65µSv/h at 1m 40 mins post injection [2].

Conclusions: The average external dose rate from a PET-CT patient undergoing whole body FDG scanning on a digital PET-CT scanner is comparable to a nuclear medicine bone scan patient. This has implications for PET-CT department design, occupational dose and overall delivered activity. There is scope to reduce interpatient and staff barrier shielding requirements for uptake rooms. Given decreased scan time using digital PET and uptake rooms being the limiting factor in maximum patient throughput, it may be possible to facilitate additional uptake rooms and patient throughput within current centers.

Case Study: Calculation of Skin Dose after Contamination with PET Isotopes

Sarah Meaney[1]*
[1]St Vincents Hospital Group, Dublin, Ireland

Purpose: Localized skin contamination by positron emitters can result in significant occupational exposure depending on the activities involved, the area exposed and the residence time on the skin. The true extent of the exposure may not be reflected in the dose reported by routine monitoring devices (TLD rings or fingerstalls) based on the location of the contamination. Hand and foot monitors (HFM) are used to assess contamination in PET departments, providing a dose-rate measurement in terms of counts per second. Isotope-specific conversion factors can be established to estimate equivalent skin dose from the HFM dose rate measurements. However, there is no standard method to calculate the equivalent skin dose. Uncertainties exist relating to the size and location of contaminated area, accurate determination of activity, and appropriate calibration of radiation monitors. This case study reports on the estimation of skin dose from two separate incidents of contamination in a PET department, involving 18F and 68Ga radiopharmaceuticals.

Materials and Methods: After measurement on the HFM, locally established cps-to-MBq isotope specific conversion factors were used to estimate the activity involved. Contamination skin dose factors from Delacroix et al., 2002 were then applied to estimate equivalent skin dose. The results obtained were compared to those calculated using Varskin software.

Results: Depending on the method employed the calculated equivalent skin dose differed by up to 100% for contamination events of < 1 MBq.

Conclusion: Significant differences were found in the estimation of skin dose depending on the calculation method employed, highlighting the need for standardization. While the HFM plays an essential role in detecting contamination, converting the measured contamination into an equivalent dose to the skin remains challenging.

How Can We Best Care for Our Transgender Patients? Combining the Patient Perspective with Radiation Safety

Naoise Donohue [1*;] Marie-Louise Ryan [1]
[1] Radiography and Diagnostic Imaging, UCD School of Medicine, Ireland

Purpose: The increased visibility and social acceptance of transgender people has exposed the dearth of research on this marginalised community, particularly within diagnostic imaging. Available literature has highlighted the systemic discrimination they face within healthcare and that the absence of education for healthcare professionals has resulted in an inability to provide patient-centred care. Currently, there has been minimal research regarding radiation safety and transgender patients. This research has aimed to determine what barriers transgender people experience in their care, the safety risks they identify in current practice, and what could be done to resolve them.

Materials and Method: Five semi-structured interviews have been conducted with transgender individuals. Question themes involved: radiation safety, education, and patient care. Prior to each question, relevant information had been presented to participants, such as the effects of radiation, to provide context for them to construct their answers. Thematic analysis has been used on each interview transcription following thorough reading.

Results: Thematic analysis has revealed four themes, which are: informed consent, healthcare professionals' education, patient identification, and patient comfort. The results have determined that current risks include healthcare professionals not gaining full consent prior to procedures, an absence of education causing inappropriate care or negative experiences, and inadequate patient identification leading to the potential for accidental foetal exposure. Recommendations for improvement consist of creating a baseline of education for healthcare professionals, a method to self-declare and record a patient's gender identity, and to amend current policies to be inclusive.

Conclusion: Transgender patients present with unique healthcare needs compared to cisgender patients. Education of healthcare professionals at undergraduate and postgraduate levels must be established to ensure appropriate patient care, and to minimise the radiation incidents that could occur. Further study with community involvement is required to determine how to improve gender identity declaration in healthcare.

Automated vetting of radiology referrals: exploring natural language processing and traditional machine learning approaches

Jaka Potočnik [1*,] Shane J Foley [1,] Ronan P Killeen [1], Aonghus Lawlor [2], John Stowe [1]
[1] University College Dublin School of Medicine, Ireland
[2] University College Dublin School of Computer Science, Ireland

Purpose: Worldwide justification rates of medical exposures, particularly CT examinations, are poor. The increasing utilisation of CT scans has raised significant concerns regarding inappropriate justification practices. Additionally, conducting regular retrospective justification audits is often impractical for several reasons. Therefore, we aimed to retrospectively audit the justification of brain CT referrals and develop a machine learning (ML) model for automated justification analysis of brain CT radiology referrals.

Materials and Methods: All adult brain CT examinations performed in a single calendar year (2019) at a tertiary referral hospital were anonymised, retrospectively collected and analysed by a radiographer with 5 years of experience and a consultant neuroradiologist with 10 years of experience, following the iGuide imaging guidelines. A cloud-based platform for structured referring was used to ensure audit consistency and minimise discrepancies between the two annotators. Cohen's kappa was computed to measure inter-rater reliability. Unstructured referrals were represented as bag-of-words and term frequency-inverse document frequency models. Spell checking and removal of redundant terms were also performed prior to subsequent ML. A test set (300/75) was used to compute weighted accuracy, sensitivity, specificity, and the area under the curve (AUC). All data science tasks were performed using Python (v 3.7.11).

Results: 17.4% (n=79) referrals were discarded due to inadequate clinical information. 67.5% (n=253) referrals were appropriate, 20.0% (n=75) inappropriate, and 12.5% (n=47) maybe appropriate. The agreement between the annotators was strong (κ=0.835). The best performing ML model achieved a weighted accuracy of 92%, a sensitivity of 91%, a specificity of 93%, and an AUC of 0.948.

Conclusions: ML models can accurately predict justification of unstructured brain CT referrals, and facilitate the effective implementation of iGuide imaging guidelines within clinical practice, as well as large-scale retrospective justification audits.

Assessment of biological effects upon Y-irradiation of cells treated with G4-DNA binders as Radiosensitizers for Chemo-radiotherapy

Sofia Cardoso[1], Ana Belchior [2,3]*, Elisa Palma[3], P. Raposinho[2,3], António Paulo[2,3]
[1]Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
[2]Centro de Ciências e Tecnologias Nucleares, Instituto Superior Técnico, Universidade de Lisboa, Campus Tecnológico e Nuclear, Estrada Nacional 10, Km 139.7, 2695-066 Bobadela LRS, Portugal
3Departamento de Engenharia e Ciências Nucleares, Instituto Superior Técnico, Universidade de Lisboa, Estrada Nacional 10, Km 139.7, 2695-066 Bobadela LRS, Portugal

Purpose: Radiotherapy is one of the major therapeutic approaches used in cancer treatment, along chemotherapy and surgery. Certain cancer types, namely prostate cancer (PCa) that is the most frequently diagnosed neoplasia and the third more frequent cause of death among men, tend to exhibit radioresistance upon initiation of the radiotherapy treatment. In this context, the use of radiosensitizing agents may play a crucial role to obtain enhanced radiobiological effects with improved therapeutic outcomes. In some cases, the radiosensitizers act themselves as anticancer drugs, thus allowing to exploit synergistic chemo-radiotherapy treatment regimens. For this purpose, G-quadruplex DNA binders have emerged as good candidates, being promising anticancer agents and, in a few cases, also radiosensitizing agents interfering with DNA repair and DNA damage response (DDR) pathways [1-3]. Despite these possibilities, the use of G-quadruplex DNA binders as radiosensitizers in cancer radiotherapy still remains an under-studied research topic.

Materials/Methods: We investigated the radiosensitive effects of G-quadruplex (G4) DNA binders, named PDS-pz and Re-PDS-pz, in combination with γ radiation on human prostate cells (PC3, 22RV1 and RWPE). Prior to the irradiation, we screened the cytotoxic activity of the compounds, using the MTT assay to assess the viability of the cells treated with increasing concentrations, in the range of 0.5–100 μM. Aiming at evaluate radiosensitizing effects mediated by combination of the compounds with radiation, we studied; i) the production of ROS by the fluorescent probe H2DCF-DA, ii) the induction of double-strand breaks by ɣ-H2AX assay and iii) the survival fraction using clonogenic survival assay.

Results: Our results indicate that both compounds exhibit a radiosensitizing action on studied cells. We observed an higher H2DCF-DA signal in cells treated in combination with radiation. Also, on cells treated in combination with radiation, the biological effects observed indicate an higher cellular damage. All in all, we observed an increasing dose-dependency.

Conclusion: The preliminary results suggest that Re-PDS-pz could be a new candidate to treat Pca in combination with radiation, overcoming resistance to conventional treatments.

Scientific Session 2A: NERIS: Biodosimetry in Emergency Preparedness and Response

The applicability and limitations of PCC methods in biodosimetry

Mingzhu Sun [1*], Jayne Moquet [1], Stephen Barnard [1], David Lloyd [1], Elizabeth Ainsbury [1]
[1] UKHSA, Department of Radiation Effects, RCEH, Chilton, United Kingdom

Purpose: This presentation is the summary of several experiments using the premature chromosome condensation (PCC) methods. The purpose of these studies was to establish the PCC methods, both cell fusion- and chemical/drug-induced PCC, in our laboratory and exploit the applicability of these methods in the estimation of absorbed radiation doses for different types of samples. It was also important to identify the limitations of these methods for optimised experiment designs.

Materials and Methods: Human peripheral blood lymphocytes were analysed using the cell fusion-induced PCC assay. Blood lymphocytes from both healthy donors and cancer patients undergoing external beam radiotherapy were examined in different projects using calyculin A-induced PCC. Ethical approval and written consent were obtained for these studies.

Results: Cell fusion-induced PCC was successfully performed especially for high dose ring analysis. This method can be used to analyse cells at interphase and provide results several hours following the receipt of the samples. Nevertheless, scoring is difficult with contamination from the small chromosomes of the mitotic PCC-inducing cells. Calyculin A-induced PCC can condense chromosomes prematurely at all phases of a cell cycle with high efficiency and allows different endpoints to be scored, such as rings, fragments and PCC objects in particular. Scoring PCC objects eliminates the necessity to distinguish different types of chromosome aberrations; nevertheless, it is associated with overdispersion and high background level. Population based studies are needed to understand the confounding factors. Ring PCC is now considered to be the most suitable method for the assessment of high dose exposures (>5Gy). The potential for PCC to be used for low dose exposures is currently being investigated in our laboratory.

Conclusions: PCC is a useful and feasible biodosimetric tool that can be used both during emergency mass casualty scenarios and during the assessment of samples following clinical and/or occupational exposures.

Surface model for possible triage applications in emergency dosimetry

Monica Pujol-Canadell [1*], Juan S. López [1], Gemma Armengol [1] and Joan-Francesc Barquinero [1]
[1] Autonomous University of Barcelona

Purpose: Ionizing radiation causes breaks in DNA that can are recognized by several cellular proteins, some of which get phosphorylated, such as γH2AX. In the event of a radiation accident, γH2AX foci detection is being accepted as a fast method for triage and dose assessment. However, due to γH2AX disappearance kinetics and signal saturation at higher doses, published calibrations have been constructed mainly for doses up to 2-3 Gy and at specific post-irradiation times up to 24 h. The present study aims to apply a single surface or tridimensional model to perform a fast triage for doses up to 7 Gy in a wider window of up to 48 h.

Materials and Methods: γH2AX data was obtained irradiating peripheral mononucleated cells from three healthy donors with gamma rays, at doses ranging from 0 to 7 Gy. γH2AX foci were detected microscopically using a semi-automatic method, at different post-irradiation times from 2 - 48 h.

Results: Samples from this study are currently being analyzed. Preliminary results indicates that γH2AX signals for high doses (5 and 7 Gy) experience a saturation during the first 4 h, although detected signals at 24 and 48 h are higher than baselines.

Conclusion: In case of a suspected overexposure to radiation, preliminary results here presented indicates that, in a realistic scenario, where blood from exposed people would be probably obtained 24 h after the exposure, this biomarker can be very useful for triage not only for lower doses but also for the higher ones.

Usefulness and limitations of various detector systems for estimation of I-131 activity in humans after an RN event

Martin Hjellström [1*], Frida Westerbergh [1], Eva Forssell-Aronsson [1], Mats Isaksson [1]
[1] Department of Medical Radiation Sciences, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden
* Presenting Author

Purpose: I-131 is a radionuclide commonly released following radiological and nuclear events, which could lead to internal contamination of the public as well as workers. The purpose of this project was to study the possibilities and limitations of using various clinically available NaI(Tl)-based detector systems for estimating I-131 thyroid activity.

Materials and Methods: Two thyroid uptake detector systems, three medical gamma cameras, and one whole-body counter were calibrated for estimation of internal contamination of I-131 (thyroid uptake) in adults, teenagers and children, using the St. Petersburg neck and brick phantom (IRINA). The minimum detectable activity was calculated for all phantom sizes and detector systems. The dead time loss and the maximum detectable activity were studied for the systems, using two vials á 100 MBq I-131 per phantom size, measured repeatedly over time to enable measurement at different activity levels due to physical decay.

Results: The study resulted in calibration factors and minimum detectable activities for abovementioned systems and phantom sizes, along with curves illustrating the dead time losses and the maximum number of detectable counts per second, and thus activities, that could be estimated.

Conclusions: The measurement capability in emergency preparedness for estimation of I-131 in adults, teenagers, and children can be increased by utilizing equipment found in many hospitals.

Scientific Session 2B: Computation and Modelling for Radiation Protection and Dosimetry

Biokinetic modelling of Rn-219 gas exhalation and its progeny from patients undergoing Ra-223-dichloride therapy

Lena Katzdobler [1]*, Sibylle Ziegler [2], Christina Kuttler [3], Wei Bo Li [1]
[1] Department of Medical and Occupational Radiation Protection, Federal Office for Radiation Protection, Oberschleißheim, Germany
[2] Ludwig-Maximilians-Universität München, University Hospital, Department of Nuclear Medicine, Munich, Germany
[3] Technical University of Munich, Department of Mathematics, Garching, Munich

Purpose: Modelling biokinetic behaviour of radiopharmaceuticals is an essential part of radiation protection in nuclear medicine. Due to the short ranges of α- and β-particles in the tissues, it is extremely difficult to measure radioactive exposure of α- and β-emitters incorporated in the human body from the outside in absence of γ-emissions. In the case of the therapeutic administration of Ra-223-dichloride, there is a chance of monitoring its progeny Rn-219 gas exhaled by the patients, even if the exhaled activity fraction is unclear. In this work, the biokinetic models for Ra-223 and its progeny are set up applying the new biokinetic models published by the International Commission of Radiological Protection (ICRP) in order to predict the exhaled radioactivity of Rn-219 gas and its progeny measured around the patients.

Materials and Methods: The systemic biokinetic models of radium and its decay products reported by the ICRP were implemented in this study. To model the biokinetic behaviours of the progeny, we applied the independent biokinetic model of each progeny and complemented them with missing compartments from their parent nuclide. The transfer rates were computed according to the principle of treatment of progeny recommended by the ICRP. The complete model was then implemented as a system of ordinary differential equations and solved numerically.

Results: The results were presented as time activity curves of Ra-223 and all its progeny in blood and various organs and tissues. A peak of activity at less than 2.5x10-7 Bq of Rn-219 exhaled per Bq injection of Ra-223 to a reference patient was observed.

Conclusion: The results show that the activity of Rn-219 gas exhaled by patients undergoing therapy with Ra-223 is only a tiny fraction of the injected activity. The model predictions of the exhaled Rn-219 activity can be used as reference inputs for clinical practical measurement developments.

Concepts of association between cancer and ionising radiation and the role of biological mechanisms

Markus Eidemüller [1]*
[1] Federal Office for Radiation Protection, Ingolstädter Landstr. 1, 85764 Neuherberg, Germany

Purpose: To investigate the individual association between cancer and preceding radiation exposure and its dependence on radiation mechanisms.

Materials and Methods: The probability that an observed cancer was caused by radiation exposure is usually estimated using baseline cancer rates and risk models from radioepidemiological cohorts and is called assigned share (AS). This definition implicitly assumes that an ongoing carcinogenic process is unaffected by the radiation. However, there is strong evidence that radiation can also accelerate an existing clonal development towards cancer, e.g. by inflammation or changes to the microenvironment. Here, we define different association measures that an observed cancer was newly induced or accelerated. To study the effects of mechanisms on the association measures, three biologically based two-stage clonal expansion (TSCE) models were derived from breast cancer data of the atomic bomb survivors of Hiroshima and Nagasaki. In the first model, radiation initiates cancer development, while in the other two, radiation has a promoting effect, i.e. radiation accelerates the clonal expansion of pre-cancerous cells. A Monte Carlo simulation for 1 million persons was performed that tracked the individual cellular development towards cancer, and the association measures were evaluated.

Results: For exposure at age 30, all three models resulted in similar estimates of AS at age 60. For the initiation model, estimates of association were nearly identical to AS. However, for the promotion models, the cancerous clonal development was frequently accelerated towards younger ages, resulting in associations substantially higher than AS.

Conclusions: This work suggests that the association between a given cancer and exposure in an affected person depends on the underlying biological mechanism and might be substantially larger than AS.

Simulation of radon and thoron inflow and behaviour inside a closed space

Krystian Skubacz [1]*, Bogusław Michalik [2]
[1] Central Mining Institute, Silesian Centre for Environmental Radioactivity, Plac Gwarków 1, 40-166 Katowice, Poland; kskubacz@gig.eu;
[2] Central Mining Institute, Silesian Centre for Environmental Radioactivity, Plac Gwarków 1, 40-166 Katowice, Poland; bmichalik@gig.eu

A model for simulating changes in the activity concentration of radon and thoron as well as their progeny in a closed space was developed. For this model a space is considered closed when a stream of radon and thoron flows into, but nothing comes out. It was also assumed that inside the space devices equipped with a filtering system may be present, which will reduce the concentration of radon and thoron decay products. These assumptions may therefore correspond to a situation when, in an isolated chamber, calibration of radon hazard monitoring devices is carried out and nuclides are supplied from an emanation or flow through sources or a workplace in well-isolated confined space (e.g. underground) where the source of nuclides is radon and thoron exhalation from surrounding walls.

The developed model was based on the analytical solutions of a system of differential equations describing decay sub-series starting with radon and thoron. Contrary to Bateman's equations, the model provides for radon and thoron inflow, which may compensate for these decay series' parent radionuclide decay. The differential equations were formulated based on the assumption that the concentration of radionuclides of concern in the space is uniform. The equations do not consider possible losses due to diffusion, as well as inertial or gravitational deposition of aerosols. If these phenomena have a limited impact on changes in the activity concentration of nuclides, the solutions provided may be used to predict the

concentration of radon and thoron activity and their decay products inside the chamber, which allows planning of activities related to devices calibration or, considering workplaces, effectiveness of air purification methods applied is evaluated.

Geochemical modelling for the prediction of NORM scaling in geothermal installations using GRE

G. de With[1]* , J.C.L. Meeussen1, S.J. van der Sar[1]
[1] Nuclear Research and Consultancy Group (NRG), Utrechtseweg 310, Arnhem, The Netherlands

Waters from geothermal reservoirs contain a range of elements that may induce corrosion and NORM scaling. This can significantly reduce the lifespan of traditional steel casing systems. Glassfiber reinforced epoxy (GRE) casings could provide a corrosion resistant alternative; however, its effect on scale formation as compared to other casing materials is not evident. This partly emanates from a general lack of understanding on scaling processes and more specifically the role of casing material.

The purpose of this work is to increase understanding of the scaling process and the role of the casing material, by simulating the formation of NORM scale in the geothermal installation. For this purpose, a model is developed, using NRG's geochemical software platform ORCHESTRA©. The model uses chemical equilibrium reactions for predicting the brine chemistry and the presence of any saturated minerals responsible for scale formation, taking account of all relevant operational conditions along the wellbore, such as temperature, pressure and CO2 degassing. The modelling differs from many mainstream studies reported in literature, as it computes the chemistry and any potential scaling along the upstream direction, considering any intermediate change in the brine chemistry.

Dedicated scenarios were calculated to compute the scale formation and its composition along the wellbore. This includes production sites prone to carbonate (CO3) and sulfate (SO4) based scales, which may contain e.g. 226Ra. In addition emphasis is given to the formation of lead (210Pb) scales from electrochemical interaction with the casing surface, as this is a type of scaling where casing material plays an essential role.

Findings of the computer simulations are validated against other studies, and simulations give information on the presence of NORM containing scales. In addition, a sensitivity analysis is performed, with around 500 simulations considering the full range of foreseeable chemical and operational conditions.

Development of Graphical User Interface (GUI) Program for Dose Assessment of Skin Contamination in Radiation Accidents

Seung Je Lee [1]*, Han Sung Kim [1], Jaeryong Yoo [1]
[1] Korea Institute of Radiological and Medical Sciences, Seoul, Republic of Korea

Purpose: In the event of a radiation accident, radioactive isotopes may be released into the environment, which can lead to contamination of the skin of workers and the general public without dosimeters. When such contamination occurs, dose assessment is important in terms of emergency response. During the response, handheld-type contamination monitors are commonly used to measure surface contamination level. However, determining the personal dose from contamination level may not be immediately feasible in practice. In the present study, we are developing a user-friendly graphical user interface (GUI) tool that can easily calculate the absorbed dose and effective dose when the skin is contaminated, providing an essential resource for emergency response.

Materials and Methods: To calculate the absorbed dose and effective dose, the adult mesh-type reference computational phantoms (MRCPs) and Geant4 Monte Carlo code were employed. The Blender software was utilized to divide the skin of MRCPs. The Qt 6 library and C++ were used in the development of the GUI program interface.

Results: The input values of the program consist of the degree of surface contamination measured in Bq cm-2 units, contaminated body parts, types of nuclides, and the estimation period of exposure. The body was divided into nine regions; the regions were classified as the head, torso, hands, forearms, upper arms, feet, lower legs, and thighs. Considering the potential types of isotopes that could be released during an accident, four representative isotopes (i.e., Co-60, I-131, Cs-137, Ir-192) were selected. A primary particle was uniformly generated on the skin surface of each divided body region using the Geant4 code.

Conclusions: Our GUI program converts the degree of surface contamination into the dose to the human body and provides results. We believe that this program can be an efficient tool for dose assessment when it is challenging to use equipment such as personal dosimeters.

Scientific Session 2C: Occupational Radiation Protection

Comparison of Organ Activity Estimates based on Bioassay Monitoring with Post-mortem Tissue Analyses

Martin Šefl [1]*, Maia Avtandilashvili [1], Joey Y. Zhou [2], Sergey Y. Tolmachev [1]
[1] United States Transuranium and Uranium Registries, Washington State University, Richland, Washington, USA
[2] Office of Domestic and International Health Studies, United States Department of Energy, Washington, DC, USA

Purpose: Monitoring data, such as urinary excretion and in-vivo body measurements are usually the primary source of information for radiation epidemiology of nuclear workers. The United States Transuranium and Uranium Registries (USTUR) complements monitoring data with post-mortem tissue radiochemical analyses for modeling of actinide biokinetics and estimation of radiation doses.

Material and Methods: Uncertainties in organ activities, and radiation dose estimates from internally deposited 239Pu were evaluated using a group of nine former nuclear workers. These individuals voluntarily donated their tissues to the USTUR. All nine workers were exposed to 'high-fired' PuO2 aerosols during the same glove-box fire accident. Plutonium bioassay data for each individual included at least five positive urine measurements. For six workers, the fire was their only intake, two had an additional wound intake, and one had an additional inhalation incident.

Results: The measured plutonium activities ranged from 9.4 to 123 Bq in the liver, from 9.2 to 215 Bq in the skeleton, and from 92.9 to 7540 Bq in the lungs. Bayesian inference was used to obtain distributions of estimates of activities and doses. Latin hypercube sampling was employed to create priors of main absorption parameters (rapidly dissolved fraction, and slow dissolution rate) and selected particle transport rates. Distributions of organ activities and organ equivalent doses were generated. The distributions of plutonium activities based on bioassay measurements were compared to the measured post-mortem 239Pu activities in the lungs and liver+skeleton.

Conclusion: Means of the modeled distributions differed from measured values on average by 49% for the lungs, and by 66% for the liver+skeleton.

The use of personal dosimeters by veterinary practitioners during portable equine radiography

Shauna Daly [1]*, Cliona Skelly [1], Rachel Toomey [1]
[1] University College Dublin, Dublin, Ireland

Purpose: The purpose of this study was to investigate the current practice of radiation safety by equine veterinary practitioners in Ireland undertaking portable radiography of horses. The use of personal dose monitors while carrying out portable x-rays on horses was examined.

Materials and Methods: An online survey was distributed via email to all veterinary clinics registered with the Veterinary Council of Ireland in which equine veterinary work makes up at least 20% of the practice profile. The survey consisted of 15 closed questions and two multiple choice grids. The questionnaire included questions on years since qualification, caseload, radiation safety training, radiation safety protocols, frequency of personal dosimetry use, types of dosimeters used, and where dose monitors are worn.

Results: The survey was received by 105 practices and garnered 33 valid responses. Participants reported a range of years since initial qualification, as well as a variety of caseloads.12% of respondents had completed additional radiation safety training. 59% of respondents reported that their clinics had radiation safety protocols in place. 41% of respondents reported that they wear a radiation dose monitor for every x-ray they take, while 17% indicated that they do not wear a personal dose monitor at all when taking portable equine x-rays. Various personal dose monitor types were reported. 27% of respondents reported that they did not know what type of dose monitor they use. 59% of respondents reported that they wear their dosimeter at their waist under a lead apron.

Conclusions: This study provides up to date information on the practice of personal dose monitoring by veterinary practitioners in Ireland during portable equine radiography. The study identifies areas where practice varies regarding the use of personal dosimeters, and highlights areas where further study may be warranted in order to determine the level of adherence to relevant guidelines.

Measurement of the 177 Lu spectral γ-ray transmission to assess the efficacy of X-ray aprons and lead screens for use by staff carrying out PRRT administrations

Danielle Maguire [1]*, Avril Mogan [1] , Ann McCann [1,2] , Niamh McArdle [1,2] , Jackie McCavana [1]
[1] Department of Medical Physics and Clinical engineering, St Vincent's University Hospital, Dublin, Ireland.
[2] Centre for physics in health and medicine, School of Physics, University College Dublin, Ireland

Purpose: Staff administering Peptide Receptor Radionuclide Therapy (PRRT) can receive a significant radiation dose. The therapy involves infusion of 7400 MBq of Lutetium-177 (177Lu) labelled DOTATOC and subsequent patient monitoring over a. 4.5 hour period. It has previously been reported that x-ray lead aprons can be employed to reduce staff dose. The spectral transmission of 177Lu through lead or lead equivalent aprons/ shields was measured to assess the dose reduction factor (DRF) provided by the materials to determine the optimum form of staff protection.

Methods: Using an energy and efficiency calibrated ORTEC® digi-DART-LFTM portable digital multichannel analyser, the spectrum of 117Lu-DOTATOC was measured free-in-air and through a variety of different PPE barrier materials – 3 models of low-Pb and Pb-free X-ray aprons and a 3.5 mm Pb mobile shield. The DRF for each barrier material was estimated by calculating the absorbed dose to a 25cm deep tissue equivalent phantom with and without the barrier material. The mass energy absorption coefficient and associated build-up factor were employed for each spectral gamma ray energy and total absorbed dose determined.

Results: Assuming 240 treatments per year are carried out by one individual, the whole body annual dose using an L-block shield and shielded administration vial was estimated to be 6mSv. The γ-ray transmission ranged from 19 – 22% and 12 – 16% at 113keV, and 26 – 37% and 23 – 31%

at 208 keV, through 0.25mm and 0.5 mm Pb equivalent materials respectively. The transmission through the mobile shield was 0.3% at 113keV and 3% at 208keV. The DRF and resultant estimated annual wholebody doses for the barrier materials will be presented.

Conclusions: Preliminary results demonstrate that while all barriers assessed reduce dose, only the 3.5 mm Pb mobile lead shield results in an annual dose of less than 1 mSv.

Radiation exposure of clinical staff during nuclear medical treatment of castration-resistant prostate cancer – Results from the ExperT project

Kerstin Hürkamp [1]*, Julia Brosch-Lenz [2], Astrid Delker [3], Shamil Samanta Galvez Febles [1], Sina Großmann [4], Lena Katzdobler [1], Wei Bo Li [1], Grigory Liubchenko [3], Veikko Oeser [5], Diana Walther [4], Sibylle Ziegler [3]
[1] Federal Office for Radiation Protection, Ingolstädter Landstraße 1, 85764 Oberschleißheim, Germany
[2] Klinikum rechts der Isar, Technical University of Munich, Department of Nuclear Medicine, Ismaninger Straße 22, 81675 München, Germany
[3] Ludwig-Maximilians-Universität München, University Hospital, Department of Nuclear Medicine, Marchioninistraße 15, 81377, Munich, Germany
[4] VKTA - Strahlenschutz, Analytik & Entsorgung Rossendorf e.V., Bautzner Landstraße 400, 01328 Dresden, Germany
[5] SARAD GmbH, Wiesbadener Straße 10, 01159 Dresden, Germany

Purpose: In novel nuclear medical therapeutic approaches for the palliative treatment of metastatic, castration-resistent prostate cancer, patients are administered MBq to GBq of 223Ra as radium-dichloride, or 177Lu or 225Ac labeled with PSMA intravenously. These radionuclides and their progeny are excreted by the patients by respiratory air, skin, urine and faeces. Clinical staff and patients' caregivers might be exposed via the emitted gamma radiation, inhalation of room and breathing air or via skin contamination as a result of patient care. In six work packages in the joint research project ExperT, funded by the German Federal Ministry of Education and Research, the radiation exposure in the clinics caused by the preparation of radiopharmaceuticals and during the cancer treatment is assessed.

Materials and Methods: Besides the development of measurement methods of room, breathing air, and excretion analysis for the alpha-emitting radionuclides 223Ra and 225Ac, biokinetic modelling and internal dosimetry are performed for patients and caregivers. The potential risk for radionuclide incorporation is estimated and SPECT/CT (single photon emission computed tomography) measurements for the imaging of 225Ac distribution in patients was successfully applied.

Results: A calibration chamber was developed for the calibration of semi-conductor aerosol filter detectors used for the air monitoring in the nuclear medical facilities. Exhaled activity of the gaseous progeny 219Rn was modelled to be <2.5x10-7 Bq per Bq injected 223Ra. However, contamination in the patient's rooms was found for 177Lu and 225Ac with up to several kBq on the floors, followed by toilet seats. Methods for the analysis of 223Ra and 225Ac in urine were developed and verified with real samples. First attempts of SPECT measurements on 225Ac with phantoms and in a single patient showed promising results.

Conclusion: The approach serves to improve radiation protection for patients, clinic staff and caregivers as well as to optimise the nuclear medical therapeutic procedures.

Radiation safety of our employees during the COVID-19 pandemic in nonhuman primate research

Niels P Beenhakker [1]*, Bart W Faber [1], Marieke A Stammes [1]
[1] Biomedical Primate Research Centre, Rijswijk, the Netherlands

Purpose: A hallmark of COVID-19 is lower respiratory tract infection and viral-induced pneumonia. Nonhuman primates have shown to mirror mild-to-moderate human disease. Lung (PET-)CTs of SARS-CoV-2-exposed nonhuman primates, has shown great promise in detecting and longitudinally evaluating disease in a non-invasive manner. High-level (bio-)containment is compulsory when studying SARS-CoV2-infected animals, which is a challenging combination during PET-CT imaging, with respect to radiation safety as there is limited space to operate in these contained areas.To investigate the level of exposure to radiation of the staff, risk analyses were performed, while all personnel was monitored by dosimetry (TLD-badge/ring).

Materials and Methods: Multiple experimentally SARS-CoV-2 infected rhesus or cynomolgus macaques were followed with several (PET-)CTs using a LFER150 (Mediso Medical Imaging Systems Ltd.) with [18F]-, [64Cu]-, or [89Zr] labeled tracers. A maximum of 20 animals per day for CT or 6 for PET-CTs were handled in the scanner room.

Results: Since the start of the pandemic around 1000 CTs and 200 PET-CTs were obtained of SARS-CoV-2 infected nonhuman primates.Initial theoretical dose-estimations were in the range of several mSv's per year. This was partly caused by the inability to keep distance to the radiation source(s) in the room (scanner and/or animal) because of the biosafety and animal welfare requirements. In order to prevent these relatively high doses, mobile lead screens and long drip lines were introduced, minimizing the radiation dose, while biosafety and animal welfare were not compromised. Dosimetric analysis showed that the maximum observed yearly dose was well below the safety limits (0.16mSv/year). Other frequently present staff showed even lower values (<0.05mSv/year).

Conclusions: This data illustrates that, while personnel has to stay relatively close to the source(s) of radiation because of biosafety and animal welfare issues, it is possible to create a safe workspace.

Population transcriptogenomics highlights impaired metabolism and small population size in tree frogs living in the Chernobyl Exclusion Zone

Clément Car[1], André Gilles[2], Elen Goujon[1], Marie-Laure Delignette Muller[3], Luc Camoin[4], Sandrine Frelon[1], Pablo Burraco[5,7], Samuel Granjeaud[4], Emilie Baudelet[4], Stéphane Audebert[4], Germán Orizaola[5,8,9], Jean Armengaud6, Arthur Tenenhaus[10], Imène Garali[1], Jean-Marc Bonzom[1], Olivier Armant[1]*

[1] Institut de Radioprotection et de Sûreté Nucléaire (IRSN). PSE-ENV/SRTE/LECO, Cadarache, France ; PSE-SANTE/SESANE/LRTox, Fontenay aux Roses, France.

[2] Aix-Marseille Université, INRAE, UMR 1467 RECOVER, Centre Saint-Charles, Marseille, France.

[3] Université de Lyon, Université Lyon 1, CNRS, VetAgro Sup, Laboratoire de Biométrie et Biologie Evolutive UMR 5558, Villeurbanne, France.

[4] Aix-Marseille University, Inserm, CNRS, Institut Paoli-Calmettes, CRCM, Marseille Proteomics, Marseille, France.

[5] Animal Ecology, Department of Ecology and Genetics, Evolutionary Centre, Uppsala University, 75236 Uppsala, Sweden

[6] Université Paris-Saclay, CEA, INRAE, SPI, Département Médicaments et Technologies pour la Santé (DMTS), Bagnols-sur-Cèze, France.

[7] Doñana Biological Station (CSIC), Seville, Spain

[8] IMIB-Biodiversity Research Institute, University of Oviedo, 33600 Mieres-Asturias, Spain

[9] Zoology Unit, Department of Biology of Organisms and Systems, University of Oviedo, 33071 Oviedo-Asturias, Spain

[10] Université Paris-Saclay, CNRS, CentraleSupélec, Laboratoire des signaux et systèmes, Gif-sur-Yvette, 91190, France

Individual functional modifications shape the ability of wildlife populations to cope with anthropogenic environmental changes. But instead of adaptive response, human-altered environment can also generate a succession of deleterious functional changes that may lead to the extinction of the population. To study how persistent anthropogenic changes impacted local species' population status, we generated transcriptome-wide data on tree frogs living along a gradient of radioactive contamination around the Chernobyl nuclear power plant, in order to characterize gene expression changes but also population structure and genetic diversity. System biology and machine learning approaches detected lower effective population size in populations most exposed to ionizing radiation that is not compensated by migrations from surrounding areas. We also highlighted a decreased body condition of frogs living in the most contaminated area, a peculiar transcriptomics signature and stop-gained mutations in genes involved in energy metabolism. Together, these data demonstrate that frog populations living in the center of the CEZ are still undergoing functional changes several decades after the accident.

Two- and Three-Dimensional Models of Radionuclide Migration from a Subsurface Repository

Cristiana Carvalhal [1]*, António Pereira [2], Isabel Paiva [3]

[1] Instituto Superior Técnico, Universidade de Lisboa, Portugal; cristiana.neves.carvalhal@gmail.com;

[2] Formerly at Dept. of Physics, Stockholm University, Sweden; antonio.de.campos.pereira@outlook.com;

[3] Centro de Ciências e Tecnologias Nucleares (C2TN), Departamento de Engenharia e Ciências Nucleares (DECN), Instituto Superior Técnico, Universidade de Lisboa, Estrada Nacional 10, ao km 139,7 2695-066 Bobadela LRS, Portugal; ipaiva@ctn.tecnico.ulisboa.pt; ORCID:0000-0002-1861-4735.

Radioactive waste in Portugal, a small inventory Member State (SIMS), originates primarily from medicine, industry and research practices. Portugal has no nuclear power plants and the spent fuel from the Portuguese Research Reactor was sent back to the USA. Portuguese radwaste consists of VLLW, LLW and ILW, storage in a centralized interim facility.

In radioactive waste management, subsurface repositories for LLW and ILW are projected to run for several hundred years. The COMSOL Multiphysics® simulation software is essential for estimating the safety conditions of a repository, contributing to an effective radiological protection of the environment and biosphere.

The aim of this project was to develop and assess the performance of two- and three-dimensional finite-element models of radionuclide migration within the near-field and through the far-field of a subsurface repository, designed for the disposal of LLW and ILW, containing Cs-137 and Ra-226.

This facility consisted of three sequential vaults assembled at a depth of 50 m within a granitic medium, where the waste was firstly enclosed in concrete drums and then isolated by concrete and bentonite engineered barriers.

The modelling strategy used a two-step numerical approach. Initially a hydrogeological model was set up to study the groundwater flow through the granitic rock. Subsequently a time-dependent model coupling the Darcy's velocity field to the transport of radionuclides was built.

Nuclide concentration as well as total flux magnitude were evaluated at the interface between the near-field and the far-field, at a distance of 100 m of the repository and at the end of the geological medium.

Results showed that both, Cs-137 and Ra-226, are strongly retained by the engineered barrier system, reinforcing the central role of the COMSOL software in the risk assessment of repositories. This work is pioneer in the application of COMSOL Multiphysics to the safety of radwaste disposal in Portugal.

Long term consequences to chronic low dose radiation exposure. Do plants adapt?

Nele Horemans [1,2]*, Paulus Laanen [1,2], Luca Boldrini [1,3], Brix De Rouck [1,4], Gustavo Duarte [1]
[1] Belgian Nuclear Research Centre, Belgium,
[2] Hasselt University, Belgium
[3] Roskilde University, Denmark
[4] University of Antwerp, Belgium

In this study the impact on plants of long-term exposure to radiation coming from nuclear accidents like Fukushima and Chornobyl is investigated and compared with lab experiments in either a chronic exposures.

Arabidopsis thaliana and Capsella bursa pastoris were sampled in Chornobyl (CEZ, May 2016) and Fukushima affected areas (FEZ, May 2016, 2019, 2020) alongside a gradient of enhanced radiation ranging from 0.5 to 50 µGy.h-1. The endophyte community was isolated from seeds from Arabidopsis thaliana harvested in the CEZ. In addition further lab experiments were performed on commercially available wild type plants of C. bursa pastoris, Pinus sylvestris and A. thaliana plants grown under chronic (at 1 mGy/h) as well as on Lemna minor plants exposed for approximately 18 generations to either elevated external radiation or Sr-90 (0-400Bq/L) or Cs-137 (0-40000Bq/L). Plants were scored gene expression of genes involved among others in DNA methylation, nuclei ploidy was analysed as well as developmental features such as germination rate, biomass accumulation.

In general little of no effects were found on the development of plants coming from seeds of the field. However, in the seeds from the field it seemed that the endophyte population (plant microbiome) was less diverse in seeds collected in regions with higher dose rates. From the multigenerational experiments in the lab it seemed that subtle changes in growth as well as gene expression were present at first for low dose exposed plants. However exposing the plants long-term and for multiple generations resulted in establishment of a new established homeostasis. So overall the data hint towards an adaptive response being present in chronically low dose exposed plants Additionally, DNA methylation seems to play a role in the response to radiation but its use as marker of exposure or in risk assessment needs further experimental evidence and discussion.

Effects of ionizing radiations across multiple generations: learning summary from non-human biota ICRP TG121 meeting subgroup

Shayen Sreetharan[1,2], Sandrine Frelon[3]*, Patrick Laloi[4], Nele Hormans[5,6], Sisko Salomaa[7] & Christelle Adam-Guillermin[3]
[1] London Health Sciences Centre (LHSC), London, Ontario, Canada
[2] McMaster University, Hamilton, Ontario, Canada
[3] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Saint-Paul-lez-Durance, France
[4] Belgian Nuclear Research Centre (SCK), Mol, Belgium
[5] University of Hasselt, Diepenbeek, Belgium
[6] Université Claude Bernard Lyon 1, Villeurbanne, France
[7] University of Eastern Finland, Kuopio, Finland

The potential for radiation-related deleterious effects in progeny, and thus, in next generations is a major concern for parents exposed to ionising radiation from occupational, medical or environmental sources. To date, there is still a lack of knowledge (and subsequent uncertainties in risk estimates) on offspring and heritable effects, underlaying mechanisms and related confounding factors. In order to summarize and improve the knowledge on this topic, a dedicated task group was launched in 2021 by the International Commission on Radiological Protection (ICRP). This group included a subgroup dealing with non-human biota, likely to be continuously exposed to ionising radiation in radio contaminated areas (environmental sources, anthropogenic activities including nuclear fallout), for which such effects have already been described in literature.

One goal of our TG121 subgroup was to review the literature on both multi-generational (in which the exposure continues across multiple generations) and trans-generational (in which later generations are not exposed during a recovery period) effects, in a wide range of non-human biota i.e. bacteria, worms, insects, crustaceans (predominant Daphnia magna), amphibians, fish, mammals, and plants.

Discussions were then structured around key questions regarding i) challenges linked to non-human biota long-term effects approaches (lab vs field studies, species of interest), ii) the different study designs, endpoints and parameters possible to assess long term effects for non-human biota, and iii) underlying mechanisms, adaptation and evolution issues.

This presentation will summarize the work done by this sub-group, the surrounding discussions, challenges and limits highlighted. Also, the possible implications for the systems of ecological radiological protection and lessons that can be learnt for humans will be addressed.

The new age of radium use: transferring risk into benefits

Bogusław Michalik [1], Govert de With [2], Hubert Makuła [3]*
[1] Central Mining Institute, Katowice, Poland
[2] Nuclear Research and consultancy Group NRG, Arnhem, The Netherlands
[3] Central Mining Institute, Katowice, Poland

Due to high demands, as miraculous cure for almost everything, radium was produced at many sites from the early twentieth century until the II WW. A rough evaluation indicated that worldwide 5 kg radium was produced of which half was obtained in Belgium, based on ores from Congo.

Application of radium against cancer was stopped in the 1960s. Available stocks of radium were appraised adequate, and radium extraction from ores was considered no longer necessary. Moreover, from the 1960s radium was viewed as a radiation hazard present in former radium producing facilities.

Recent innovations in nuclear medicine shine a whole new light on the importance of radium. Different cancer indications can now be treated by Targeted Alpha Therapy (TAT) using alpha-emitting radionuclides obtained from irradiation of a radium-226 target in a nuclear reactor. Currently the production of TAT isotopes is based on Ra-226 from legacy material. However, to meet further demands, Ra-226 production must be reconsidered.

In nature, Ra-226 occurs in U-238 decay series, enclosed in uranium rich minerals. Radium may be produced by separation of the radium-barium salts from minerals, followed by fractionated crystallisation, enabling a radium concentrate of about 97%.

Conversely, radium is present in produced water released due to fossil fuels exploitation and in residues from mineral processing industries, causing environmental problems. Many efforts are spent on purification of such residues. These processes may be efficient, however, radioactive residues are generated.

Considering purified material and residues received as each having their own inherent value, and further transmutation Ra-226 into short-lived TAT radionuclides let one conclude that zero waste technology is achievable. Notwithstanding specific residues, a sourcing of Ra-226 emerged from their valorisation provides a win-win situation.

Identified options and ongoing activities are provided. Expected challenges are discussed using examples of radium sourcing trials from mine sediments.

The winner takes it all: Is the Baltic or the Irish sea higher contaminated with Cs-137

Pedro Nogueira[1]*, Marc-Oliver Aust[1], Ulrike Kammann[1]
[1] Thünen Institut of Fischeries Ecology, Herwigstraße 31 27572 Bremerhaven, Germany

Purpose: The Irish Sea and Baltic Sea are still nowadays two of the most radioactive contaminated Seas worldwide. However, the origins of this contaminations are completely different. While the Baltic Sea was unintentionally contaminated due to the Chernobyl nuclear powerplant accident in 1986; the Irish sea was intentionally used, between the 50's and 90's, as dumping ground for the nuclear fuel reprocessing industry waste. Nowadays, more than 30 years later, it's still possible to measure these contaminations in the fish and sediments of both Seas. The purpose of this work is to find out which sea is the most contaminated with Cs-137.

Materials and Methods: In the frame of the German monitoring program for anthropogenic radioactive substances, two annuals surveys with the research ship Walther Herwig III are dedicated to the collection of marine species samples in German waters. From this monitoring program, one survey was recently dedicated to collect samples in the Irish Sea, nearby Sellafield; another survey has focused on the collection of samples in several reference areas across the Baltic Sea.

The collected fish samples radioactive content was analysed using gamma spectrometry.

Results: It was found that a direct comparison between both Seas contaminations is not a trivial task. Since difference fish species live in both seas and they have different tropic levels in the food chain. The results and Pitfalls of this comparison will be presented and discussed in this presentation.

Conclusions: Despite both seas being the most contaminated Seas with Cs-137 worldwide they don't represent any dangerous for the human consumption. And the Winner is…

Scientific Session 4A: NERIS: Emergency Preparedness and Response

Radiological Hazard Assessment of the ARPANSA Yallambie Site

Blake Orr [1]*, James De Corrado [1], Katherine Gouin [1], Stephen Long [1]
[1] Australian Radiation Protection and Nuclear Safety Agency, Yallambie 3085, Victoria, Australia

Purpose: Radiological hazard assessments are typically performed during the design phase of a facility to ensure potential consequences of a radiological emergency are minimised. They can also be used to demonstrate the acceptability of design solutions and periodically review safety and emergency planning and response arrangements for existing facilities. Expected radiological consequences off-site are assessed with respect to the Emergency Preparedness Category and interventions as recommended within RPS G-3 - Guide for Radiation Protection in Emergency Exposure Situations (ARPANSA 2019).

Materials and Methods: This work presents a hazard assessment of the radiological consequences of a severe credible incident scenario (thermal stress on radioactive sources) at the ARPANSA Yallambie site and provides an example of source term selection, dispersion modelling, and consequence analysis. The ARGOS decision support tool is used with the RIMPUFF atmospheric dispersion model to simulate release of a model source term with high-resolution numerical weather prediction data provided by the Australian Bureau of Meteorology. The use of a range of local weather data during atmospheric dispersion simulations allows for site-specific assessment to inform protective action planning. Postulated source terms are added through post-processing procedures to reduce computational time. Spatial visualisation and statistical methodology are applied to the resulting outputs and expected radiological consequences to off-site members of the public are assessed with respect to RPS G-3.

Results and conclusion: The predicted results of the hazard assessment showed that a Reference Incident release from the Yallambie site would not exceed the criteria for Urgent or Early protective actions. Therefore, the determination from this assessment is that the ARPANSA Yallambie site can be considered an EPC III site.

Following an incident, it may be prudent to monitor out to a distance of 100 m from the site boundary.

Building geometry input for urban atmospheric dispersion modelling

Dana S Lüdemann [1]*
[1] Technical University of Denmark, Roskilde, Denmark

Purpose: The local street and building geometry in cities strongly affects the atmospheric wind flow and, thereby, also the spreading of airborne pollutants and harmful contaminants. Hence, the real complexity of the building layer should be represented in the input data to urban atmospheric dispersion models. Methods to obtain highly realistic 3D digital surface model (DSM) products such as airborne lidar have radically improved in resolution and availability over the last 20 years. These data products allow for a more realistic building representation compared to simple polygon input files. This study aims to identify and discuss the benefits and new limitations of an improved building layer representation in emergency urban dispersion simulations.

Materials and Methods: Test cases are established focusing on buildings at the DTU Risø campus, which has been the center of nuclear research in Denmark with three test reactors. Starting from a single building, different 3D DSM products are compared and used as input to the computational fluid dynamics (CFD) flow solver EllipSys. Further, the useability of more complex building representation as input to the current functionality in the decision support system ARGOS is investigated.

Results: The 3D digital surface models are demonstrated as input data for modern CFD simulations and urban dispersion modelling. Special focus is given to data storage, resolution and availability highlighting new opportunities compared to simple polygon shapes.

Conclusions: The rapid technological development of airborne lidar technology has resulted in radically improved accuracy and realism in 3D digital surface models of buildings. To fully benefit from such products in atmospheric dispersion models for the urban environment used in emergency response tools such as ARGOS, we need to carefully consider which level of detail needs to be included in the flow model.

Continental-scale Atmospheric contaminant dispersion modeling by the artificial neural network based on the event of release Ru-106 October 2017

Anna Wawrzynczak [1]* , Piotr Kopka [1]
[1] National Centre for Nuclear Research, NCBJ, Poland

Accidental or intentional releases of hazardous substances (e.g., radionuclides) in large-scale areas is a significant concern for all people responsible for the security of society. Considering the large scale of potentially harmful hazardous release of radioactive materials stored, transported, or used in other ways, this concern is more than justified. The assessment of consequences on health and the environment also depends on sufficiently accurate knowledge about the dispersion of released material. An essential contribution to efficient emergency response to accidental releases is a reliable prediction of airborne hazmat dispersion as atmospheric dispersion models provide it. In this case, artificial neural networks (ANNs) can be helpful. The main advantage of the ANNs is discovering and learning the rules governing a given system based on experience. This feature makes ANNs a powerful tool in the modeling field. Once well-trained ANNs can solve the stated task very quickly. These characteristics make the ANNs an excellent tool in real-time working systems. Especially an emergency-response system able to localize the airborne toxin source location in real-time might be beneficial by applying the ANNs. Such a system should be able to pinpoint the most probable contamination source location quickly based on the sparse concentration data reported by the sensor network.

This paper presents the results of training the ANN to simulate the contaminant spread on a continental scale. The ANN training data set was generated based on the event in October 2017, when many European countries reported atmospheric detections of ruthenium Ru-106. In many scientific papers, the authors deliberated on probable locations of the sources of Ru-106 agent in the atmosphere. Based on airborne concentration measurements and chemical assumptions, it is possible to assume that the release occurred in the Southern Urals region in the Russian Federation. This scenario is accepted during the generation of the ANNs training dataset in the J-RODOS system. The training datasets also cover the measurements from 35 countries with a 1-day interval. The quality of the trained ANNs is judged using a set of statistical measures.

Voluntary radiation measurement team to enhance the radiation measurement preparedness in Finland

Maarit Muikku*[1], Petri Smolander[1], Jukka Sovijärvi[1], Tommi Hietamies[1], Jukka Kupila[1], Iida Kuurne[1] , Antti Takkinen[1]
[1] STUK – Radiation and Nuclear Safety Authority, Vantaa, Finland

A large scale nuclear or radiological emergency like a severe accident at a nuclear power plant, use of a nuclear weapon or a radiological dispersion device could threat the functioning of the whole society. Radiation and Nuclear Safety Authority (STUK) has together with The National Defense Training Association of Finland (MPK) and National Emergency Supply Agency (NESA) launched a co-operation program to enhance the national radiation measurement preparedness by recruiting, training and equipping a voluntary radiation measurement team. The focus lays primarily on the measurement of potentially contaminated people. In later phase the measurement of the surroundings and infrastructure will become important.

The voluntary radiation measurement team consists of about 40 persons divided into three measurement groups and one supporting group. The team is equipped with diverse and modern measurement tools, and it is capable to independently carry out its duties, for example, to determine the radiation situation, to check the contamination of people and vehicles as well as to support other organizations with radiation measurements.

By the end of year 2022 about 90 volunteers have been trained. The background of the volunteers is diverse. However, there are different kinds of tasks available for the volunteers, from a member of monitoring patrol to more challenging tasks like trainer or the operative leader in the volunteer organization.

The concept of the voluntary radiation measurement team as well as the content of the basic training are shortly described in this presentation.

A citizen monitoring network - a Croatian pilot project proposal

Ivica Prlić[1]*, Luka Pavelić[1], Mladen Hajdinjak[2,] Zdravko Cerovac[3], Mihovil Jurdana[1], Jerko Šiško[1], Carnet[4]
[1] Institute for Medical Research and Occupational Health, 10001 Zagreb, Croatia
[2] Haj-Kom LtD, 10001 Zagreb, Croatia
[3] Alara instruments LtD, 10001 Zagreb, Croatia
[4] CARNET, 10001 Zagreb, Croatia

Public interest in policy decisions of a complex, technical nature, in particular in the field of technologies which use ionizing radiation, has grown in recent years. The proposed project should support further development of risk assessment and risk management approaches supported by technological, in particular telecommunication technologies, to cope with various accident scenarios arising from new and future nuclear radiological technologies and, specially, from new threats arising from was situations like Ukraine one. We are using state of the art project results of the ongoing "e-Schools pilot project - https://pilot.e-skole.hr/en/e-schools/project-description/) project performed in Croatia building up fast internet educational network of the country with the purpose of establishing a system for the development of digitally mature schools.

Picked up schools will build the base of AI and big data technologies in radiological impact assessments compiling the databases that are required by AI technologies, with historic scenario information. Monitoring strategies with newly developed or upgraded mobile and advanced monitors, connected to a e-Schools fast internet networks relying also on citizen science approach and providing early detection of threats together with educational purpose in understanding radiation as a whole.

The Area electronic dosemeters- ionizing radiation monitoring devices together with the devices monitoring the nonionizing telecommunication electromagnetic spectrum are to be operational throughout all Croatian schools building up educational and independent emergency network and filling up big-data database enabling the development of indicators for resilience strategies solving social and psychological challenges for emergency actors and citizens and their impacts on the effectiveness of protective measures, legal basis and practical arrangements for emergency response and recovery. The citizens in our pilot project proposal are children, pupils up to 18 years of age, the ones who need to be educated and prepared for future technological challenges to cope with societal resilience and novel ethical considerations.

European Metrology Network for Radiation Protection: Education and Training activities

Oliver Hupe[1]*, Liz Ainsbury[2], João Alves[3], Steven Bell[4], Argiro Boziari[5], Margarida Caldeira[3], Florian Gering[6], Denis Glavič-Cindro[7], Mihail-Razvan Ioan[8], Behnam Khanbabaee[1], Linda Persson[9], Miloš Živanović[10], Hayo Zutz[1], Steffen Ketelhut[1]

[1] Physikalisch-Technische Bundesanstalt (PTB), Germany

[2] United Kingdom Health and Safety Agency (UK HSA), United Kingdom,

[3] Instituto Superior Técnico, LPSR-LMRI, (IST), Portugal

[4] National Physical Laboratory (NPL), United Kingdom

[5] Greek Atomic Energy Commission (EEAE), Greece

[6] Bundesamt für Strahlenschutz (BfS), Germany

[7] Institut Jožef Stefan (JSI), Slovenia

[8] INCD pentru Fizica si Inginerie Nucleara ""Horia Hulubei"" (IFIN-HH), Romania

[9] Swedish Radiation Safety Authority (SSM), Sweden

[10] Vinca Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade (VINS), Serbia

Purpose: The European regulation for protection against exposure to ionizing radiation is essentially laid down in the Council Directive 2013/59/EURATOM. The practical implementation of the European basic safety standards has become more complex due to the lack of consideration of the metrological implications and the adaptation to new technological developments. To overcome such a difficulty, a European Metrology Network for Radiation Protection (EMN RP) was stablished in September 2021 to act as a focal point between the metrology communities and the relevant radiation protection stakeholders, including regulators, standardization bodies, manufacturers, users of radiation sources and international organizations.

Materials and Methods: In the work package knowledge transfer, the supporting project 19NET03 supportBSS, together with its EMN RP partners, EURADOS and the German Federal Office for Radiation Protection (BfS), organizes an international training course on dosimetry and emergency preparedness in collaboration with the UK Health and Safety Agency (UK HSA) and the Greek Atomic Energy Commission (EEAE) as local host. The course will be held at EEAE in Athens, Greece, from 18 to 21 September 2023. Webpage: http://www.ptb.de/tceurados-wg2-2023

Results: The aim of this course is to provide the theoretical background of dealing with emergencies and to enhance it with practical measurement exercises. The course consists of three days of lectures and discussions combined with one day of practical exercises in small groups of five people. Lecturers from different European institutes will present various topics from different perspectives.

Conclusions: This paper evaluates the course content and the feedback from the participants. This course can serve as a basis for further courses that can then be offered by appropriate platforms.

Overall risk of cancer incidence attributable to adult CT examinations: impact of a 7 years dose optimization program

Federica Zanca [1], Benoit Dufour [1], Charles Kaltenbach [2], Damien Racine [3], Pauline Sastre [2], Benoit Rizk [1], Natalie Heracleous [1]*, Cyril Thouly [1], Hugues Brat [1]
[1] Groupe 3R, SIon, Switzerland
[2] GE Healthcare, Paris France
[3] CHUV, LAusanne, Switzerland

Purpose: To estimate the impact of a dose optimization program on radiation-induced cancer risks in adult computed tomography (CT).

Materials and Methods: From 2016 to 2022, after a phase (P1) of protocol harmonization according to clinical indication, three phases of dose optimization were implemented at our institution (9 centers). P2 (first dose optimization); P3 (second with the introduction of new generation CT scanners); P4 (third with the introduction of deep learning reconstruction).

To estimate individual radiation-induced cancer risk associated with each phase using the BEIR VII model, patient-specific organ doses, age at exposure and sex were extracted from our dose monitoring system (DoseWatch, GE Healthcare). Finally, lifetime risk and organ-specific risk of developing cancer were estimated using RadRAT (version 4.2.1).

Results from each phase were compared by using the mean risk (Kruskal-Wallis test, significance $p<0.05$). Data were also stratified per anatomical region, organ and clinical indication (chest (emphysema, pulmonary embolism and pneumonia) and abdomen (appendicitis, diverticulitis, kidney stones, liver, pancreas tumor, renal tumor and infection)). The evolution of our local clinical DRLs over the four phases was also estimated.

Results: The number of exams collected per P1/P2/P3/P4 were respectively 1010/961/5348/4651 for a total of 11970, with 60 excluded. 47,5% were male vs 52,5% female (average age 60 years). An overall reduction of 53.1% lifetime risk of developing cancer was observed. When stratifying per anatomical region, the reduction was 52.5%/53.7% for thorax/abdomen respectively. The highest excessive risk reduction was observed for emphysema (59.1%) and diverticulitis (61.2%) exams; the lowest impact was on pneumonia and renal tumor exams, with 30.0% and 37.3% respectively.

Conclusion: The continuous process of CT protocol optimization allowed for a significant reduction of cancer risk associated with ionizing radiation. Excess of radiation-induced cancer cases can be reduced by fostering continuous dose optimization and avoiding scanner obsolescence.

Global Noise Level as Noise Metric for Low-Dose Chest CT in Lung Cancer Screening

Kwinten Torfs [1]*, Dimitar Petrow [2], Hilde Bosmans [1,2]
[1] KU Leuven, Leuven, Belgium
[2] UZ Leuven, Leuven, Belgium

Purpose: Screening with low dose CT (LDCT) is today the most accepted method of reducing lung cancer mortality through early detection. In light of the rollout of a Flemish screening program, quality of participating scanners/models/centres should pass minimal standards. Currently there are neither established metrics nor reference data to evaluate and optimize the LDCT protocols. Here, Global Noise Level (GNL) is investigated as a possible, population representative noise metric for low-dose chest CT when applied on an anthropomorphic Lungman phantom.

Materials and Methods: Measurements for patients and phantom were performed on a Siemens SOMATOM Definition Edge CT under identical convolution kernel (Br38f and Br59f), slice thickness (3 mm), tube voltage (120 kVp) and with or without Tube Current Modulation (TCM). Global Noise Levels (GNL) were determined for each slice in the axial plane for soft tissue regions (0-170 HU).

The Lungman Phantom is scanned under TCM and at different reference mAs to simulate different dose levels. Further, these results are compared to 16 patient scans with water-equivalent diameter (WED) similar to Lungman with and without fat slabs (22-28cm). Half of the patient images are conventional thorax scans at an average CTDI around 5 mGy (the Belgian p50 DRL). The other half are covid screening scans at low dose (CTDIavg = 1.35 mGy).

Results: Preliminary results show the ability to measure GNL in all axial slices, for all scans.

Further, GNL results obtained for patients coincide with those measured in Lungman at TCM. Next, our analysis demonstrates a significant inverse relation between GNL and mAs (and thus dose) for patient cross-sections with similar WED levels. GNL provides a discriminating parameter between different doses.

Conclusions: GNL can be used as noise metric in patient and phantom images for research into low-dose chest CT. Also, Lungman is representative for a population of real patients in terms of GNL measurements.

Total out-of-field dose distribution in Hodgkin lymphoma patients receiving proton therapy

Maite Romero-Expósito [1,2*], Mona Azizi [2,3], Ignacio Espinoza [4], Beatriz Sánchez-Nieto [4], Isidora Muñoz [4], Iuliana Toma-Dasu [2,3], Ola Norrlid [5], Christina Goldkuhl [6], Daniel Molin [7], Alexandru Dasu [1,7]

[1] The Skandion Clinic, Uppsala, Sweden
[2] Karolinska Institutet, Stockholm, Sweden
[3] Stockholm University, Stockholm, Sweden
[4] Pontificia Universidad Católica de Chile, Santiago de Chile, Chile
[5] Uppsala University Hospital, Uppsala, Sweden
[6] Sahlgrenska University Hospital, Gothenburg, Sweden
[7] Uppsala University, Uppsala, Sweden

Purpose: Hodgkin lymphoma (HL) is frequently diagnosed among young adults, who have a high chance of cure and a long lifetime expectancy after treatment. Therefore, the risk of developing a second cancer is a concern. A comprehensive evaluation of this risk relies on assessing the total out-of-field dose received by the patient during the treatment. This work presents a methodology for the evaluation of the total dose for HL patients under proton therapy.

Materials and Methods: The cohort under evaluation included patients with targets located in the neck and thorax region, with volumes ranging from 60 to 630 cc. Total dose was calculated as the sum of the proton RBE dose, neutron dose equivalent and photon absorbed dose in out-of-field regions. Proton doses were obtained from the treatment planning system. The neutron and photon contributions were determined through Monte Carlo simulations (MCNP 6.2 code). Calculations were performed on a virtual whole-body phantom consisting of the original CT, along with a reconstruction of the rest of the body obtained using the IS2aR software.

Results: Dose levels in organs depend on the position and volume of target. For plans including the neck area (volume≈65 cc), total dose to thyroid (out-of-field volume) ranges between 120 and 50 mSv/Gy(RBE), to lungs between 20 and 10 mSv/Gy(RBE), and to brain between 7.6 and 0.10 mSv/Gy(RBE). Remaining organs more distant to the target receive doses lower than 0.10 mSv/Gy(RBE).

Conclusions: Organs partially within the target area may receive doses of the order of 1 Sv (for 20 Gy(RBE) prescription) while the doses to the remaining organs become smaller as they are farther away from target. As a result, low risks of second cancer are expected in out-of-field organs. However, additional studies are required to include the contribution of imaging procedures for an accurate risk estimation.

Peripheral organ doses from volumetric modulated arc therapy (VMAT) for Hodgkin lymphoma

Mona Azizi [1,2*], Maite Romero-Expósito [2,3], Ignacio N López-Martínez [4], Isidora Múñoz [4], Ignacio Espinoza [4], Ola Norrlid [5], Christina Goldkuhl [6], Iuliana Toma-Dasu [1,2], Daniel Molin [7], Alexandru Dasu [3,7], Beatriz Sánchez-Nieto [4]

[1] Stockholm University, Stockholm, Sweden
[2] Karolinska Institute, Stockholm, Sweden
[3] The Skandion Clinic, Uppsala, Sweden
[4] Pontificia Universidad Católica de Chile, Santiago, Chile
[5] Uppsala University Hospital, Uppsala, Sweden
[6] Sahlgrenska University Hospital, Gothenburg, Sweden
[7] Uppsala University, Uppsala, Sweden

Purpose: Long-term follow-up of Hodgkin lymphoma (HL) survivors has shown a risk for long-term effects, including risk of second cancers. However, an accurate calculation of out-of-field organ doses using treatment planning systems is challenging, hampering the assessment of the risk of second cancers and other effects. The aim of this study is to investigate the determination of out-of-field doses from photon treatments for HL using volumetric modulated arc therapy (VMAT).

Materials and Methods: Two integrated MATLAB-based software programs were used in two steps to calculate the Dose-Volume Histogram, and then, the corresponding mean dose in out-of-field organs for a representative cohort of 14 HL patients with mediastinal and neck involvement. Firstly, the planning CT was used to generate a whole-body CT image using the IS2aR software. Then, mean out-of-field organ doses were assessed in the whole-body phantom with the Periphocal 3D software using the prescribed dose, monitor units, mean field size, and location of isocenter in the photon plan.

Results: VMAT can deliver out-of-field doses to distant organs from the target. The mean out-of-field doses for 1 fraction (~2 Gy) in the low dose regions (<5% of prescribed dose) were calculated for organs-at-risk in the whole-body phantom. The mean doses for the thyroid ranged from 4.5 to 5 cGy/Gy. The heart and lungs received doses of 2 to 3.5 cGy/Gy, while the salivary glands had a mean dose of 1 to 4.5 cGy/Gy. For organs situated farther from the target, the peripheral doses to the esophagus and spinal cord ranged from 2.5 to 4 cGy/Gy and 2 to 3 cGy/Gy, respectively. The brain had mean dose values of 1 to 2.5 cGy/Gy.

Conclusion: Dose to peripheral organs could be integrated in dose assessment protocols. The out-of-field doses for the most distal organs are less than 1% of the prescription dose.

Noradrenergic agonists attenuate microglial inflammation and impairments in hippocampal neurogenesis induced by whole-brain irradiation

De Bie I.[1,2], Peeters B.[1], Berden L.[1], Caestecker S.[2], Raedt R.[2], Benotmane MA.[1]*
[1] Belgian Nuclear Research Centre, SCK CEN, Mol, Belgium
[2] BRAIN, Department of Head and Skin, Ghent University, Ghent, Belgium

Purpose: Cognitive decline is the most commonly reported as side effect after radiotherapy for patients with a pediatric brain tumor. Pathogenic mechanisms that are believed to underlie radiation-induced cognitive decline involve deficits in hippocampal neurogenesis associated with increased apoptosis of neuronal progenitor cells and increased neuroinflammation in the subgranular zone (SGZ) of the hippocampus. Increased noradrenergic (NA) neurotransmission can reduce cell death and neuroinflammation and thus potentially rescue hippocampal neurogenesis and limit radiation-induced cognitive decline. In this study, we investigated whether NA agonists can reduce radiation-induced hippocampal injury and inflammation and can rescue neurogenesis.

Methods: In this study, 48 juvenile P22 mice were randomly allocated to a control group, 10 Gy irradiated group, 10 Gy irradiated group plus 20 mg/kg Reboxetine, and a 10 Gy irradiated group plus 1 mg/kg Atipamezole (n= 3/sex/treatment). Therapy with NA agonists was delivered as 7 daily intraperitoneal injections starting immediately after radiation. Sham therapy was administered in an identical manner by injecting equivalent volumes of sterile 0.9% NaCl. At 6 hours and 1 month post-radiation, early and late radiation-induced injury in the SGZ of the hippocampus was investigated using specific markers for inflammation (Iba1), apoptosis (CC3), and neurogenesis (Sox2 and DCX).

Results: A single fraction of 10 Gy induces a high apoptotic and inflammatory response in the subgranular zone of the hippocampus, shown by an increased number of CC3+ apoptotic cells and Iba1+ microglia 6 hours after radiation. Both Atipamezole and Reboxetine significantly reduce the amount of CC3+ cells and Iba1+ microglia within the subgranular zone compared to sham treatment, which demonstrates the neuroprotective and anti-inflammatory action of NA. One month after radiation exposure there was a substantial reduction in the number of Sox2+ and DCX+ cells within the dentate gyrus. The deleterious effect of 10 Gy irradiation on neurogenesis were significantly mitigated in the Reboxetine and Atipamezole group, as shown by an increase in the mean DCX+ and SOX2+ cell density in the dentate gyrus.

Conclusion: These findings suggest that administration of a NA agonist immediately post-radiation is sufficient to reduce radiation-induced apoptosis and inflammation in the neurogenic region of the hippocampus. Repeated administration of NA agonists for 7 days partially preserves/restores hippocampal neurogenesis. For this reason, we conclude that the NA system is a novel potential target to mitigate radiation-induced brain injury. Future research will examine whether NA stimulation will improve cognitive performance after radiation therapy, which is important to eventually help to improve the quality of life of young cancer survivors.

Practical and Regulatory Radiation Protection experience in the delivery of the first Radioligand Lutetium PSMA Therapy Doses to Patients in Ireland

D. Murphy [1], S. Maguire [2], M. 0'Connell [1], J. Mc Caffrey [1,3] T. Fitzpatrick [1], S. Sundraham [1], E Loughman [2], E. Kenny [1], M. Dooley [1], A. Dolan [1],B. Byrne [1], P. Gilligan [1,3]*.
[1] Mater Misericordiae University Hospital, Dublin Ireland
[2] Mater Private Network, Dublin, Ireland
[3] University College Dublin, Ireland

Purpose : Lu177 PSMA-617 (half-life 6.7 days) is a beta particle based radioligand therapy that has been shown to be effective in delivering patient benefits for metastasised castration resistant prostate cancer. In December 2022 our hospital administered the first two doses of Lutetium PSMA in the state. This paper outlines the steps involved in achieving this and learnings gained during the process.

Materials and Methods: After detailed planning, training programs, site visits and risk assessment, regulatory approval was obtained to deliver outpatient based standardised doses (7.5 GBq) of PLUVICTO™ (lutetium Lu 177 vipivotide tetraxetan) Novartis (CH) by infusion pump using a three-way tap reservoir system. The process was carried out in the uptake room of our PET centre with surfaces covered in adhesive polyethylene sheet (PAC ex, UK). External Dose rates (~50 uSv/hr@ 1m), occupational dose and contamination surveys reflected those encountered at other centres. Three further doses have been administered to one of the patients (four sessions in total) and a third patient has had their first dose (six sessions for all patients).

Discussion: Setting up this service had extensive multidisciplinary team involvement from nuclear medicine, radiology, oncology, nursing, administration and medical physics. The administration and set up was resource intensive from a radiation protection perspective. Waste storage and setting up of the tap were identified as areas requiring further consideration. This was initially carried out in our PET centre but now has moved to our nuclear medicine department, Next steps involve progression of individual patient dosimetry, funding and streamlining processes.

Conclusion: Detailed consideration of radiation protection aspects facilitated a new radioligand therapy option for castration resistant metastasised prostate cancer in Ireland.

Possible impact of diagnostic reference levels on administered activity in nuclear medicine

Anja Almen [1]*
[1] Swedish Radiation Safety Authority

Purpose: The concept of diagnostic reference levels (DRLs) is well known. In X-ray diagnostics, the system has been developed, implemented, used and published. In nuclear medicine, the concept does not seem to have received the same attention and the number of publications on the subject is considerably fewer. This study aimed to empirically study used administered activity for common examinations over 20 years. During this period, Sweden has had NDRLs, and for the last 5 years, some of the NDRLs are given as administered activity per body weight.

Materials and Methods: Three common adult examinations, myocardial perfusion (exercise), bone imaging, and PET tumour imaging was included. The average administered activity per year from 8 to 31 clinics depending on examinations, was analyzed. For PET the values were studied from, 2008 and onwards because a NDRL was issued in 2008.

Results: The median administered activity per year from 2002 and 2021 varied between 450 MBq and 600 MBq for myocardial perfusion and 454 MBq and 557 MBq for bone scintigraphy. For PET tumour examinations the values from 2008 and 2021 varied between 240 MBq and 320 MBq. The trend was rather stable. Reported typical values for the last 5 years suggest that an essential part of the hospitals administer per body weight, which makes employing the NDRL per body weight maningful. All hospitals were below the current NDRL.

Conclusions: The study suggests that NDRL may have functioned as a gatekeeper for increased values and that setting the NDRL concerning body weight when possible may be useful. Reference curves for nuclear medicine may be possible using body weight as a size indication. Optimisation of radiation protection, including both dosimetry and methodological issues, may be important to include in the drug development because of the, in practice, little change in administered activity when introduced into clinical practice.

Domain specific language models for enhanced training in radiation protection

Niki Fitousi [1]*, Nidhi Mishra [1], Tom Van Herpe [1], Bojan Arnaudovski [1], Thomas De Waelheyns [1], Anna Romanyukha [1], Jurgen Jacobs [1]
[1] Qaelum NV, Kolonel Begaultlaan 1B, 3012 Wilsele (Leuven), Belgium

Purpose: In the modern era of Artificial Intelligence (AI) and vast availability of information on the internet, technological advancements can facilitate continuous education to medical professionals. A new AI 'chatbot' for continuous learning on radiation protection was designed and tested on the subject of contrast usage in computed tomography exams.

Materials and Methods: A domain-specific language model was built using the LlamaIndex library. This model can be trained on different domains with relevant educational material for each purpose, considering that the user owns the rights to use this material. Powered by this domain-specific model, a chatbot webservice was developed. The end user can pose a question and receive an answer based on the material that was previously provided to train the model. To test the value and performance of the model from the perspective of a health professional, a proof-of-concept in the domain of contrast management was implemented in an already existing software which monitors contrast and radiation usage (Contrast management software, Qaelum, Belgium), and tested by certified medical physicists.

Results: A series of questions relevant to the subject was asked. This contained straightforward questions (example: In 10 words give me some benefits of contrast in imaging), but also advanced questions (example: What are the recommendations when an extravasation event happens?). The vast majority of the replies were correct and satisfactory. Limitations were mainly found in more complex requests (example: Create a multiple choice of right and wrong answers) and in the retention of previously submitted queries in the memory.

Conclusions: The intense workload of a medical imaging department sometimes makes it difficult for health professionals to find the right information at the right time. This proof-of-concept shows promising results that will alleviate the workload for professionals, allowing them to focus more on improving the quality of their practice.

EFOMP Malaga Declaration 2023: An updated vision on Medical Physics in Europe

Brenda Byrne [1*,] Loredana Marcu [2], Lorenzo Nicola Mazzoni [3], Carmel J Caruana [4], Amanda Barry [5], Guadalupe Martín Martín [6] Michele Stasi [7], Samuel Ruiz [8], Antonio Lopez Medina [9], Kalliopi Platoni [10], Ad J.J. Maas [11], Sam Agius [12], Efi Koutsouveli [13], Paddy Gilligan [14]

[1] Chair EFOMP Professional Matters Committee, Mater Misericordiae University Hospital, Dublin, Ireland

[2] Chair EFOMP European and International Matters Committee, Faculty of Informatics and Science, University of Oradea, Oradea, Romania

[3] USL Toscana Centro, Pistoia, Italy

[4] Faculty of Health Sciences, University of Malta, Msida, Malta

[5] Dept. Applied Science & Dept. Health and Sports Science, South Eastern Technological University, Waterford, Ireland

[6] Hospital Universitario de Fuenlabrada, Madrid, Spain

[7] Ospedale Ordine Mauriziano di Torino, Umberto, Italy

[8] Marqués de Valdecilla University Hospital, Santander, Spain

[9] Servizo Galego de Saúde, Vigo, Spain

[10] National and Kapodistrian University of Athens, Greece

[11] Retired Medical Physics Expert, MREC Brabant for Medical Devices, Netherlands12 lMinistry for Health, Malta

[13] Secretary General EFOMP, Hygeia Hospital, Athens, Greece

[14] President EFOMP, Mater Misericordiae University Hospital, Dublin, Ireland

In 2006, the European Federation of Organisations for Medical Physics (EFOMP) adopted the "Malaga Declaration". The declaration asserted the fundamental role of Medical Physics professionals in the radiation protection of patients, workers, general public, carers and comforters and research participants in hospitals. However, since that time the Medical Physics profession has evolved in Europe and new regulations and documentation have

been issued, such as directive 2013/59/Euratom and the "European Guidelines on Medical Physics Expert" (RP174). EFOMP has published updated core-curricula and strived towards the recognition of the profession at the European level. In view of this, an update of the original Malaga Declaration was deemed necessary, to define the future vision that will guide the actions of the Federation in the years to come. This Declaration, which has

been approved by the national member organizations of EFOMP in April 2023, is much broader than the original Malaga version. This is expected considering the rapid evolution of medical device technology over the last 17 years. The Radiation Protection Expert in hospital settings should be an MPE, since the latter has the highest level of radiation protection knowledge and training. Given the passion and energy that animated the debate,

which led to the updating of the Malaga Declaration, we are confident that it represents a solid basis for the development of our profession in Europe which is in consonance with the aspirations of us all.

Scientific Session 4C: Low Dose Research

Age- and sex-specific differences after low-dose radiotherapy of human TNFα tg mice

Lisa Deloch[1,2]*, Antonia Völlings[1,2], Thomas Weissmann[1], Lena Winterling[1,2], Tom Unterleiter[1,2], Michael Rückert[1,2], Rainer Fietkau[1], Benjamin Frey[1,2], Udo S. Gaipl[1,2]

[1] Department of Radiation Oncology, Universitätsklinikum Erlangen, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

[2] Translational Radiobiology, Department of Radiation Oncology, Universitätsklinikum Erlangen, Fried-rich-Alexander-Universität Erlangen-Nürnberg, Germany

Purpose: Rheumatoid arthritis (RA) is a multifactorial autoimmune disease. Its hallmarks are inflammation accompanied by a progressive destruction of the joints. Despite of many available treatment options, 20% of patients are considered non-responders. For this group of patients, a therapy with low doses of X-rays (Low-dose radiotherapy, LDRT) could be a beneficial additive therapy option as LDRT is known for its anti-inflammatory and analgesic effects. These effects are partially mediated by the immune system, whereas an inflammatory primed system shows different responses to LDRT than a healthy one. Other factors that influence the immune system and the response to ionizing radiation are age and sex, that so far, have not been sufficiently examined in LDRT settings.

Methods: We are looking into age- and sex-mediated effects after LDRT using the human TNFα transgenic (hTNFα tg) mouse model of RA and healthy littermates via histomorphological as well as ELISA- and qPCR-based methods. We examined the base levels of inflammatory and osteoimmunological components alongside the influence of a single irradiation dose of 0.5Gy on 6- and 8-weeks old animals.

Results: While inflammatory fibroblast-like synoviocytes and bone cells, showed significant differences in their base levels of differentiation and activation markers with regards to their age- and sex-dependent differences, no significant changes were found in the clinical response to LDRT. However, histomorphological examinations showed that 8-week-old animals showed a significant improvement especially in the inflammatory areas, in contrast to 6-week old ones.

Conclusions: Age- and sex-dependent differences in base levels of RA progression differences seemed to have no significant impact on the clinical response after LDRT treatment. Nevertheless, especially 8-week-old animals showed a positive response to LDRT. Thus, we will further look into the molecular mechanisms behind LDRT in order to identify the respective pathways.

Supported by the BMBF (TOGETHER, 02NUK073, GREWIS, 02NUK017G, GREWIS-alpha, 02NUK050E)

Late effects of chronic low dose rate total body irradiation on the heart proteome of ApoE-/- mice resemble premature cardiac ageing

Omid Azimzadeh[1]*, Juliane Merl-Pham[2], Vikram Subramanian[3], Kateryna Oleksenko[4], Franziska Krumm[1], Mariateresa Mancuso[5], Emanuela Pasquali[5], Ignacia Braga-Tanaka III[6], Satoshi Tanaka[6], Michael J. Atkinson[4,7], Soile Tapio[4], and Simone Moertl[1]

[1] Section of Radiation Biology, Federal Office of Radiation Protection (BfS), Nauenberg, Germany;

[2] Metabolomics and Proteomics Core, Helmholtz Zentrum München, German Research Center for Environmental Health GmbH, Munich, Germany;

[3] Abboud Cardiovascular Research Center, Division of Cardiovascular Medicine, Department of Internal Medicine, Carver College of Medicine, University of Iowa, Iowa City, USA;

[4] Institute of Radiation Biology, Helmholtz Zentrum München, German Research Center for Environmental Health GmbH, Neuherberg, Germany;

[5] Laboratory of Biomedical Technologies, Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile (ENEA), Rome, Italy;

[6] Institute for Environmental Sciences (IES), Rokkasho, Aomori, Japan;

[7] Radiation Oncology, Klinikum rechts der Isar, Technical University Munich, Germany

Purpose: Recent epidemiologic studies support an association between chronic low-dose radiation exposure and the development of cardiovascular disease (CVD). The molecular mechanisms underlying the adverse effect of chronic low-dose exposure are not fully understood.

Materials and Methods: To address this issue we have investigated here, changes in the heart proteome of ApoE deficient (ApoE-/-) C57Bl/6 female mice chronically irradiated for 300 days at a very low dose rate (1 mGy/day) or at a low dose rate (20 mGy/day), resulting in cumulative whole-body doses of 0.3 Gy or 6.0 Gy, respectively. The heart proteomes were compared to those of age-matched sham-irradiated ApoE-/- mice using label-free quantitative proteomics. Radiation-induced proteome changes were further validated using immunoblotting, enzyme activity assays, immunohistochemistry or targeted transcriptomics.

Results: The analyses showed persistent alterations in the cardiac proteome at both dose rates, however, the effect was more pronounced following higher dose rate. The altered proteins were involved in cardiac energy metabolism, ECM remodelling, oxidative stress and ageing signalling pathways. The changes in PPAR, SIRT, AMPK, and mTOR signalling pathways were found at both dose rates and in a dose-dependent manner, whereas more changes in glycolysis and ECM remodelling were detected at the lower dose rate. Alterations in the proteins involved in autophagy were found only at higher dose rate.

Conclusions: These data provide strong evidence for the possible risk of cardiac injury following chronic low-dose irradiation and show that several affected pathways following chronic irradiation overlap with those of ageing-associated heart pathology. A deeper understanding of the molecular mechanisms of CVD following chronic low-dose irradiation will allow the identification of target molecules or pathways that can be used in bioassays to measure endpoints relevant to radiation risk assessment.

Differential outcomes of co-exposure to low-dose irradiation and inhalation of tungsten particles on brain toxicity parameters in rat

Théo Fréchard [1], Chloé Brizais [1], Véronique Ménard [2], Florence Bachelot [1], Céline Gloaguen [1], Frédéric Voyer [1], Virginie Monceau [1], Dmitry Klokov [1], Chrystelle Ibanez [1]*

[1] Institut de Radioprotection et de Sûreté Nucléaire, Pôle Santé Environnement-SESANE, BP17, 92262 Fontenay aux Roses, France.

[2] Commissariat à l'Energie Atomique, Institut de Biologie François Jacob, Institut de Radiobiologie Cellulaire et Moléculaire, 92262 Fontenay aux Roses, France.

Purpose: Throughout life, an individual will be exposed to various stressors that can have an impact on brain health. Its professional activities will involve specific pollutants. We propose to consider the radiological component of nuclear workers' exposome in the form of a low dose gamma irradiation combined to a chemical co-exposure. On the one hand, low dose irradiations raise a scientific challenge due to potential non-linear effects. On the other hand, tungsten is an emerging chemical contaminant linked to the operation of fusion reactors. Tungsten particles have been the subject of previous work, as particulate aerosols are the main source of contamination.

Our goal is to determine whether differential effects can be observed on brain toxicity parameters when comparing co-exposed groups to single-exposed or control groups.

Materials and Methods: Male Sprague-Dawley rats undergo a low dose gamma irradiation (50 mGy, 50 mGy.min-1) and/or a nose-only inhalation of a tungsten particulate aerosol (80 mg.m-3, 30 minutes). Neuronal integrity, cell survival, inflammation, and oxidative stress in the frontal cortex (FC) and olfactory bulb (OB) were analyzed 24 hours and 28 days after exposure.

Results: Immunohistological studies reveal significant differences when comparing co-exposed groups to control and single-exposed groups. Variations in cortical cell density and the occurrence of a neuron suffering phenotype in the FC are observed. Microglial density is modified in the co-exposed groups in FC at both time points, as well as in OB at 28 days where morphological changes are also revealed. Molecular biology analyses show an increase of antioxidant gene expression in the FC of co- and single-exposed groups compared to the control at 28 days, while no change is observed in OB.

Conclusion: These results suggest a synergy or an additivity between our two stressors and potential persistent effects. Investigations on the precise mechanisms involved are in progress.

Multigenerational effect of gestational exposure to uranium on the metabolic profile of rat spermatozoa

Stéphane Grison[1]*, Audrey Legendre[1], Dimitri Kereselidze[1], Céline Gloaguen[1], Christelle Elie[1], Benadjaoud Mohamed Amine[1], Philippe Lestaevel[1], Ljubica Svilar[2], Jean-Chales Martin[3], Maâmar Souidi[1]

[1] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), PSE-SANTE/SESANE/LRTOX, Fontenay-aux-Roses, F-92260 France

[2] C2VN, CRIBIOM, Aix Marseille Université, France

[3] C2VN, BIOMET, Aix Marseille Université, France

Purpose: In the context of increasing human exposure to low doses of ionizing radiation (IR) and other pollutants, the International Commission on Radiological Protection (ICRP) is particularly interested in the health risks to offspring and subsequent generations (TG 121). A recent experimental study in rats investigated the intergenerational effects of chronic exposure to non-toxic doses of uranium on the male reproductive system.

Materials and Methods: The offspring of rats exposed to a chronic non-toxic dose of uranium were followed for two generations. Several sperm parameters were measured and complemented by analyses of DNA methylation levels and metabolomic profiles of epididymal spermatozoa.

Results: Sperm morphology was affected over three generations with no change in concentration. The first F1 generation with the observed F1 pregnancy rate seemed to be the most affected. The epigenetic profile of sperm DNA methylation is altered only for the F2 generation (Legendre et al., 2019). Finally, the epididymal sperm metabolome varies significantly between generations. The tryptophan and nicotinate-nicotinamide pathways, previously identified in the kidney (Grison, Habchi, et al., 2022; Grison et al., 2019)), are the most discriminated, as well as others more specific to the reproductive system, such as those involved in sperm motility, energetics, steroidogenesis, and cell growth (Grison, Legendre, et al., 2022).

Conclusions: These experimental results demonstrate that chronic exposure to non-toxic doses of uranium can have multigenerational effects on the male reproductive system at the molecular and phenotypic levels for at least two generations. They provide new data useful for radiation protection to assess and prevent risks to future generations.

A mathematical formulation of Elkind recovery

Takahiro Wada [1]*, Tetsuhiro Kinugawa [2], Yuichiro Manabe [2]
[1] Kansai University, Suita, Japan
[2] Osaka University, Suita, Japan

Purpose: The biological effects of radiation are dose-dependent, but even when the dose is the same, the effects tend to decrease as the dose rate decreases. This is called the dose-rate effect. The reason for this is thought to be the recovery from damage caused during irradiation. In this paper, Elkind recovery from sublethal damage is revisited from the viewpoint of mathematical modelling.

Materials and Methods: Sublethal damage (SLD) can be understood by assuming that multiple factors (targets) are involved in cell death. When the number of targets is N, it is assumed that the cell does not die and continues to have the ability of colony formation while the number of damaged factors is less than or equal to N-1. We formulate the N-target-1-hit model in terms of simultaneous differential equations with time as a variable, where each step corresponds to the cells in which specific targets have been hit. The recovery effect is then introduced as a recovery term.

Results: Because we formulate the equations as functions of time, it is straightforward to calculate the fractionated irradiation or continuous low-dose-rate irradiation. The interval between the irradiations and the number of fractionation can be chosen freely. By solving the differential equation numerically, we showed that the essential features of Elkind recovery were reproduced, such as the reappearance of the shoulder in survival rate, the increase of the survival rate with the number of fractionation, the dependence of the recovery on the interval time and so on.

Conclusions: We have formulated a mathematical model which shows essential features of Elkind recovery. Our model incorporates radiation-induced damages and their recovery, which allows us to discuss the dose-rate effects. We believe that the mathematical model is very powerful in studying the dose-rate dependence of the effects of radiation.

Study of potentially renal cancerous effect of uranium in genetically-engineered mouse models: UKCAN project

Laurie De Castro[1]*, Olivier Claude[1], Myriam Brisset[1], Clara Gillot[1], Annabelle Manoury[1], Amandine Sache[1], Frédéric Voyer[1], David Suhard[1], Christelle Elie1, Virginie Monceau1, Céline Bouvier-Capely1, Chrystelle Ibanez1, and Yann Guéguen1
[1] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), PSE-SANTE/SESANE, BP17, 92262 Fontenay aux Roses Cedex, France.

Exposure to uranium compounds can occur in nuclear fuel processing, military activities, and environmental exposure. Uranium, a nephrotoxic radioactive element which accumulates preferential in the kidneys, his potential carcinogenic remains controversial. To elucidate the potential association between uranium exposure and the risk of renal cancer, we have used genetically-engineered mouse models (GEMM) specifically designed to simulate his development. These GEMMs are mutated in key kidney cancer predisposition genes (Vhl and Pbrm1, or Tsc2), which mimic genetic alterations observed in human kidney cancer cases.

The objectives of our study are:

- To evaluate the benign and malignant renal tumor lesions development as a function of time and dose following uranium exposure : ultrasonography were used throughout the animal's lifespan and postmortem analyses thanks to histological and immunohistological methods provides details characterization of the tumor lesions.
- To elucidate the underlying biological mechanisms (initiation, promotion, and proliferation) in renal oncogenesis and carcinogenesis associated with human exposure byclinical biochemistry, molecular biology and protein-array techniques.
- To analyze the concentration of uranium in targets organs and excretory samples using ICP-MS techniques.

Histological analyses of our preliminary studies showed delineated areas comprising various tumor types within the GEMMs. By using immunostaining of clinically relevant proteins (CA-IX, CK-7), we can identify and quantify specific subtypes of tumor within renal tissue. This approach allows for the correlation of histological with ultrasound imaging data, in order to follow endogenous renal tumors exceeding 200µm, and to characterize their type, number, and volume. Moreover, the screening of genes and proteins using RT-qPCR and protein-array enables us to select various targets involved in renal carcinogenesis and in the mechanisms of uranium toxicity.

These findings will enable us to identify the most relevant parameters for the experimental evaluation of the potential link between uranium exposure and the development of kidney cancer in our GEMMs.

Investigating transcriptional and translational responses to low-dose ionising radiation: towards an integrated low-dose response model

Sarah Eivers [1], Melissandre Gomot [1], Arthur Thomas-Joyeux [1], Dmitry Klokov [1], Guillaume Vares [1]*
[1] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Fontenay-aux-Roses, France

The cellular response to ionising radiation, either naturally occurring or otherwise, involves an intricate and coordinated chain of events. These events encompass activation of DNA damage response and DNA repair pathways via post-translational modification, regulation of transcription and translation, defining the health relevant outcomes such as apoptosis, genomic instability or proliferation. The precise nature and interactions within the cellular response to ionising radiation largely depend on the damage incurred. Although the biological response and effects of high doses of ionising radiation are well documented, less is known about responses to low-dose exposure.

Given the potential implications for human health, we aimed at investigating the regulation and coordination of transcriptional and translational events and how they relate to DNA double-strand break repair after exposure to low-dose ionising radiation using biologically relevant in vitro models, namely human-derived fibroblast cell lines. Following a combination of molecular and bioinformatic lines of interrogation including RNA-seq, ribo-seq, mRNA stability analysis, m6A RNA methylation, ribopuromycylation and γH2AX foci analysis, we present observed changes as a

function of time in coordinated transcriptional, post-transcriptional, translational and DNA double-strand break repair pathway responses to low doses (20 mGy and 100 mGy) of γ-rays. Taken together, these data help to decipher early molecular responses to low-dose radiation within the context of delayed health related outcomes, such as genomic instability, and represent the first steps to building an integrated low-dose response model.

Dose rate-dependent cellular effects of low doses in AHH-1 lymphoblasts

Milagrosa López-Riego [1]*, Pamela Akuwudike [1], Michal Marczyk [2,3], Joanna Polańska [2], Lovisa Lundholm [1], Andrzej Wojcik [1,4]
[1] Centre for Radiation Protection Research, Department of Molecular Biosciences, The Wenner-Gren Institute, Stockholm University, Sweden
[2] Department of Data Science and Engineering, Silesian University of Technology, 44-100 Gliwice, Poland
[2] Yale Cancer Center, Yale School of Medicine, New Haven, Connecticut, USA
[4] Institute of Biology, Jan Kochanowski University, Kielce, Poland

Purpose: Understanding the relationship between low doses of ionizing radiation (IR), dose rate, and biological effects requires radiobiological experiments to circumvent epidemiological data uncertainties. Our results contribute to improved understanding of low dose and dose rate cellular effects.

Materials and Methods: Radiation-induced early and/or late effects on global gene expression, cell growth, viability, survival and chromosomal aberration frequency were investigated in AHH-1 lymphoblasts exposed to 0-100 mGy at 1.6-12 mGy/h or 0.35 Gy/min.

Results: RNA-sequencing revealed minor global gene expression differences between dose rates. Several histone genes were upregulated 5 h after 1.6 and 12 mGy/h exposure. DNMT1 and CDK18 were additionally up- and downregulated, respectively, at 12 mGy/h. LYRM1 was downregulated 5 h after 8 mGy/h. Numerous differentially expressed genes were detected 21 days after acute exposure, including upregulated BRCA2, CDK11A and EZH1 and downregulated EGLN3, GLRX and LGALS3. H4C8 was downregulated at 1.6 and 12 mGy/h, while SH3BP2 was upregulated with dose rate on day 21. Many pathways were altered, but few global differences between dose rates were identified on either pathway or function level activation. Downregulated chronic myeloid leukaemia-associated genes were among the 14 affected pathways 5 h after 1.6 mGy/h. Moreover, 6 functions, including stress response and apoptosis, were downregulated. At all dose rates, 25-100 mGy-exposed AHH-1 cells presented trends of reduced viability and survival fraction. After acute exposure, cell growth (from day 17) and chromosomal aberration frequency (at day 30) were statistically significantly higher than control. A dose rate effect was evident for chromosomal aberrations, where 100 mGy delivered chronically at 1.6 mGy/h displayed reduced frequencies compared to acute exposure, yet with a tendency towards increased aberrations than control.

Conclusions: Altogether, these results show the potential cytotoxic effect of low doses in AHH-1 cells and a dose rate effect at the transcription and cytogenetic levels.

Mathematical modelling of low dose hyper-radiosensitivity and induced radioresistance

Szabolcs Polgár[1,2]*, Balázs Madas[2,3]
[1] Doctoral School of Physics, ELTE Eötvös Loránd University, Budapest, Hungary
[2] Environmental Physics Department, Centre for Energy Research, Budapest, Hungary
[3] Department of Physical Chemistry and Materials Science, Budapest University of Technology and Economics, Budapest, Hungary

Purpose: The surviving fraction of cells decreases exponentially with the increase of the absorbed dose at high doses. At low doses, however, experiments show that in many different cell lines the surviving fraction differ from this due to the effects of hyper-radiosensitivity and induced radioresistance. The result is a function that starts steeper and after a local minimum starts to increase to a local maximum as the dose increases before following the exponential decrease at higher doses.

The aim of this study was to test if the hypothesis of minimum mutation load can describe both hyper-radiosensitivity and induced radioresistance at low doses. Here this principle means that the most damaged cells in a vicinity use apoptosis to reduce the mutation rate in the tissue.

Methods: To test this hypothesis a mathematical model was developed. For the model validation a database was used, consisting various experimental data featuring low dose hyper-radiosensitivity. The model has been developed in Python. A total of 600 cells were placed randomly in a circle with a given radius. The cells are able to communicate their DNA damage by a signal, its concentration following normal distribution, centered on the cell. The DNA damage of the cells follow Poisson distribution for any given dose.

Results: The fit parameters for the model were acquired by fitting with the Nelder-Mead method to the experimental data. The parameter calculation consisted first a preliminary calculation (using the starting slope and the local minimum of each dataset) to acquire the initial parameters, then a two dimension fit with the Nelder-Mead method was calculated to reach the best values for them. The results then were evaluated and compared to the induced repair model where possible (where there was a fit in the original article), this comparison shows a similarly good fit to the data.

Use of intestinal organoid models to study low-dose radiation effects

Matthew Flegal [1], Holly Laakso [1]*
[1] Canadian Nuclear Laboratories, Chalk River, ON, Canada

Purpose: The intestine is a highly regenerative tissue, with regeneration to the epithelium occurring every 5 to 7 days. This regeneration allows for rapid repair from tissue damage resulting from various internal and external factors, such as ionizing radiation. As a radiosensitive organ, exposure of the intestine to high-doses of radiation (HDR; defined as absorbed doses of 100 mGy or higher) causes characteristic gastrointestinal (GI) syndrome. The effects of low doses of radiation (LDR) on the GI tract, however, are less defined and yet are an important component of understanding radiation risk.

Materials and Methods: In this study, the effects of LDR on intestinal regeneration and cellular pathways will be examined using 3D intestinal organoid models. Intestinal organoids were developed at CNL from extracted murine intestinal stem cells and differentiated using previously developed methodologies. Irradiation and subsequent cell profiling methods were developed in this study. The differentiated organoids were treated with acute exposure to low doses of gamma-rays, 10 mGy and 100 mGy, including sham-treated (0 mGy) and high-dose (2,000 mGy) controls.

Results: Organoid cultures were imaged using immunocytochemistry techniques to examine key cellular markers, such as Lgr5 and CA1. As radiation has been shown to alter DNA methylation patterns, epigenetic profiles of exposed organoids will be examined using DNA and histone methylation sequencing techniques. Lastly, ongoing work at CNL is to develop human induced pluripotent stem cell (hPSC)-derived organoids to corroborate and expand on findings in the murine organoids.

Conclusion: Overall, this work will increase understanding on the radiation response of the intestine, provides the opportunity to examine LDR effects on clinically-relevant, human intestinal cells, and offers a novel methodology to examine individual radiosensitivity.

Use of multi-lineage differentiating stress enduring cells (MUSE cells) in an irradiated mouse model treated with senolytic agent

Domenico Aprile [1]*
[1] University of Campania "Luigi Vanvitelli"

Purpose: Low and medium doses of ionizing radiation (X-rays) induce premature senescence. Cell senescence, in particular stem cell senescence, is a highly negative event that may compromise tissue renewal and function. The aim of this ongoing research is to reduce senescence by treatment with a senolytic agent (ABT263) after IR exposure. Senolytic drugs selectively induce apoptosis in senescent cells, resulting in their elimination and subsequent replacement by adult stem cells. However, senolytics may damage healthy cells, including stem cells. In order to reduce this effect, MUSE (MUlti-lineage differentiating Stress Enduring cells) cells could help the endogenous stem cells. MUSE cells (SSEA3+) are self-renewable, express pluripotent genes, and can differentiate into triploblastic cell phenotypes from a single cell. They can home within damaged tissue, suggesting their potential contribution to tissue and organ repair.

Materials and Methods: 12-week-old male C57BL/6J mice were irradiated with X-rays (100 mGy total body), treated with the senolytic ABT263 for two weeks and then transplanted with MUSE cells.

Cellular senescence is correlated with the acquisition of the senescence-associated secretory phenotype (SASP), characterized by the secretion of inflammatory cytokines and other factors. For this reason, three months after transplantation, the mice were sacrificed and serum samples were collected. By sandwich enzyme-linked immunosorbent assay (ELISA), we investigated two of the most prominent proinflammatory cytokines of the SASP: interleukin-6 (IL-6) and tumor necrosis factor-α (TNF-α).

Results: We noted that both TNF- α and IL-6 levels decreased significantly in irradiated mice after treatment with ABT263 and, interestingly, decreased even more in the group of mice transplanted with MUSE cells.

Conclusions: From this preliminary analysis, it can be assumed that both treatments with the senolytics ABT263 and MUSE cells reduce the inflammatory state of IR-irradiated mice and probably also induce the elimination of senescent cells.

Viewpoint on the use of the Linear No-Threshold (LNT) model in radiological protection

Dominique Laurier[1]*, Yann Billarand[1], Dmitry Klokov[1], Klervi Leuraud[1]
[1] Institute for Radiological Protection and Nuclear Safety (IRSN), Fontenay-aux-Roses, France

Purpose: The linear no-threshold (LNT) model, introduced into the radiological protection system in 1966. is still hotly debated today. Based on a recently published article (https://iopscience.iop.org/article/10.1088/1361-6498/acdfd7), the presentation will summarise recent results in radiobiology and epidemiology and will discuss their impact on the use of the LNT model in assessing the risks of cancer associated with low-dose low-LET ionising radiation.

Results: The scientific results published in radiobiology and epidemiology have clearly strengthened our scientific knowledge of low-dose cancer risks. In radiobiology, early stages of mutational carcinogenesis are considered to play a key role in carcinogenesis, with linear responses at doses as low as 10 mGy.

Today, some non-mutation mechanisms clearly appear as non-linear, but their impact on the overall carcinogenesis process remains difficult to assess. In epidemiology, excess cancer risk is observed at dose levels of 100 mGy or less. Some recent findings suggest that for some cancers non-linear dose relationships may exist, but overall the LNT model does not seem to overestimate the risks of cancer at low doses. Current results, in radiobiology or epidemiology, do not demonstrate the existence of a dose threshold below which the risk of radiation-induced cancer would be zero. Uncertainties remain, but if such a dose threshold existed, it could not be greater than a few tens of mGy.

Conclusions: Recent scientific knowledge does not call into question the use of the LNT model to assess cancer risks associated with exposure to ionizing radiation. The use of this model seems reasonable from a scientific point of view. Today, no other dose-response model seems to be more appropriate or justified for radiological protection purposes.

Effects of low doses of gamma irradiation (137-Cesium) on the development of cardiovascular pathologies in the heart-lung axis

F. Saliou*[1] ; F. Bachelot [1] ; N. Suffee[2] ; N. Mougenot[2] ; F. Atassi[2] ; V. Ménard[3]; J.Vetel[1], D. Daydé[4] ; D. Klokov [1] ; S. Nadaud[2] ; E. Morel[4] ; V. Monceau[1]
[1] SESANE / LRTOX, Institut de Radioprotection et de Sûreté Nucléaire - IRSN, Fontenay-aux-Roses, France.
[2] UMR 1166, unité de recherche sur les maladies cardiovasculaires et métaboliques, INSERM, Paris, France.
[3] DRF, iRCM, Platforme d'irradiation, CEA Fontenay-aux-Roses, France.
[4] UMR-S 1180, Signalisation et physiopathologie cardiovasculaire, bâtiment Henri Moissan, faculté de pharmacie, Université Paris-Saclay, Orsay, France.

Populations living in contaminated areas after nuclear accidents are exposed to low doses (<0.5Gy) radiation whose cardiovascular consequences remain controversial. The aim of this study is to examine whether exposure to low doses of gamma radiation can induce remodelling of cardiac and pulmonary tissues and potentially identify signalling pathways involved in potential long-term cardiovascular disease (CVD) after exposure to Cesium 137 (137Cs). We exposed C57Bl/6J male mice to whole-body single external gamma ray doses ranging from 0.05 to 2Gy (137Cs). The heart function was examined by ultrasound doppler, signalling pathways by Western-Blotting (WB) and fibrosis by Sirius red staining. At 3months post-IR, WB analysis showed a significant decrease in the expression of proteins involved in cardiac conduction (Connexin43 at 0.25Gy in the left ventricle; $p<0.001$) and a significant increase of Synapsin (at 0.5 and 2Gy in the atriums and 0.25Gy in the left ventricle; $p<0.01$) which is playing a role in the propagation of the nerve impulse. This proteins expression modulation may lead to disturbances in cardiac contraction which seems to be confirmed by a reduced ejection fraction observed from 0.25 to 2Gy (60% irradiated vs 70% control; $p<0.05$), suggesting a cardiac function alteration without modification of the ventricular wall thickness. At the tissue level, fibrosis was observed at 0.1 and 0.5Gy ($p<0.05$). In addition, an increase in atrial fibrillation time (from 0.25 to 2Gy; $p<0.05$) after stimulation, suggesting susceptibility to a rhythm disorder. Finally, we observed a significant increase in right ventricle systolic pressure (all doses, $p<0.05$) revealing pulmonary hypertension induction associated with neo-muscularization of small pulmonary vessels (0.5Gy; $p<0.05$). To conclude, low-doses exposure (<0.5Gy) showed for the first time molecular and functional alterations that generate CVD. This study could be used as a prospective human follow-up study for the development of long-term CVD bioindicators in exposed cohorts.

Dose assessment of the radiation effects of liquid discharges from the Krško NPP supported by the 3D numerical modelling

Benjamin Zorko [1*], Rudolf Rajar[5], Matija Škrlep [3], Borut Breznik [4], Matjaž Četina [5], Gregor Omahen [3], Andrej Širca [6], Matjaž Stepišnik [2]
[1] Department for low and medium energy physics, Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia
[2] Radiation Protection Unit (SVPIS), Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia
[3] Institute of Occupational Safety, Pot k izviru 6, 1260 Ljubljana-Polje, Slovenia
[4] Krško Nuclear Power Plant, Vrbina 12, 8270 Krško, Slovenia
[5] Faculty of Civil and Geodetic Engineering, University of Ljubljana, Jamova cesta 2, 1000 Ljubljana, Slovenia
[6] IBE d.d., Hajdrihova ulica 4, SI-1001 Ljubljana, Slovenia

A new methodology for assessing the effects of liquid discharges under normal operation of the Krško NPP on the human and non-human biota has been proposed. The new methodology was developed in the framework of the technical specification Dose calculation and dilution modelling of a run-of-river Brezice Hydro Plant Accumulation No. TO.RZ-5/2020. All legislative acts and international guidelines and recommendations have been taken into account.

For the theoretical prediction of mixing and dilution in the Sava River, the three-dimensional hydrodynamic transport model PCFLOW3D, developed at the Faculty of Civil Engineering and Geodesy of the University of Ljubljana (UL FGG) in cooperation with colleagues of the company IBE (IBE d.d.), was used. The hydrodynamic model simulates the Sava River flow in the Brežice HPP's reservoir. The transport-dispersion module then simulates the transport and dispersion of effluents over this area. Based on the simulations for different scenarios or flow rates of the Sava River, the dilution coefficients in different layers in the river's column were estimated. The outcomes of model calculations can be considered reasonably accurate for the assumed input data.. For the estimation of monthly concentrations of radionuclides in the river, the following assumptions have been made:

- Sava River water is sampled continuously;
- the constant flow of the Sava River in the Brežice HPP reservoir at the time of each discharge;
- the impact of a discharge is unconditionally attributed to the month in which the discharge starts;
- due to time averaged values of measured data the accuracy of the results (to an order of magnitude) was regarded as acceptable;

Software (DOSENEK), developed in the Microsoft Visual Studio integrated development environment, was developed to estimate effective doses to representative persons and reference animals and plants.

Latest developments and highlights from the research project RadoNorm

Warren A. John [1*], Ulrike Kulka [1] on behalf of RadoNorm consortium
[1] Federal Office for Radiation Protection (BfS), Munich, Germany

Purpose: RadoNorm aims to reduce scientific, technical and societal uncertainties in the assessment of risks from low-dose ionising radiation with a special focus on radon and naturally occurring radioactive material (NORM). This talk will present RadoNorm's latest developments.

Materials and Methods: 57 European partners contribute to five scientific work packages (WPs). These focus on: understanding exposure scenarios; improving dose coefficients and dosimetry models for epidemiology; understanding the biological effects of radon and NORM exposure; assessing mitigation strategies in dwellings and the workplace; elucidating the societal aspects of radon and NORM.

Results: To better understand radon and NORM exposure situations, a tool for characterisation of NORM sites has been developed, which has made it possible to identify case-study sites for modelling NORM transfer in the environment, and test remediation strategies. An assessment of underground workplaces has shed light on easier exposure measurement techniques and also developed models for decay of radon and thoron to improve radon monitors. Radon mitigation technologies have been rated in terms of their environmental impacts.

Dose-distribution in lungs have been quantified and provide realistic exposure conditions for in vitro laboratory experiments, helping identify biomarkers for carcinogenesis and develop adverse outcome pathways for radon exposure. Dosimetry calculations revealed smoking reduces radon progeny dose to lungs, and epidemiological studies also revealed surprising connections between radon and lung cancer.

Efforts are underway to map people's behaviour towards radon and understand what motivates people to test and remediate against radon and NORM. Citizen science projects and Europe-wide surveys have been useful tools in understanding risk perception. Communication tools are also being tested among various target groups.

Conclusion: Based on a highly motivated consortium and the engagement of various stakeholders, 23 scientific publications and 15 deliverables have been thus far accomplished and these have established RadoNorm as a thriving research project.

Characterisation of a novel calibration chamber for radioactive aerosol detectors

Shamil S Galvez Febles [1]*, Veikko Oeser [2], Kerstin Hürkamp [1], Werner Rühm [1]
[1] Federal Office for Radiation Protection, Ingolstädter Landstraße 1, 85764 Oberschleißheim, Germany
[2] SARAD GmbH, Wiesbadener Straße 10, 01159 Dresden, Germany

Purpose: In the nuclear medical palliative treatment of metastatic, castration-resistant prostate cancer, innovative targeted alpha therapies with intravenous injection of Ra-223 and Ac-225 are applied. Patients may excrete these radionuclides and their daughters, e.g. through their breath, posing a radiation exposure to clinical staff. The aim is to measure the activity concentration of the radionuclides in the room air of clinical treatment rooms with an active semi-conductor alpha detector. For the calibration, a suitable calibration chamber was developed and tested to achieve a homogeneous aerosol deposition on the filter detectors, which is representative for the composition of human breath.

Materials and Methods: An aerosol with a size distribution comparable to human breath was produced with an aerosol generator using 0.9% NaCl. Varying the flow rates and position at the outlet, the time-dependent homogeneity of the aerosol field in the calibration chamber was characterised with an electrical low-pressure impactor for online measurements of aerosol concentrations with sizes between 6 nm and 10 µm.

Results: By increasing the compressed air flow rate, a significant, non-proportional decrease in the aerosol concentration due to dilution effects can be observed. Spatial homogeneity was determined at the outlet of the aerosol tube. Concerning time stability, there is an overall increase in the aerosol concentration and size, and it especially affects particles >100 nm, which means moisture accumulates inside the tube causing particle growth by condensation due to their hygroscopic nature.

Conclusions: The experiments focused on the characterisation of a novel calibration chamber for radioactive aerosol detectors under pre-defined lab conditions. The results showed that the produced aerosol is homogeneous and representative for patient's breath, though it is not stable over time. This effect will be overcome by applying a correction factor.

Radon hazards. Validation of dose conversions based on measurements in Polish operating and show underground mines

Krystian Skubacz [1]*, Katarzyna Wołoszczuk 2, Agata Grygier 1, Krzysztof Samolej 1
[1] Central Mining Institute, Silesian Centre for Environmental Radioactivity, Plac Gwarków 1, 40-166 Katowice, Poland; kskubacz@gig.eu
[2] Central Laboratory for Radiological Protection (CLOR), Warsaw, Poland

In Poland, issues related to radiological protection in underground mines are included in the general system of radiological protection. The basic principles, such as exposure limits, reference levels, classification of workers and workplaces, etc., are regulated by the Atomic Law and relevant executive regulations. According to these requirements, to evaluate the effective dose based on PAEC measurement the dose coefficients recommended by ICRP Report 65 should be used as 1.4 mSv/(mJ×h×m-3) and 0.5 mSv /(mJ×h×m-3) for radon and thoron respectively.

The presentation compares dose coefficients recommended by Polish regulation as well as the new one recommended by ICRP 137 with actual dose conversions evaluated based on the results of measurements taken in the underground workings of active and tourist mines. In these facilities, the aerosol size distributions of ambient aerosols at key workplaces and the distributions of radioactive aerosols containing radon decay products were determined. Radon concentrations and alpha energies of radon decay products were also measured in the mines to determine equilibrium factor as well as unattached fraction that measured in active coal mines ranged from 0.01 - 0.23, in tourist mines from 0.09 - 0.44, and in the tourist cave it was 0.43.

The evaluated dose conversion varied between 2 - 7 mSv/(mJ×h×m-3). The results showed significant discrepancies between the effective doses determined from current recommendations and local regulations, and those determined from direct measurements of parameters affecting exposure.

Scientific Session 5B: Education, Training, and Citizen Science

Building European Nuclear Competence through continuous Advanced and Structured Education and Training Actions

Tom Clarijs [1], Michèle Coeck [1]*, Roberta Cirillo [2]
[1] Belgian Nuclear Research Centre SCK CEN, Mol, Belgium
[2] European Nuclear Education Network ENEN, Brussels, Belgium

Development, construction, operation, decommissioning, waste management and oversight of nuclear and radiological facilities require personnel with excellent knowledge, skills and competences: professionals that are equipped to work in multidisciplinary and competitive environments. A competent workforce remains the basic enabler of safe operation of existing and development of advanced facilities.

The ENEN2plus project is the largest Education and Training project in the nuclear field, including radiation protection, and brings together 51 institutions from 20 countries. Its objectives are set in a broad range of nuclear and radiological disciplines, such as: radiation protection, waste and disposal, decommissioning, medical applications, nuclear technology, fusion, space applications, integration of social sciences and humanities in nuclear, etc.. Its activities involve :

- Analysing the needs of human resources in the nuclear and radiological sector
- Informing and attracting new talents to the nuclear field
- Enhancing competences by continuous E&T programmes
- Developing sustainable vocational training programs and networks
- Establishing a successful mobility scheme for nuclear talents
- Internationalization and stakeholders involvement

This presentation will highlight the relevant activities for the radiation protection community, from the outreach activities towards potential young talents which could be inspired into a STEM career in radiation sciences, towards the professional requiring advanced education and training activities to keep up with the scientific and technological developments. It will also inform about the mobility programme which could be of interest for the research community allowing the participation to conferences and training courses, as well as internships (including thesis work) and research exchanges.

ENEN2plus is a project funded by the European Union. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Educating the people for understanding radiation risk: the impact of dose-response models

Radu A. Vasilache[1*]
1 Canberra Packard SRL, Bucharest, Romania

Given the current trend for the reduction of CO2 emissions, there are more and more countries which are turning towards nuclear energy as a reliable and clean source of electricity. Even in the current context, however, there are countries where an extremely strong public opposition to nuclear, bordering the irrational, still exist. The answer to why such an opposition exists is the low understanding about radiation risks and how nuclear industry works, and this is mainly due to rather poor communication and education of the public on that matter.

So, how are we to educate the public about the real risks of radiation? First, stop using the LNT model for estimating and communicating risks. Besides the fact that, by now, there is an important body of evidence that suggest that this model is highly inaccurate, the message conveyed by this model is quite threatening for the general public: every dose carries a risk. Second, use comparisons between radiation risks and other risks incurred by the general public o the daily basis. Third, never try to hide any data – sooner or later this will backfire. Fourth, make wise use of "citizen science".

The presentation explores the way in which the perception of risk generated by the LNT gives shapes the public response to nuclear energy production. We also show that we are reaching an inflection point: faced with the energy price crisis, a short study across various media seems to indicate a change in perception and an increased acceptance of the nuclear, despite the fierce opposition still existing in some countries. We believe that a clear, fact based and candid communication that does neither overestimate nor underestimate the risks will lead to a better education of the public and a wider acceptance of the civil use of nuclear energy.

Radiography and medical student perceptions of radiation protection teaching using three-dimensional virtual reality simulation

Jaka Potočnik [1]*, Michelle O'Connor [1], Louise Rainford [1]
[1] University College Dublin School of Medicine, Ireland

Purpose: Virtual reality (VR) simulation-based learning is increasingly used in healthcare education to prepare students for clinical practice. This study investigates radiography and medical students' experience of learning radiation safety in a simulated interventional radiology (IR) suite.

Materials and Methods: Medical (n=35) and radiography (n=100) students were introduced to 3D VR radiation dosimetry software designed to improve the learners' understanding of radiation safety in IR. Dean of Medicine approval was attained to involve students and an institutional waiver from full ethical review was confirmed. All students were introduced to the VR system virtually over Zoom and this was then followed up by time in the VR suite. Radiography students aligned this learning activity to clinical placements, and they completed a formal low stakes summative assessment using the VR. An online questionnaire containing Likert questions and open-ended questions was used to gather student feedback on the perceived value of VR-based radiation safety education. Descriptive statistics and Mann-Whitney U tests were used to analyse Likert-questions. Open-ended question responses were thematically analysed.

Results: A survey response rate of 49% (n=49) and 77% (n=27) was obtained from radiography and medical students, respectively. Most respondents (80%) enjoyed their 3D VR learning experience, favouring the in-person VR experience to online VR. 73% felt that VR learning enhanced their confidence across all relevant learning outcomes. Whilst confidence was enhanced across both cohorts, VR learning had a greater impact on confidence levels amongst medical students with respect to their understanding of radiation safety matters ($U=375.5$, $p<0.01$). 3D VR was deemed a valuable assessment tool.

Conclusions: Radiation dosimetry simulation-based learning in the 3D VR IR suite is perceived to be a valuable pedagogical tool by radiography and medical students and enhances curricula content.

Education and training in radiation protection in Europe: results from the EURAMED Rocc-n-Roll project survey

Joana Santos[1] , Shane Foley[2], Jonas Andersson[3], João Paulo Figueiredo[1], Christoph Hoeschen[4], John Damilakis[5], Guy Frija[6], Francisco Alves[1], Katrine Riklund[7], Louise Rainford[2], Ursula Nestle[8,9], Jonathan McNulty[2], Klaus Bacher[10], Monika Hierath[11] and Graciano Paulo[1]*
[1] Instituto Politécnico de Coimbra, ESTESC - Coimbra Health School, Medical Imaging and Radiotherapy, Rua 5 de Outubro, S. Martinho Do Bispo, 3046-854 Coimbra, Portugal.
[2] Radiography and Diagnostic Imaging, Schoolof Medicine, University College Dublin, Dublin, Ireland.
[3] Department of Radia- tion Sciences, Radiation Physics, Umeå University, Umeå, Sweden.
[4] Institute of Medical Technology, Otto-von-Guericke University Magdeburg, Magdeburg, Germany.
[5] School of Medicine, University of Crete, Iráklion, Crete, Greece.
[6] Uni- versité de Paris, Paris, France.
[7] Department of Radiation Sciences, Diagnostic Radiology and Umeå Centre for Functional Brain Imaging, Faculty of Medi- cine, Umeå University, Umeå, Sweden.
[8] Department of Radiation Oncology, Kliniken Maria Hilf, Mönchengladbach, Germany.
[9] Department of Radiation Oncology, University Hospital Freiburg, Freiburg, Germany.
[10] Division of Medi- cal Physics, Department of Human Structure and Repair, Ghent University, Ghent, Belgium.
[11] European Institute for Biomedical Imaging Research (EIBIR), Vienna, Austria.

Purpose To analyse the existing radiation protection (RP) education and training (E&T) capabilities in the European Union and identify associated needs, problems and challenges.

Method An online survey was disseminated via the EURAMED Rocc-n-Roll consortium network and prominent medical societies in the field of radiological research. The survey sections analyse the RP E&T during undergraduate, residency/internship and continuous professional development; RP E&T problems and legal implementation. Differ- ences were analysed by European geographic regions, profession, years of professional experience and main area of practice/research.

Results The majority of the 550 respondents indicated that RP topics are part of undergraduate curricula in all courses for their profession and country (55%); however, hands-on practical training is not included according to 30% of the respondents. The lack of E&T, practical aspects in current E&T, and mandatory continuing E&T were considered the major problems. The legal requirement that obtained higher implementation score was the inclusion of the prac- tical aspects of medical radiological procedures on education (86%), and lower score was obtained for the inclusion of RP E&T on medical and dental school curriculums (61%).

Conclusions A heterogeneity in RP E&T during undergraduate, residency/internship and continuous professional development is evident across Europe. Differences were noted per area of practice/research, profession, and Euro- pean geographic region. A large variation in RP E&T problem rating was also obtained.

Scientific Poster Exhibition

Computation and modelling for radiation protection and dosimetry

Random Threshold Model: A Low-dose Radiation-induced Risk Assessment Approach Considering Individual Susceptibility to Cancer

Hisanori Fukunaga [1]*, Takashi Yanagawa [2]
[1] Faculty of Health Sciences, Hokkaido University, Japan
[2] Biostatistics Center, Kurume University, Japan

Purpose: The linear no-threshold (LNT) model, which has long been used for radiation protection purposes, was developed based on the assumption that exposure to even a small amount of radiation may cause cancer. However, although there is variation in susceptibility to cancer among individuals, the LNT model does not adequately consider radiosensitive subgroups. Especially in the low-dose range, where the contribution of differences in radiosensitivity would be greater, a more valid risk assessment would be needed to replace the LNT model. Thus, the objective of this study is to establish a novel risk assessment model that takes radiosensitivity into account.

Materials and Methods: We represent susceptibility to contract cancer by radiation exposure by means of the threshold of a dose-response function, introduce a random threshold (RT) model to represent the variation of the susceptibility, and then propose a new method for determining safe dose limits to protect susceptible individuals to contract cancer by radiation exposure. In this study, we applied the developed method to protect the hazard of the any rare ATM missense variant carriers predicted to be deleterious to induce cancer.

Results: The proposed safe dose limits were remarkably smaller than those safe dose limits calculated from the LNT model. For cancer risk associated with low-dose radiation exposure, the contribution of radiosensitivity cannot be ignored, thus the RT model would be more suitable for risk protection instead of the LNT model.

Conclusions: Our proposed approach with the RT model could be widely applicable for risk assessment of exposure to not only low-dose radiation but also other external stresses such as environmental pollutants.

Development of Physical Counterparts for Adult Mesh-type Reference Phantoms

Han Sung Kim [1]*, Young-su Kim [2], Jae Seok Kim [1], Jaeryong Yoo [1]
[1] Korea Institute of Radiological and Medical Sciences, Seoul, Republic of Korea
[2] Korea Atomic Energy Research Institute, Daejeon, Republic of Korea

Purpose: Physical human phantoms serve crucial purposes across many applications, such as experimental radiation dosimetry, radiodiagnosis, radiation protection, and medical imaging. However, only a few physical phantoms are commercially available. Moreover, they do not represent the Reference Person, which hinders the estimation of dose quantities defined for the Reference Person. Recently, ICRP Publication 145 introduced Adult Mesh-type Reference Computational Phantoms (MRCPs) in mesh format, thereby facilitating the utilization of 3D printing techniques. The objective of this study is to develop physical counterparts of MRCPs for measurement through 3D printing.

Materials and Methods: The constructed phantoms comprised three distinct tissue-equivalent materials: soft tissue, lung, and bone. In the pursuit of appropriate tissue-equivalent materials, two criteria were considered: physical density and effective Z number. Both 3D printing technology and the casting method were employed in phantom construction. Specifically, soft tissue and lungs were produced using 3D printing, while the casting method was employed for bone fabrication.

Results: The physical phantoms included almost all organs for measurement. Tissues or organs within the phantoms were distinguishable due to the use of silkscreen colors. The torso of the phantoms was sliced at intervals of 2.5 cm, resulting in 38 and 35 slices for male and female phantoms, respectively. Dosimeter holes, in which a glass dosimeter can be inserted, were placed at intervals of 3 cm in grid patterns. To validate the physical phantoms, measurements were performed using a Co-60 source with an activity of 77.8 Ci, and corresponding Monte Carlo simulation were conducted using the MCNP code. The absorbed doses for representative organs were generally in good agreement, with the effective dose difference for male being only 1%.

Conclusions: Our physical phantoms are believed to complement the existing MRCPs and have the potential to be utilized as a comprehensive set in relevant applications.

Bayesian methods for biological dosimetry in case of non-homogeneous exposures with two doses

Xenia Behr*[1], David Endesfelder[1], Ursula Oestreicher[1]
[1] Department of Effects and Risks of Ionising and Non-Ionising Radiation, Federal Office for Radiation Protection, Neuherberg, Germany

Purpose: In many radiation accidents a retrospective estimation of the received dose is desirable to supplement clinical decision-making in case of radiological or nuclear events. Biological dosimetry based on the dicentric chromosome assay is a well-established method for a retrospective estimation of the blood dose and allows the assessment of homogeneous as well as non-homogeneous exposure scenarios. A central part of dose estimation is the use of reliable statistical models and methods for the estimation of the received dose and the corresponding uncertainty. Most real-life exposure scenarios will be non-homogeneous, where different parts of the body were not irradiated with the same dose. For this exposure scenario we developed a novel method based on Bayesian statistics and compared this method with recently developed corresponding frequentist approaches, to uncover the strengths and limitations of the different approaches.

Materials and Methods: To validate the different approaches, we simulated data based on exposure scenarios with more than one dose with different model parameter values. Parameter estimation was then performed based on these data using the Maximum Likelihood method, and the posterior distributions of the parameters were determined using Markov chain Monte Carlo (MCMC) algorithms.

Results: The simulation study demonstrated that the Bayesian approach delivers more reliable estimates in cases of radiation exposures with small distance between the two doses, relatively low cell number or a small proportion of the body exposed to one of the doses, even with "weakly informative" prior distributions for doses and fractions of the body irradiated used for the Bayesian approach.

Conclusions:

- Bayesian approach for a non-homogeneous exposure with two doses was introduced and implemented with MCMC algorithms
- Validation and comparison with established frequentist methods were done using Monte Carlo simulations
- Bayesian approach provides more reliable estimation of the uncertainty in critical parameter settings as the established frequentist approach.

Lung and Lung tumor segmentation of CT images during MWA therapy using unsupervised learning algorithm

Naghmeh Mahmoodian [1],Sadat Hasan Chowdhury [1], Marilena Georgiades[2], Maciej Pech [2], Christoph Hoeschen [1]
[1] Otto von Guericke University, Faculty of Electrical Engineering and Information Technology, Institute for Medical Technology, Chair of Medical Systems Technology, Otto-Hahn-Strasse 2, 39106 Magdeburg, Germany.
[2] Otto von Guericke University, Medical Faculty, University Clinic for Radiology and Nuclear Medicine, Leipziger Str. 44, 39120 Magdeburg, Germany

The use of microwave ablation (MWA) therapy is increasing for lung tumors. Computed tomography (CT) imaging is commonly used to monitor this minimally invasive procedure. However, the start and end points of tumor treatment are subjectively determined by the doctor's expertise in tumor segmentation. Inaccurate segmentation can result in tumor recurrence and higher patient doses. Therefore, precise tumor segmentation and determining therapy stop points are crucial to prevent recurrence and minimize patient dose.

Artificial intelligence has gained attention in medical image segmentation for its capability to generate segmented tumor images even without predefined annotated images. The U-Net model, a type of conventional neural network (CNN), effectively utilizes lower-level information during sampling and combines high-level information. However, supervised learning models, which require labelled data (ground truth) for training, manual data segmentation to create ground truth is a time-consuming task for both scientists and clinicians.

To overcome the mentioned problem, an enhanced unsupervised W-shaped fully conventional neural network was developed. The proposed W-Net model utilizes an EfficientNet V2 encoder pre-trained on ImageNet instead of VGG-19 for the first V-shaped encoder. Using unsupervised DL methods can be helpful in learning from the input texture and replacing manual and time-consuming tasks with automatic ones. The results were compared with the conventional W-Net, supervised U-Net, and ResLU-Net models. The approach is applied to the CT images of 20 lung cancer patients obtained during MWA therapy from a CT scanner at University Hospital, Magdeburg. Two evaluation factors, the Dice coefficient and Structural similarity index (SSIM), are employed to measure the similarity and compare the output prediction results. The result shows the SSIM of 80%, in addition to particular well tumor segmentation, which leads to decrease in tumor recurrence by accurately determining the tumor margin area.

Multimodal 3D Image Rigid Registration of Directional Deep Brain Stimulation Electrodes via a Convolutional Neural Network

Fadil Al-Jaberi [1], Melanie Fachet [1], Matthias Moeskes [2], Martin Skalej [3], and Christoph Hoeschen [1]
[1] Otto von Guericke University Magdeburg, Faculty of Electrical Engineering and Information Technology, Institute for Medical Technology, Chair of Medical Systems Technology, Magdeburg, Germany
[2] Otto von Guericke University Magdeburg, Medical Faculty, Institute of Biometry and Medical Informatics, Magdeburg, Germany
[3] Martin Luther University Halle-Wittenberg, Medical Faculty, Neuroradiology, Halle, Germany

Deep brain stimulation (DBS) is a common surgical approach to treat movement disorders. It involves inserting electrodes into the brain nucleus and providing high-frequency stimulation to reduce symptoms. Precise electrode placement is crucial for optimal therapeutic. Deviations from the target can significantly impact outcomes, especially in Parkinson's disease (PD). The electrode's position relative to the target is critical for programming, but accurately reconstructing the postoperative location remains challenging in functional neurosurgery. A conventional method for localizing electrodes involves merging postoperative computed tomography (CT) or Magnetic Resonance Imaging (MRI) with preoperative MRI using a planning system. By comparing the coordinates of electrode contacts to the target position, the placement accuracy can be determined. This method is widely used but has limitations such as labor-intensiveness and limited tissue contrast in postoperative CT. Postoperative MRI may help overcome these challenges, but artifacts can distort the images, and performing MRI on DBS patients carries inherent risks.

We retrospectively gathered datasets from patients' that underwent bilateral DBS implantation, following image processing, and a Convolutional Neural Network (CNN) approach was employed to perform 3D rigid registration of CT and high-resolution-cone-beam computed tomography (hrCBCT).

A comprehensive workflow of image analysis, pre-processing, and 3D registration by supervised CNN was applied in this work. It included training, registration and applying the predicted transformation to the moved image, and comparing the registered image with the previously registered images using another registration method.

Image registration involving hrCBCT and CT generates detailed images that retain the anatomical context and enable a subsequent fusion with MRI. The knowledge gained from accurately identifying the position of each segmented contact can significantly reduce the time required for electrode programming. While standard CT imaging can not provide suitable images for this purpose, hrCBCT, with its smaller-voxel-sizes and limited field-of-view, offers superior image quality and serves effectively.

Physics-based Computational Approaches for Intraocular Tritium Transport and Implications to the Eye-Lens Dosimetry

Lucian Ivan[1]
[1] Canadian Nuclear Laboratories

Purpose. Cataracts are a leading global cause of visual impairment and blindness with multiple aetiologies, including one epidemiologically associated with radiation exposure. To counter this risk, newly revised occupational eye-lens dose limits are recommended by the International Commission on Radiological Protection. Implementing these recommendations into workplace practices underscores the need for accurate dosimetry-prediction methods for the radiosensitive eye-lens that account for both external fields and internalized radionuclides, thereby assisting in demonstrating regulatory compliance. Materials and Methods. In environments in which radionuclide(s) intakes represent a hazard, the chemical and radiological character of the radionuclide will impact the eye-lens dosimetry prediction. The present study considers the dosimetry implications from workplace exposures to internalized tritium by focusing on the transport of tritiated water (HTO) to and within the ocular structures. This investigation employs a physics-based modelling approach for tritium transport within the eye compartments, mainly provided by the aqueous humor global circulation and lens microcirculation. Computational-fluid-dynamics approaches are employed to predict the time-dependent tritium transport driven by: secretory aqueous humor flow; buoyancy-driven flow arising from temperature gradients within the anterior chamber; and microcirculation flow of water (hydrodynamics) and of ions (electrodynamics) within the eye lens itself. Model outputs allow for transient tritium dosimetry-prediction for the eye geometries and material composition. Results. Transient multi-dimensional predictions of tritium concentration examine multiples impacting factors, including the head position and circadian rhythm. Conclusions. The presented results will demonstrate the feasibility of the proposed modelling approach, thereby providing a basis for evaluating the internalized tritium dosimetry implications on the eye lens. Ultimately, this work has the potential to advance current workplace practices in whole-body dosimetry that incorporate specifics related to eye lens.

Emergency response

Influence of the nutrients in fortified salts on OSL response for application in retrospective dosimetry

Aleksander Krleski [1], Kristina Smokrović [2], Ivica Đilović [3], Luka Bakrač [4], Nadica Maltar-Strmečki [2]*
[1] Department of Mathematics and Physics, Faculty of Electrical Engineering and Information Technologies, Ss Cyril and Methodius University, Skopje, Republic of North Macedonia
[2] Division of Physical Chemistry, Ruder Bošković Institute, Zagreb, Croatia
[3] Department of Chemistry, Faculty of Science, University of Zagreb, Zagreb, Croatia
[4] Secondary Standard Dosimetry Laboratory, Ruđer Bošković Institute, Zagreb, Croatia

Purpose: In a radiological or nuclear mass casualty incident, the fast triage of individuals into those who are unaffected and those who require medical attention is a high priority. Often, the individuals who were present at such an accident do not have a professional dosimeter, so the assessment of their exposure to ionizing radiation depends on fortuitous dosimeters. Optically stimulated luminescence (OSL) is one of the most commonly used techniques in the field of retrospective dosimetry. The sea and rock salts are very well established as highly sensitive materials for (OSL) dosimetry. Nevertheless, new lifestyles, health and nutritional trends have led consumers to demand healthy foods and meals. Therefore, there are various modified chloride table salts on the market.

Materials and Methods: Sea salts fortified with potassium, calcium and magnesium, and with reduced sodium content were analyzed with SUERC portable OSL reader using blue light stimulation and their dosimetric properties were compared with those of ordinary household salt. The samples were irradiated with doses ranging from 1 mGy to 5 Gy.

Results: A significant difference in OSL sensitivity was observed between the selected types of modified salt. Dose response and detection limits for the samples were determined and compared.

Conclusions: This study has conclusively demonstrated that dosimetry using modified salts with a portable OSL reader is a rapid and effective procedure. However, further work is needed to define the exact details for the use of such systems in nuclear or radiological emergency response.

Emergency dosimetry with NaCl detectors

Daniela Ekendahl [1], Zina Čemusová [1], Zdeněk Sofer [2]
[1] National Radiation Protection Institute, Prague, Czechia
[2] University of Chemistry and Technology, Prague, Czechia

Purpose: In the event of a large-scale nuclear radiation accident or an incident with radioactive sources, the task of a rapid quantitative estimate of the radiation dose to exposed members of the public and to first responders is of cardinal importance. The capacity of existing monitoring networks and systems may not be sufficient. Common household salt represents a cheap and widely available material that can be used for dosimetry based on stimulated luminescence and neutron activation. The aim of this study was to prepare and test NaCl detectors in form of pellets repeatedly deployable in radiation emergency situations.

Materials and Methods: Detectors in form of pellets with a diameter of 4.5 mm and a thickness of 1 mm were prepared by pressing common grain salt (NaCl). Both unsintered and sintered pellets were used for comparison. The pellets were measured using optically stimulated luminescence (OSL) and tested for basic dosimetry characteristic of OSL signal such as reproducibility, dose response, minimum detectable dose, fading and photon energy response. A simple analytical protocol was employed. Inserted in aluminium containers, the detectors were deployed in conditions of area monitoring.

Results: The OSL signal exhibited very good reproducibility and dose response, which made it possible to apply a simple analytical protocol. The detectors can be employed for measurements of doses as low as several hundred µSv. The energy response of OSL signal was satisfactory for purposes of environmental dosimetry. The results of dose measurements were in good agreement with results of classical environmental thermoluminescent dosemeters.

Conclusions: Salt detectors are suitable for environmental dosimetry in case of a radiation emergency situation. They can be easily, cheaply and relatively quickly made. A pre-prepared stock of these detectors can be used if the capacity of radiation monitoring needs to be increased.

Validation of a rapid method for Sr-89 determination in water and vegetable samples

A. Salas[1], J.L. Figueredo[1], J. Guillén*[1], J.G. Muñoz-Muñoz[1]
[1] LARUEX, Dpt. Applied Physics, Faculty of Veterinary Sciences, University of Extremadura, Avda. Universidad, s/n, 10003 Cáceres, Spain

The establishment of rapid method for radiochemical separations is related to the need to assess the radionuclide concentration of a given sample in scenarios when a fast response is essential for decision making. In this work, we present the validation of a rapid method for Sr-89 determination in water and organic samples, including whole milk, which can be considered a complex matrix due to the occurrence of fat. This rapid method consists on a pretreatment step, in which Sr is co-precipitated along with calcium phosphate. The precipitate is dissolved and purified in order to remove interferents. Then, strontium separation is carried out using a Sr-resin column, precipitated as strontium carbonate and measured by Liquid Scintillation Counter. The validation of the method took into account the elapsed time for sample preparation and measurement, the reutilization of the Sr-resin column, and the assessment of quality parameters, such as recovery, accuracy and precision.

Acknowledgments: This work was partially funded by Junta de Extremadura through the project ""Realización de actividades relativas a la protección radiológica ambiental y a la vigilancia de las emisiones industriales en Extremadura. Anualidades 2022-2023"" Expte.: 1855999FD020, and Fondos Europeos FEDER del Programa Operativo de Extremadura 2014-2020 "Una manera de hacer Europa".

Induction of radioadaptive responses by chronic low dose radiation in human lymphocytes

H.W. Tan [1], C. Chua [1]
[1] Singapore Nuclear Research and Safety Initiative, National University of Singapore, Singapore

Purpose: While high doses of ionizing radiation have been known to result in DNA damage and genomic instability in cells, the biological effects of low dose ionizing radiation remain poorly understood. Numerous studies have demonstrated the existence of radioadaptive responses (RARs), in which low conditioning doses of ionizing radiation could reduce the detrimental effects of a subsequent high challenge dose. The aim of this study is to investigate if RARs can be observed in human lymphocytes derived from the local male Chinese population.

Methods: Peripheral blood mononuclear cells (PBMCs) isolated from human whole blood were primed with radioactive Cs-137, at a low dose rate of 1 mGy/h for 96 hours. Subsequently, these cells were given a 6-hour rest interval, before a high challenge dose of 4 Gy X-ray at 1 Gy/min dose rate. On the other hand, cells in the control group were only exposed to 4 Gy X-ray.

Results: In general, most of the low dose primed PBMCs prior to the challenge dose exhibited lower γH2AX levels and lower apoptosis rates than the control group. Furthermore, the mRNA levels of the DNA repair-associated genes such as ATM and TP53 were elevated in the primed group. These results were consistent with those observed in human lymphoblastoid cell lines which have a similar profile to the PBMCs.

Conclusion: Taken together, these data support the presence of RARs in human lymphocytes, suggesting that low dose ionizing radiation priming could potentially enhance the cells' defense mechanisms through the induction of repair enzymes to stimulate a more efficient DNA damage repair capacity, thereby mitigating the extent of radiation-induced cell death following a high challenge dose. A deeper understanding on the mechanisms of RAR will allow us to better evaluate the health risks of chronic low dose ionizing radiation exposure and improve radiation protection standards.

Cytogenetic effects of low-dose ionizing radiation after medical and occupational radiation exposure

Nora Kostova [1]*, Albena Staynova [1], Dimka Georgieva [1], Ljubomira Popova-Hadjiiska [1], Margarita Atanasova [1], Ilonka Ivanova [1], Elena Zacharieva [1], Hristo Tsonev [2] and Rositsa Hristova [1]
[1] National Centre of Radiobiology and Radiation Protection; Sofia, Bulgaria
[2] University Multi-profile Hospital for Active Treatment "St. Ivan Rilski", Sofia Bulgaria
[3] Bulgarian National Science Fund (Contract № КР 06 Н63/6/2022)

Purpose: Ionizing radiation causes DNA damage and various types of chromosome abnormalities, which have been related to increased cancer risk. The analysis of unstable aberrations is one of the most sensitive biomarkers for radiation exposure. It has been shown that low cumulative doses after some diagnostical procedures are related to higher yield of dicentrics and chromosome fragments. On the other hand, the workers in Nuclear Power Plants (NPP) are long-term exposed to low doses and low dose rates. The purpose of the present study is to assess the frequency of unstable chromosome aberrations after both medical and occupational low-doses irradiation.

Materials and Methods: Cytogenetic studies were performed by conventional Dicentric assay. The low-doses effect was estimated in patients undergoing fluoroscopy-guided vertebroplasty. Their cumulative dose varies in the ranges from 7 mSv to 21 mSv for time interval up to 3 min. Whole blood samples before and after medical procedure were taken and routinely proceed to get Giemsa stained metaphases. Cytogenetic analysis was also applied to 18 NPP workers, all accumulated doses between 100 and 200 mSv for the entire working period. Group of 9 persons from the administrative staff served as reference control.

Results: In preliminary studied patients group, the frequencies of aberrant cells, dicentrics and chromosome fragments after medical procedure were increased about 2-fold compared to frequencies before vertebroplasty. In workers group, the frequencies of aberrant cells, dicentrics plus rings and chromosome fragments were respectively 0.011 ± 0.002 ($P<0.005$); 0.004 ± 0.001 ($P<0.005$) and 0.006 ± 0.001 ($P<0.05$). The observed increase in chromosome aberrations was three to four times higher than in controls. No positive correlation was found between chromosome aberrations and cumulative dose.

Conclusion: Our cytogenetic results show higher chromosomal damage after both medical and occupational low-doses radiation exposure.

Assessment of radiation induced DSBs and translocations in peripheral blood lymphocytes of patients after spinal stabilizations

Ljubomira Popova[1], Albena Staynova[1], Nora Kostova[1], Dimka Georgieva[1], Ilonka Ivanova[1], Elena Zaharieva[1], Margarita Atanasova[1], Hristo Hristov[2], Rositsa Hristova[1]

[1] National Centre of Radiobiology and Radiation Protection, Sofia, Bulgaria

[2] University Multi-profile Hospital for Active Treatment "St. Ivan Rilski", Sofia, Bulgaria"

[3] Bulgarian National Science Fund (Contract № КР 06 Н63/6/2022)

Purpose: Spinal disorders are one of the leading causes of disability globally, and surgical treatment under fluoroscopic control of these diseases significantly improves the quality of life of patients. Ionizing radiation (IR) initiates a wide variety of DNA lesions including double strand breaks (DSBs). Possible consequences of misrepaired DSBs include chromosome translocations, deletions and inversions, which can cause cancer and haematological malignancies.

The aim of the study is to evaluate the incidence of radiation-induced DNA DSBs and the frequency of stable chromosomal aberrations, translocations, in peripheral blood lymphocytes (PBL) of patients subjected to medical irradiation during spinal interventional procedures.

Materials and Methods: The effects of low dose IR were assessed in patients underwent surgical procedures under fluoroscopic control to restore stability and mobility of the spine.

The assessment of DSBs in PBL of patients before and after the medical procedure was realised by immunofluorescence staining method for visualising DSB sites (foci) using antibodies against γ-H2AX and 53BP1 proteins.

To evaluate the frequency of radiation-induced translocations in PBL of patients before and after the medical procedure we applied fluorescence in situ hybridization (FISH) protocol for fluorescence labelling of three chromosome pairs: 1, 4 and 11.

Results: A statistically significant increase of γ-H2AX/53BP1 foci frequency was found in patients after spinal surgery under fluoroscopic control, in compare to initial frequency before the procedure.

No statistically significant difference was found in the genomic frequency of translocations in patients before and after spinal stabilizations.

Conclusions: Low doses medical exposure can cause significant increase of DSBs. DSBs can be realized as stable translocations but no statistically significant increase of translocations level was detected in patients after spinal stabilizations.

The results are preliminary but there is no evidence for excess cancer risk from low dose ionizing radiation after minimal invasive spine procedures.

Uncertainty Analysis of Dose Coefficients using R code: A Case Study of U-238 inhalation by workers

Thomas Makumbi*[1], Bastian Breustedt[2], Wolfgang Raskob[1]
[1] Institute for Thermal Energy Technology and Safety (ITES), Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz Platz1, 76344 Eggenstein-Leopoldshafen, Germany
[2] Department of Electrical Engineering and Information Technology, Karlsruhe Institute of Technology, Fritz-Haber-Weg1 D-76131 Karlsruhe, Germany

Purpose: This study demonstrates the extension of the R-code to perform parameter uncertainty analysis on the calculated doses for the inhalation of U-238 by workers. The study is motivated by the fact that the biokinetic models provided by ICRP are reference models whose parameters are representative of a reference person. By definition, these parameter values are fixed numbers with no uncertainties. Therefore, parameter uncertainty and sensitivity analysis in biokinetic models need to be performed to give a better understanding of the models and to estimate the influence of single parameters on the model predictions and hence dose coefficients.

Materials and Methods: An extended version of the R-code developed earlier by the authors was used to perform Monte Carlo simulations; this code was able to randomly sample parameters from defined probability distributions of the parameters and was interfaced with the dosimetry code to calculate doses and bioassay predictions in the model compartments. In this study 50000 runs were made for the model parameters using the lognormal probability distributions. Each of the 50000 simulations involved calculating the bioassay predictions at logarithmically spaced intervals up to 50 years and the associated dose coefficients that were later used to derive dose distributions.

Results: Results showed that the median values of the distributions are reasonably close to the ICRP values but the mean of the distributions is 10-18% higher; also, the values were distributed around the ICRP value as depicted by the uncertainty factor and were in agreement with those generated by other authors. The calculated values of the effective dose followed a lognormal distribution with a geometric mean of 2.37E-07 Sv/Bq and a geometric standard deviation of 1.49.

Conclusion: The R-code is able to handle uncertainty analysis of the decay chains of long-lived radionuclides . Future work will aim at performing a sensitivity analysis.

Degree of intra-, and inter-individual variability for the risk of developing second malignant neoplasms after radiotherapy for cancer

Prabodha Kumar Meher [1]*, Magdalena Płódowska [2], Halina Lisowska [2], Aneta Węgierek-Ciuk [2], Janusz Braziewicz [3], Ans Baeyens [4], Anne Vral [4] and Andrzej Wojcik [1,2]
[1] Centre for Radiation Protection Research, Department of Molecular Biosciences, The Wenner-Gren Institute, Stockholm University, Stockholm, Sweden
[2] Institute of Biology, Jan Kochanowski University, Kielce, Poland
[3] Holy Cross Cancer Centre, Kielce, Poland
[4] Radiobiology, Department of Human Structure and Repair, Ghent University, Ghent, Belgium

Purpose: Radiotherapy (RT) is an important treatment method for cancer. Although utilization of ionizing radiation is very effective for cancer treatment, it also significantly induces second malignant neoplasms (SMN). It is known that ionizing radiation-related cancer risk and genetic susceptibility to cancer varies for each individual. Important factors that influence this variability are age, sex, individual life-style, comorbidities, genetic and epigenetic make-up. There is insufficient information to establish the magnitude of these differences or whether biomarkers exist allowing identification of patients with a high genetic susceptibility to SMN.

Materials and Methods: Within the SINFONIA project we are investigating to address these issues by studying the in vitro radiosensitivity of lymphocytes isolated from 200 brain, lymphoma and breast primary cancer patients and 100 SMN patients. Blood samples are being collected before and one or two times after RT. We are utilizing whole chromosome paint fluorescence in situ hybridization (FISH) assay for determination of individual mutation levels; γH2AX focus assay together with cytokinesis block micronucleus assay to evaluate the in vitro individual radiosensitivity and genome wide single nucleotide polymorphism (SNP) markers to assess factors that influence the risk of SMN.

Results: We have collected and processed about 194 blood samples from primary cancers and about 45 SMN patients. While analysis of these samples are still undergoing, we will present the initial results from FISH assay in this presentation.

Conclusions: The outcome of this investigation will give us new knowledge and further understanding of the inter- and intra-individual variability for susceptibility to SMN due to radiotherapy.

Keywords: Cancer, Radiotherapy, Second malignant neoplasm, Individual radio-sensitivity

ProZES – leukemia risk models for occupational exposures

Janine Becker[1]
[1] Bundesamt fuer Strahlenschutz (BfS)

Purpose: The software ProZES is one tool used in Germany in compensation claims for possibly radiation-induced cancer due to occupational exposure. Since individual association between cancer and radiation cannot be established from tumor tissue, the program estimates the probability of causation/assigned share from radioepidemiological data. Leukemia risk shows highly complex age and dose dependencies. Prior existing risk models did not provide feasible estimates for all ranges of occupational exposure scenarios. Therefore, robust new leukemia risk models were developed.

Materials and Methods: The leukemia risk models comprise five four groups (ALL, CML, AML and, lymphoma, and multiple myeloma). Risk models with different age and dose dependencies were derived from? fitted to the LSS cohort of the atomic bomb survivors. The resulting risk models were combined using the method of multi-model inference (MMI) where each model was weighted according to its goodness of fit. Uncertainties were estimated by Monte Carlo simulation and include model uncertainty.

Results: CML has very strong temporal dependencies, and a single risk model was not able to predict reasonable estimates for the whole age range. A combination of three CML models with different age dependencies was found to show plausible estimates for all exposure scenarios. MMI was also used for lymphoma where epidemiological data showed a biologically implausible difference between male and female risk. The dose response of AML and ALL was non-linear. To avoid underestimation of risk for protracted exposures, additional linear 'twin' models were introduced and combined by MMI with the non-linear models. The multiple myloma model was linear in dose without age dependencies.

Conclusions: Risk estimates for the new leukemia models were shown to be plausible for all possible occupational exposure scenarios, and were implemented in the ProZES software for calculation of the assigned share. It is planned to further advance ProZES with new epidemiological data and methodological developments.

GuideRadPROS: Updating the basis of radiation protection dosimetry by harmonization, update and implementation of standards

Hayo Zutz[1], Steffen Ketelhut [1], Oliver Hupe [1]*, Teemu Siiskonen [2], Argyro Boziari [3], Milos Živanović [4], Nikola Kržanović [4], Olivier Van Hoey [5]
[1] Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
[2] Radiation and Nuclear Safety Authority (STUK), Finland
[3] Greek Atomic Energy Commission (EEAE), Greece
[4] Vinca Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade (VINS), Serbia
[5] Belgian Nuclear Research Centre (SCK CEN), Belgium

Purpose: The recent update of the ISO 4037, in conjunction with the new radiation protection quantities introduced in ICRU Report 95, present significant challenges to calibration laboratories and industry. Furthermore, there is a need to address gaps and conflicts between standards that set requirements for photon dosimeters, and to incorporate upcoming and new technologies into standardization.

Materials and Methods: The European Partnership Project 23NRM07 GuideRadPROS started in June 2023 and will address these issues in the next three years. The objectives are:

- to develop harmonized X-ray spectrometry in accordance with the ISO 4037 standard series, evaluate discrepancies between measured and calculated half value layer of X-ray spectra, and produce data to update requirements for reference X-ray fields.
- to develop guidance for the calibration of dosimeters.
- to produce guidance on validated procedures for harmonized type testing based on IEC standards.
- to assess future standardization needs and to produce a guidance document for the implementation of the new operational quantities of ICRU Report 95 into standards and regulations.
- to collaborate with ISO and IEC and users of their dosimetry standards to ensure that project outputs align with their needs.

Results: The outcome of this project will lead to improved and comparable procedures in calibration and type testing within Europe. Furthermore, the evaluation of the impact of the ICRU Report 95 quantities will allow for an informed realization of calibration fields.

Conclusions: GuideRadPROS will improve the confidence in radiation protection dosimetry, both via the promotion of the implementation of the ISO 4037 standard series, and via the assessment of the impact of the ICRU Report 95 operational quantities on daily measurements in radiation protection.

The project (22NRM07 GuideRadPROS) has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

The impact of digital PET on occupational staff doses

Eamon Loughman [1], Caroline Banahan [1], Paul Hastings [1], Susan Maguire [1], Paddy Gilligan [2]
[1] Mater Private Network, Dublin, Ireland
[2] Mater Misericordiae University Hospital, Dublin, Ireland

Purpose: Historically, PET-CT has been known as a high dose modality both in terms of patient dose and occupational exposure. With the advent of digital PET, a reduction in patient injected activity is possible. The recent installation of a digital PET-CT scanner (Biograph Vision 450, Siemens, Erlangen) at our center enabled a reduction in patient injected activity of ~ 50%. This dose reduction benefits patients, while also positively impacting occupational dose. The aim of this study was to determine external dose-rates from patients attending for a whole-body FDG scan, with reduced injected activity, to assess the impact on occupational doses.

Materials and Methods: A RadEye B20-ER survey meter was used to measure external dose-rate from consented patients at three time points: (i) immediately following injection, (ii) 60 minutes post-injection, after voiding, prior to scan and (iii) immediately following scan. Measurements were recorded at abdomen height with the patient seated at set distances of 0 cm, 50 cm and 100 cm. These distances mimic typical staff positions for the three time points respectively.

Results: 30 patients consented to participate. Mean and standard deviation of injected activity was 193 ± 49 MBq. Initial measurements were recorded on average 5 minutes post-injection with a mean dose rate of 288.9µSv/h (0 cm), 58.6µSv/h (50 cm) and 21.3µSv/h (100 cm). At 60 mins post-injection and post-voiding, a mean patient surface dose rate of 182.7µSv/h (0 cm), 40.2µSv/h (50 cm) and 14.6µSv/h (100 cm). At 90 mins post-injection, the average surface dose rate was 150.6µSv/h (0cm), 35.7µSv/h (50cm) and 12.3µSv/h (100 cm).

Conclusion: From initial results, surface dose rates at 100cm from PET-CT patients post scan are comparable to Nuclear Medicine bone patients (13.65µSv/h at 100cm, 40 mins post-injection).1 Future work will compare occupational doses recorded via electronic personal dosimeter to historical occupational doses with higher patient injected activities.

Feasibility of an electronic massager to reduce occupational radiation dose in prostate cancer nuclear medicine therapy extravasations

C. Costello* [1,2] , D. Cody [2] , T Fitzpatrick [1], M. Dooley [1],D. Caldwell [1], M. O Connell [1,3], D. Murphy 1 , P.Gilligan [1,3].
[1] Mater Misericordiae University Hospital, Dublin , Ireland
[2] TU Dublin, Dublin Ireland
[3] University College Dublin , Dublin , Ireland

Purpose: Extravasations (where the injection is delivered subcutaneously rather than intravenously) are rare events in nuclear medicine therapies. However, they have the potential to cause severe tissues effects and necrosis. Manual massage is a common approach to distributing toxic agents and limiting their effects after such an accident. Risk assessment has shown that this has the potential to contribute significant occupational radiation doses to the hands of the operator.

Electronic massager units are commercially available as pain relief devices for muscle injuries and tension. The purpose of this paper to assess their potential in reduction of occupation dose after extravasation of a nuclear medicine therapy such as Lutetium PSMA (prostate specific membrane antigen)

Materials and Methods: Modelling of skin dose and finger contact doze for Lutetium PSMA after extravasation was carried out using Varskin (US Nuclear Regulatory commission). A comparison of the pressure and heating effects of an electronic massager gun to manual methods by an experienced extravasation practitioner was undertaken using physical techniques. The potential dose reduction for particular clinical scenarios was also modelled.

Results: The electronic massage gun can provide some occupational dose reduction. However, its applicability for nuclear medicine therapies will depend on the volume delivered, the nature of the agent and may form only one part of an overall extravasation strategy.

Conclusions: Electronic massage guns should be considered as part of an overall extravasation risk mitigation strategy in Nuclear Medicine therapies.

Radiation protection and dosimetry in the medical context

Development and evaluation of multilayered non-lead radiation shielding fabric with bismuth and tungsten

Ju-Hee Kang [1]*, Yong-Suk Choi [2], Jo-Eun Kim [3], Min-Suk Heo [3], Sam-Sun Lee [3]
[1] Department of Oral and Maxillofacial Radiology, Seoul National University Dental Hospital, Seoul, Korea.
[2] Doctor-view Dental Clinic, Uijeongbu, Korea
[3] Department of Oral and Maxillofacial Radiology and Dental Research Institute, School of Dentistry, Seoul National University, Seoul, Korea.

Purpose: The purpose of this study is to develop the multilayered non-lead radiation shielding fabric using bismuth and tungsten powder and to evaluate the radiation shield effect, physical properties, and biological safety of these fabrics.

Methods: Total four shielding fabrics were fabricated according to application method and powder type. Bi fabric (bismuth), W fabric (tungsten), Bi-W fabric (bismuth-tungsten in ordre) and W-Bi fabric (tungsten-bismuth in order). The fabric's physical performance in terms of flexural and abrasion resistances was evaluated by International Organization for Standardization (ISO) 12947-2 and ISO 5402-1. For biologic safety test, the 191 kinds of hazardous substances detection tests were performed.

Results: Radiation shielding rate was higher in order of Bi fabric, W fabric, Bi-W fabric and W-Bi fabric. The shielding rate of 60 and 70 kVp were 68.1% and 63.3% for Bi fabric, and 72.6% and 67.0% for W fabric respectively. The results of the abrasion resistance test (ISO 12947-2) were 10000 wear cycles for both Bi fabric and W fabric. In the flexural resistance testing results (ISO 5402-1), Bi fabric revealed 3500 cycles and the W fabric revealed 1000 cycles of flexural resistance. Biologic safety test confirmed that none of the 191 hazardous substances were detected in both Bi fabric and W fabric.

Conclusions: Tungsten-based fabric has better radiation shielding effect than bismuth-based fabric, and revealing better shielding performance when laminating two kinds of radiation shielding solution. Owing to the harmless to the human body, flexibility, and strength of the fabric, it can be expected to replace the currently used lead protective apron.

Improving radiation protection methods for mental health patients at risk of multiple radiation exposures

Helen Carroll

Purpose: The purpose of this study was to improve the radiation protection measures for patients who are suffering from mental health conditions, which can lead to multiples episodes of swallowing foreign bodies. This behaviour puts them at risk of excessive doses of radiation from repeat imaging.

Materials: I analysed data retrospectively over 7 months and was able to gain information on 10 patients that presented at the department for this issue. The data I looked at included:

- Background of mental health condition
- Total DAP received from x ray due to ingestion of foreign body.
- Male/female
- Age range
- Evidence of repeated examinations.
- The Ct doses
- Likelihood of future doses

Methods-

- I looked at the doses received from abdomen x rays.
- I converted the DAP to effective dose
- I used the average effective dose from an abdomen Xray and looked at the lifetime risk of fatal cancer as a guide, I then compared it to the actual effective dose the 10 patients received and used this to calculate a more realistic 'additional lifetime risk' to highlight the need for better radiation protection measures.

Results

- 60% of the patients had increased their risk of potentially developing a fatal cancer, some significantly.
- All patients had a history of self-harm and imaging.
- 90% of patients were female
- age range was between 17-34 years old.
- All patients were deemed a risk of future imaging

Conclusion: These patients are vulnerable due to their mental health condition, they are unable to grasp the increased risks they may face due to increased exposure from imaging and how this may impact them later in life. By creating an educational poster I'm hoping to educate the profession and demonstrate how it is our responsibility in protecting these vulnerable patients. The poster will cover awareness and radiation protection methods.

Research In Radiation Risk Appraisal for Detrimental Effects From Medical Exposure During Management Of Patients With Lymphoma Or Brain Tumours: The SINFONIA Project

John Damilakis[1]
[1] University of Crete, Iraklion, Crete, Greece

Purpose: The SINFONIA (Radiation risk appraisal for detrimental effects from medical exposure during management of patients with lymphoma or brain tumour) project is a European Commission research project that aims to develop novel methodologies and tools for risk appraisal of radiation exposure during the management of patients with lymphoma or brain tumor.

Materials and Methods: The project employs patient models with an exact representation of body contour and internal anatomy and advanced computer-based phantoms that can model an unlimited set of anatomies. Monte Carlo (MC) simulations and artificial intelligence (AI) algorithms are utilized to develop personalized dosimetry methods and AI-assisted tools for estimating radiation exposure.

Results: A tool based on personalised dosimetry and AI algorithms is under development for estimation of patient organ doses and risks from CT and radiography examinations performed on those with suspected or diagnosed lymphomas and benign and malignant brain tumours. Research on PET–CT has been focused on the development of tools for patient-specific internal radiation dosimetry calculations. SINFONIA is currently performing measurements and simulations to develop a tool to determine 3D dose distributions within the patient and estimate organ doses from imaging in radiotherapy. A physics-based analytical method for stray-dose calculations from megavoltage radiotherapy is under implementation. Measurements have also been performed to characterise the neutron doses from proton fields. A computational system for real-time dose assessment of nuclear medicine staff is under development, involving tracking of personnel and relevant source objects and combined with MC simulations and AI algorithms. Research work is in progress to determine the degree of intra- and inter-individual variability for the risk of developing second malignant neoplasms (SMNs) after radiotherapy for lymphoma and brain cancer and validate functional and genetic biomarkers of susceptibility to SMNs.

Conclusions: SINFONIA tools and methodologies produce new knowledge on parameters affecting radiation detriment.

ACKNOWLEDGMENTS. This work was supported by the Euratom research and training programme 2019-2020 Sinfonia project under grant agreement No 945196.

Transcriptional radiation exposure signature of human skin

Lourdes Cruz-Garcia[1], Grainne O'Brien[1], Antonella Tabasso-Smith[1], Mustafa Najim[1], Paul Finnon[1], Marie Polozova[2], Elena Makaruk[2], Sergei Artukh[2], Stanislav Polozov[3], Veronika Goriacha[3], Christophe Badie[1,4]
[1] Centre for Radiation, Chemical and Environmental Hazards, UK Health Security Agency, Oxfordshire, United Kingdom
[2] Grigoriev Institute for Medical Radiology and Oncology of the National Academy of Medical Science of Ukraine, Kharkiv, Ukraine
[3] HQ Science, St Ives, Cambridgeshire, United Kingdom
[4] Environmental Research Group within the School of Public Health, Faculty of Medicine at Imperial College of Science, Technology and Medicine

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 370C. 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.

Deficient Radiation Transcription Response in COVID-19 Patients

Stanislav Polozov [1], Lourdes Cruz-Garcia [2], Grainne O'Brien [3], Veronika Goriacha [1], Farah Nasser [2], Penelope Jeggo [3], Serge Candéias [4], Christophe Badie [2]

[1] Science Limited, St. Ives, Cambridgeshire, United Kingdom.

[2] Cancer Mechanisms and Biomarkers Group, Radiation Effects Department, Radiation, Chemical & Environmental Hazards, Harwell Campus, UK Health Security Agency, Didcot, Oxfordshire, United Kingdom.

[3] Genome Damage and Stability Centre, University of Sussex, Falmer, Brighton, United Kingdom.

[4] Commissariat à l'Energie Atomique et aux Energies Renouvelables, Centre National de la Recherche Scientifique, Interdisciplinary Research Institute - Grenoble, Laboratory of Chemistry and Biology of Metals, Unité mixte de Recherche 5249, 38054, Grenoble, France.

Purpose: The ongoing SARS-CoV-2 pandemic has resulted in over 6.3 million deaths and 560 million COVID-19 cases worldwide. Clinical management of hospitalized patients is complex due to the heterogeneous course of COVID-19. Low-dose radiation therapy is known to dampen localized chronic inflammation and has been suggested to be used to reduce lung inflammation in patients with COVID-19. However, it is unknown whether SARS-CoV-2 alters the radiation response and associated radiation exposure related risk.

Methods and materials: We generated gene expression profiles from circulating leukocytes of hospitalized patients with COVID-19 and healthy donors.

Results: The p53 signaling pathway was found to be dysregulated, with mRNA levels of p53, ATM, and CHK2 being lower in patients with COVID-19. Several key p53 target genes involved in cell cycle arrest, apoptosis, and p53 feedback inhibition were upregulated in patients with COVID-19 while other p53 target genes were downregulated. This dysregulation has functional consequences as the transcription of p53-dependant genes (CCNG1, GADD45A, DDB2, SESN1, FDXR, APOBEC) was reduced 24 hours after x-ray exposure ex vivo to both low (100 mGy) or high (2 Gy) doses.

Conclusions: SARS-CoV-2 infection affects a DNA damage response that may modify radiation-induced health risks in exposed patients with COVID-19.

Coincidence distribution in 2-layer hemispheric PET featuring different materials on each layer

Knuth Scheiff [1]*, Ali Pashazadeh [1], Christoph Hoeschen [1]

1 Otto-von-Guericke-Universität Magdeburg, Magdeburg, Germany

Positron Emission Tomography (PET) is used for diagnostic and research purposes of a wide range of brain diseases, requiring high resolution of ~1mm. To achieve such resolution, brain-dedicated PET-systems, mostly based on (hemi-)spherical geometries, were proposed and prototyped in recent years. Most PET-systems utilize detectors that equipped with pixelated crystals. Detectors using monolithic crystals can achieve intrinsic resolutions comparable to pixelated ones, while providing higher sensitivity. Since the intrinsic resolution of monolithic crystals is related to their thickness, a second detector layer can be added to achieve the same total crystal depth as in pixelated detectors. Employing two-layers of detectors with pixelated and monolithic crystals enables the combination of time-of-flight and depth-of-interaction resolution, as well as the combination of different materials. We investigate the sensitivity and coincidence distribution in such systems.

The simulations were conducted using the GEANT4 toolkit GATE. We simulated 2-layer-hemispheric-PET-geometries using detectors with pixelated crystals on the inner layer and monolithic crystals on the outer layer, for the crystal combinations LYSO-BGO and LYSO-LSO and LYSO-LYSO as benchmark system. An in-house coincidence sorter was utilized to differentiate between inner-layer-coincidences, outer-layer-coincidences and inter-layer-coincidences.

The coincidence rates of the LYSO-BGO or LYSO-LSO systems are more than twice as high as those in the LYSO-LYSO system. However, the ratio of inter-layer-coincidences for LYSO-BGO and LYSO-LSO are lower than the benchmark-systems. The quantity of inner-layer-coincidences is similar in all systems, but their contribution to the coincidence rate in LYSO-BGO and LYSO-LSO is less than half that of the benchmark systems. The outer layer provides not only higher coincidence rates, but also nearly twice the contribution ratios to the total count rate.

The LYSO-BGO-system and LYSO-LSO-system provide higher sensitivities than the LYSO-LYSO-system. The significant reduction of the inner-layer-coincidences ratio reduces the impact of the inner layer on the overall performance of the system.

Exome-wide association study of radioactive iodine therapy induced salivary disorders in papillary thyroid cancer

Ángela Solana [1]*, Elia Palma Rojo [1], Clémence Baudin [2], Charlotte Lussey-Lepoutre [3,4], Alice Bressand[5], Camille Buffet [6], Fabrice Menegaux [6,7], Marine Soret [3,8], David Broggio [9], Céline Bassinet [10], Christelle Huet [10], Laurence Leenhardt [6], Marie-Odile Bernier [2], Francesc Barquinero [1], Gemma Armengol [1]

[1] Department of Animal Biology, Plant Biology and Ecology, Faculty of Biosciences, Universitat Autònoma de Barcelona, 08193 Bellaterra, Catalonia, Spain
[2] Laboratory of Epidemiology, Institut de Radioprotection et de Sûreté Nucléaire, Fontenay-aux-Roses, France
[3] Sorbonne University, Department of Nuclear Medicine, AP-HP, Pitié-Salpêtrière Hospital, F-75013, Paris, France
[4] PARCC, INSERM, Equipe Labellisée par la Ligue contre le Cancer, F-75015, Paris, France
[5] AMAREXIA France, F-75016, Paris, France
[6] Thyroid and Endocrine Tumors Unit, Pitié-Salpêtrière Hospital APHP, Sorbonne University, Groupe de Recherche Clinique Tumeurs Thyroïdiennes n°16 F-75013, Paris, France
[7] Sorbonne University, Department of General and Endocrine Surgery, AP-HP, Pitié-Salpêtrière Hospital, F-75013, Paris, France
[8] Sorbonne University, CNRS, INSERM, Biomedical Imaging Laboratory, LIB, F-75006, Paris, France
[9] Internal Dose Assessment Laboratory, Institut de Radioprotection et de Sûreté Nucléaire, Fontenay-aux-Roses, France
[10] Ionizing Radiation Dosimetry Laboratory, Institut de Radioprotection et de Sûreté Nucléaire, Fontenay-aux-Roses, France

Purpose: Thyroid cancer (TC) is one of the most common endocrine malignancy, of which papillary thyroid cancer accounts for 96% of all diagnosed endocrine cancers. TC has a high survival rate and the treatment usually consists of a thyroidectomy, followed by a radioactive iodine (RAI) therapy. Although RAI is a highly effective treatment, between 16%-54% of adult patients develop side effects such as salivary gland dysfunction (including xerostomia). The occurrence of these may be influenced by several risk factors, as well as individual genetic variability.

Previous studies about side effects after radiotherapy in head and neck cancer showed preliminary evidence of genetic susceptibility to xerostomia. However, there are no such studies in TC patients. The present study aims to identify potential genetic variants that are associated with salivary disorders after RAI therapy in papillary TC patients.

Materials and Methods: The study is carried out using DNA extracted from 2 mL of saliva samples from a total of 90 RAI-treated TC patients, of which 38 patients have developed salivary disorders 18 months after treatment. Once the DNA is obtained using the Oragene DNA OG-500 kit (DNAgenotek. Inc., Ontario, Canada), whole exome sequencing NovaSeq600 2x150bp, >90x is performed. Then, genetic variants are compared between patients with and without salivary disorders, and the differences are analysed using bioinformatic tools.

Results: Until now, samples from all papillary TC patients have been collected. These samples are currently being processed and analysed using the techniques described above.

Conclusions: Conclusions will be presented during the meeting. The identification of genetic variants associated with salivary dysfunctions, if confirmed in further studies, would improve our knowledge of the genetic susceptibility to salivary dysfunctions in TC patients and, in the long term, would make it possible to adjust patient treatment to limit the occurrence of side effects.

Rad Central: a one-stop shop for radiation protection in a major academic teaching hospital

Jose Jr Binghay [1], Ruth Bridcut [1], Maria Dooley [2], Ruth Faulkner [1], Emma Fitzpatrick [1], Lynn Gaynor [1], Barry Hallinan [1], Thomas Heary [1], Barbara Martin [1], Áine Matthews [1]*, Jack O'Shea [1], Rachael Pyper [1]

[1] Beaumont Hospital, Dublin, Ireland
[2] Mater Misericordiae University Hospital, Dublin, Ireland

Purpose: Compliance with SI 30 (2019), regulated by the Environmental Protection Agency (EPA), and SI 256 (2018), regulated by the Health Information & Quality Authority (HIQA), represents a significant operational and administrative overhead to the undertaking. 'Rad Central' is an internal Beaumont Hospital website developed by the Radiation Protection Unit (RPU) to facilitate regulatory compliance and the sharing of radiation protection documents with relevant stakeholders.

Materials and Methods: The website is built on a Microsoft SharePoint platform. An iterative approach was applied to the website build, allowing for the expansion of the website in response to the requirements of the Hospital. The website contains up-to-date records for many regulatory requirements including radiation safety training, equipment management, risk assessments, staff dosimetry, diagnostic reference levels, audits, radiation safety meetings, imaging protocols and more.

Results: The intranet-based site was rolled-out in the Hospital in 2019 and initially consisted of just three applications; a document management system, an equipment management ticketing system and a staff dosimeter request form. The platform was well received throughout the Hospital and has since been expanded to over 15 applications, as indicated above, with further developments planned for the non-ionising sector.

Conclusions: The transition to an online platform has facilitated role-based sharing of important radiation safety information and has transformed the tracking and reporting capabilities of the undertaking. It has played a central role during recent inspections allowing any documentation requested

by the Regulators to be easily accessed on a single platform. 'Rad Central' has been embedded into routine use across the Hospital and is continuously updated and improved upon to meet the ever changing requirements of both the Hospital and the Regulators.

Establishment of Diagnostic Reference Levels (DRLs) for Computed Tomography at Hospital CUF Santarém, Portugal

Diogo Madaleno [1, 2]*, Cecília Borges [1], João Fatana [1], Rui Barros [1], Manuel Marques [1], Pedro Vaz [2]
[1] CUF Hospitals, Lisboa, Portugal
[2] Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

Purpose: The establishment of DRLs is recommended (ICRP) as a way to implement the optimization of patient protection and promote best clinical practice. This study was aimed at auditing doses in CT and establishing local DRLs for computed tomography (CT) examinations based on clinical indication, at Hospital CUF Santarém, Portugal.

Materials and Methods: Computed Tomography Dose Index (CTDIvol) and total Dose Length Product (DLP) were collected retrospectively for CT procedures on 430 adults (18-99 years old) performed on a Siemens Somaton Emotion CT scanner between 2021 and 2023. The sample included CT referrals for various clinical indications: head (trauma, headaches, dizziness and sinusitis); lumbar spine (lower back pain); chest (interstitial pathology, pulmonary embolism); abdomen-pelvis (kidney stones) and chest-abdomen-pelvis (oncology staging). The median CTDIvol and DLP were obtained for each clinical indication (protocols).

Results: Head CT (dizziness, headache, trauma) CTDIvol 58,1 mGy, DLP [1110-1166 mGy.cm]; Head CT (sinusitis) CTDIvol 9,3mGy, DLP 140 mGy.cm; Abdomen CT (kidney stones) CTDIvol 9,7 mGy and DLP 494 mGy.cm; Lumbar spine (back pain), CTDIvol 17,0 mGy, DLP 522 mGy.cm; Chest CT (cough) CTDIvol 10,2 mGy, DLP 388 mGy.cm; Chest CT (interstitial pathology) CTDIvol 11,2 mGy, DLP 17 mGy.cm, Chest CT (Pulmonary Embolism) CTDIvol 9,3 mGy, DLP [366-630 mGy.cm]; Chest-abdomen-pelvis (oncology staging, one series) CTDIvol 10,0-10,2 mGy, DLP 696-1385 mGy.cm.

Conclusions: The median CTDI and DLP were globally higher when compared with international published references. The preliminary analysis indicates that local referral practices and equipment characteristics are key contributors to these results. Further analysis is ongoing. The results will be discussed with the clinical team to identify opportunities for optimisation. This study lays foundations for the establishment of national DRLs in Portugal.

Analysis for the development of quality assurance regulatory guidelines in particle therapy

Jiyoung Kim[1]
[1] Korea Institute of Nuclear Safety, S.Korea

Particle therapy (protons, heavy particles) has the advantage of being able to intensively deliver a beam to a target while minimizing unnecessary exposure to normal tissues with a finite range. According to the IAEA GSR, a comprehensive quality assurance program for medical exposures should be established to ensure optimization of protection. In Korea, in accordance with the Radiation Regulations of the Nuclear Safety Act and the Medical Notification, quality assurance procedures must be performed during radiation therapy to ensure that the patient's exposure dose is maintained as prescribed by the doctor. In particular, quality assurance methods, execution cycles, and tolerance levels are described in detail for each radiation treatment equipment. However, even though there are currently two proton therapy devices and one heavy particle therapy device in Korea, specific asterisk items for particle therapy have not yet been prepared. In addition, there is an opinion that it may not be appropriate to present specific quality assurance items that must be implemented in consideration of the circumstances of each hospital in the notice.

To this end, it is necessary to provide guidance on regulatory management from the perspective of preventing accidents and leading to a safety culture.

In order to prepare regulatory guidelines, major items for on-site inspections in the field of quality assurance were derived based on notifications and IAEA and ICRP reports. Items that can be used for regulation during on-site inspection were checked and a graded approach based on risk was considered.

The results of this study are expected to help develop guidelines based on safety culture while determining the direction and scope of regulation for particle therapy quality assurance.

Evaluation of Size-Specific Dose Estimates for Optimizing Abdomen CT Protocol in pediatric

Walia allah Amine [1], Sebihi Rajaa [2]
[1] Université MOHAMMED 5, Rabat, Maroc
[2] Université MOHAMMED 5 FSR, Rabat, Maroc

CT scan is known to be the largest source of radiation dose to the patient. It is well known that cancer risk increases with increasing radiation dose, so high dose CT is of great concern. The objective of this study is to evaluate the effectiveness of size-specific dose estimation (SSDE) in compensating for underestimated pediatric absorbed dose.

This retrospective study was performed by extracting dose indicators including, CTDIvol and DLP volume, available on the dose report page 320 patients aged ≤15 years who were admitted to Rabat hospital for an abdominal CT scan

CT images of the abdomen were acquired in axial and helical modes. A digital ruler was used to measure the lateral LAT dimensions across the chest and anterior-posterior (AP). SSDE was calculated by the product of the CTDIvol and the conversion factor, found in report number 204; for a 32 cm CTDI phantom. SPSS version 19.0 was used to statistically evaluate the data obtained.

The results of the present study showed that there is a linear correlation between CTDIvol and SSDE, regardless of age. However, age significantly influenced CTDIvol and also SSDE. This study demonstrated that the effective diameter of the pediatric patient is much smaller than the standard 32 cm diameter phantom used to determine CTDIvol. As a result, the SSDE was greater than the CTDIvol reported in the dose report page accessible at the end of the CT image series.

The results show that SSDE is a useful tool and could potentially educate CT operators on its effective use as a means of optimizing radiation dose instead of CTDIvol, especially for establishing diagnostic baselines.

Identification and Management of Patient Exposed to a Significant Radiation Dose from a Fluoroscopy-guided Interventional Procedure: An Initiative at Beaumont Hospital to Enhance Patient Safety

Jose Jr Binghay [1]*, Jack O'Shea [1], Thomas Heary [1], Lynn Gaynor [1], Ronan Faulkner [1], Aine Matthew [1], Ruth Bridcutt [1], Barry Hallinan [1], Barbara Martin[1], Emma Fitzpatrick [1], Andrew Whelan [1], Eimear Boylan [1], Aisling Walsh [1], Eoin Fahy [1], Mark Given [1]
[1] Beaumont Hospital, Dublin, Ireland

Purpose: This study aimed to establish a comprehensive safe system process to reduce the inherent risks associated with Fluoroscopy-Guided Interventional Procedures (FGIPs). These risks, which include the potential of radiation-induced cancer and radiation tissue reactions (RTRs), require significant attention to optimise patient safety and outcomes at Beaumont Hospital.

Methods: The proposed process incorporates guidelines from the Society of Interventional Radiology and the Cardiovascular and Interventional Radiological Society of Europe. The authors developed a multi-faceted approach to risk management. The core of this approach was a radiation safety checklist, which was designed to ensure consistent adherence to all necessary steps, thereby improving process standardisation and efficiency. To supplement this, the RPOP mnemonic serves as a constant reminder of the process's pillars, namely Referral Justification, Pre-Procedural Planning, Optimization during Procedure, and rigorous Post-Procedure follow-ups. The safe system process was integrated into existing protocols, emphasising comprehensive application, and maintaining high compliance rates among the clinical team.

Results: Patient safety improved significantly after the system was implemented at all FGIP stages. Patients who exceeded the pre-determined radiation exposure threshold were quickly identified and given an educational briefing on RTR symptoms and the importance of self-monitoring. Following the procedure, these patients were scheduled for clinical follow-ups to identify and manage any potential radiation-induced complications. Early indications demonstrate that the safe system process significantly improved the detection, management, and mitigation of these potential complications.

Conclusions: The study found that systematic implementation of safe system processes improved patient safety significantly during FGIPs at Beaumont Hospital. This process offers a model for other medical institutions seeking to reduce the risks associated with FGIPs. Further studies are recommended to monitor the long-term impact of the system processes on patient outcomes and to explore its applicability in different clinical settings.

The effect of mattress compression on Peak Skin Dose value and area estimation in interventional procedures

Matthew Reade [1]*, Anita Dowling [1], Jackie McCavana [1]
[1] St. Vincent's University Hospital, Dublin, Ireland

Purpose: High dose interventional procedures can potentially lead to a high peak skin dose (PSD) and subsequent patient skin reaction. A reliable source-to-skin distance (SSD) is critical for accurate PSD estimation. Skin Dose Calculation (SDC) software packages typically use the SSD reported by the system, or calculate the SSD using the reported table height with a fixed correction for mattress thickness. However, as previously reported, patient mattress thickness can vary considerably, depending on weight distribution of the patient. The purpose of this work is to establish the range of mattress compressions encountered clinically and examine the resultant impact on the PSD value and area.

Materials and Methods: A range of clinical mattress compressions was generated using a Perspex phantom of varying thickness (and weight). In-house software was used to generate skin dose maps for three clinical procedures based on those described by the VERIDIC project for SDC software validation. The SSD was varied for each map using the clinical range of mattress compressions. The maps generated were compared to establish a range of PSD values and associated areas for comparison.

Results: The range of mattress compressions encountered clinically will be reported. This work affirms that small variations in compressed mattress thickness can have a significant effect on the PSD and associated area. Initial tests have shown changes of as much as 200% in the PSD skin area and 31% in the PSD itself.

Conclusion: The AAPM TG357 and EFOMP joint report on PSD estimation (2021) noted that an error of 5cm, at an SSD of 60cm, would give rise to a 15% error in skin dose, based on the inverse square law. The additional contribution due to the associated change in the spatial distribution of dose from angular fields was examined in this work, revising this uncertainty to approximately 31%.

Personalised Dose Reduction Factors for Dose Surrogates in Occupational Eye Lens Dose Assessment with and without Lead Protective Glasses

E. Loughman [1], D. Murphy [3], B. Mahady [2], Z. Harrison [3], L. Oonan[3], C. Costello [3], S. Burke [3], C. Banahan [1], S. Maguire [1], P. Gilligan [3,4]
[1] Mater Private Network, Dublin Ireland
[2] Beacon Hospital, Dublin Ireland
[3] Mater Misericordiae University Hospital Dublin Ireland
[4] University College Dublin Ireland

Purpose: Maintaining eye lens dose below the 20 mSv limit in interventional cardiology is a challenge for a small cohort of workers. Assessment of eye lens dose relies on surrogates such as left side collar dose so as not to interfere with clinical practice. Some work has been done to establish quantitative eye lens surrogate dose ratios known as Dose Reduction factors (DRF). The assessment of distribution of scattered doses and the relationship between these and the eye lens dose will depend on machine geometry and individual practice, height, fit of lead protective glasses. This paper looks at the generation of DRFs for individual workers based on practical dose measurements in a simulated clinical scenario.

Materials and Methods: A number of workers were scanned using a T1 weighted MPRAGE scan on a 1.5 T MRI scanner (Siemens Magnetom Sola). The images were used to generate a 3D printed shell of the head of the worker (Prusa, Czechia). The 3D head, filled with gelatin for back scatter was placed on an alderson rando phantom at the same height as the operator's head in an interventional laboratory (Siemens Artis Zee). Dose measurements were carried out using real time electronic dosimeters, survey meters, TLD and OSL HP 0.03 monitors. These were carried out with and without lead glasses.

Results: A number of Personalised DRF's were generated, initial survey meter results showed up to 40 % dose reduction for the left-hand side collar dose to eye dose with no PPE. Earlier TLD experiments showed that tight fitting glasses could generate DRFs in excess of the standard 2 used in risk assessments.

Conclusion: It is possible to generate personalised dose reduction factors, and these have a role in occupational eye lens dose assessment in individual radiation workers.

The use of a novel quinazoline derivative for the Radiosensitisation of tumor cells overexpressing EGFR

Sotiria Triantopoulou [1]*, Konstantina Makrypidi [2], Ioannis Pirmettis [2], Maria Tolia [3], John Damilakis [4], Maria Paravatou-Petsota [1], Georgia Terzoudi [1]
[1] Laboratory of Health Physics, Radiobiology & Cytogenetics, Institute of Nuclear & Radiological Sciences & Technology, Energy & Safety, National Center for Scientific Research ""Demokritos"", Athens, Greece.
[2] Laboratory of Radiopharmaceutical Chemistry, Institute of Nuclear & Radiological Sciences & Technology, Energy & Safety, National Center for Scientific Research ""Demokritos"", Athens, Greece.
[3] Department of Radiotherapy, University Hospital of Heraklion, School of Medicine, University of Crete, Heraklion, Greece.
[4] Department of Medical Physics, School of Medicine, University of Crete, Heraklion, Greece

Purpose: The radiosensitising effect of quinazoline derivatives through inhibition of Epidermal Growth Factor Receptor (EGFR) is of great importance for the cancer treatment in cases of tumors overexpressing EGFR. The purpose of this study is the evaluation of a new quinazoline derivative, synthesised and chemically characterised at the National Centre for Scientific Research "Demokritos" (NCSRD) as radiosensitizer, as well as the elucidation of the mechanisms underlying the radiosensitising actions.

Materials and methods: The A431 cancer cell line as well as peripheral blood lymphocytes were used. The cytotoxicity of the new compound and its capability of inhibiting EGFR was evaluated using the MTT and the Western Blotting technique respectively. The radiosensitising action was evaluated using the clonogenic assay, while the mechanisms underlying were investigated using the Premature Chromosome Condensation (PCC) and the G2 chromosomal radiosensitivity assay.

Results: The results obtained firstly showed a satisfactory pharmacological action of the derivative with a half maximum inhibitory concentration (IC50) of 1.86 μM for cell viability and cytotoxicity, and an IC50 below 50 nM for EGFR inhibition. After combined with radiation, the clonogenic assay showed that the compound acts as a radiosensitiser. Furthermore, using the PCC technique and the G2 assay, it was shown that the derivative does not increase the initial radiation-induced DNA damage but it affects the residual damage and repair mechanisms involved, indicating the implication of the derivative in the Non Homologous End Joining (NHEJ) repair.

Conclusion: The new tyrosine kinase inhibitor has the potential to radiosensitise A431 cells overexpressing EGFR, mainly by inhibiting the EGFR activation induced by irradiation as well as by affecting the DNA repair mechanisms activated post irradiation. The cytogenetic methodologies of PCC and G2 assay can provide important information for the rapid screening of newly synthesised effective radiosensitisers and the mechanisms underlying.

Comparison of Institutional Diagnostic Reference Levels for Cervical Spine X-Ray Examinations in Adult Patients in Sri Lanka: An Inter-hospital Study

Sachith Welarathna[1] , Sivakumar Velautham[2], Sivananthan Sarasanandarajah[3]
[1] Department of Physics, University of Peradeniya, Sri Lanka
[2] Postgraduate Institute of Science, University of Peradeniya, Sri Lanka
[3] Peter MacCallum Cancer Institute and RMIT University, Melbourne, Australia.

Purpose: To compare institutional DRLs (IDRLs) in adult patients referred for cervical X-ray examinations in six public hospitals in Sri Lanka.

Materials and Methods: The hospitals selected for this study were labelled as A, B, C, D, E, and F. Data on patient demographics (age, sex, weight, and BMI), exposure parameters (kVp and mAs), and kerma-area product (KAP) measurements were collected from 386 patients (58±20 kg). The Kruskal-Wallis Test was utilised to compare the differences in the median KAP values across the hospitals ($p<0.05$).

Results: The median value of the KAP distribution for each hospital was proposed as IDRL. The mean BMI in kg.m-2 of patients was comparable among hospitals. The IDRLs of hospitals A, B, C, D, E, and F were 0.46, 0.24, 0.18, 0.21, 0.25, and 0.23 Gy.cm2 for anteroposterior (AP) view and 0.35, 0.19, 0.35, 0.32, 0.22, and 0.31 Gy.cm2 for lateral (LAT) view, respectively. Hospital A reported the highest IDRLs for the AP view, while hospitals A and C reported the highest IDRLs for the LAT view. These elevated levels were attributed to the utilisation of high mAs values. There were significant differences in the median KAP values across the hospitals for both views. The median kVp used for the AP view ranged from 60 (E) to 70 (A, B, C), while for the LAT view, it ranged from 65 (D, E) to 71 (C). The median mAs for the AP view varied from 12.5 (C, D) to 20.0 (A), while for the LAT view, it varied from 14.0 (D) to 25.0 (C).

Conclusions: The IDRLs presented in this study can serve as baseline doses for establishing national DRLs for cervical spine examinations in Sri Lanka. Owing to the significant variations observed in KAP values and exposure parameters, this study recommends reviewing current practices, including the selection of exposure parameters and collimation.

How Can We Best Care for Our Transgender Patients? Combining the Patient Perspective with Radiation Safety

Naoise Donohue [1*], Marie-Louise Ryan[1]
[1] Radiography and Diagnostic Imaging, UCD School of Medicine, Ireland

Purpose: The increased visibility and social acceptance of transgender people has exposed the dearth of research on this marginalised community, particularly within diagnostic imaging. Available literature has highlighted the systemic discrimination they face within healthcare and that the absence of education for healthcare professionals has resulted in an inability to provide patient-centred care. Currently, there has been minimal research regarding radiation safety and transgender patients. This research has aimed to determine what barriers transgender people experience in their care, the safety risks they identify in current practice, and what could be done to resolve them.

Materials and Method: Five semi-structured interviews have been conducted with transgender individuals. Question themes involved: radiation safety, education, and patient care. Prior to each question, relevant information had been presented to participants, such as the effects of radiation, to provide context for them to construct their answers. Thematic analysis has been used on each interview transcription following thorough reading.

Results: Thematic analysis has revealed four themes, which are: informed consent, healthcare professionals' education, patient identification, and patient comfort. The results have determined that current risks include healthcare professionals not gaining full consent prior to procedures, an absence of education causing inappropriate care or negative experiences, and inadequate patient identification leading to the potential for accidental foetal exposure. Recommendations for improvement consist of creating a baseline of education for healthcare professionals, a method to self-declare and record a patient's gender identity, and to amend current policies to be inclusive.

Conclusion: Transgender patients present with unique healthcare needs compared to cisgender patients. Education of healthcare professionals at undergraduate and postgraduate levels must be established to ensure appropriate patient care, and to minimise the radiation incidents that could occur. Further study with community involvement is required to determine how to improve gender identity declaration in healthcare.

Determining Effective Radiation Dose from modern PET CT imaging: Single centre dose calculations of multiple PET CT protocols

Kevin O'Regan [1], Michael Manley [1], Laura Corkery [1], Catherine Gell [2], Peter Murphy [2], Stephen Stone [2]
[1] Cork University Hospital
[2] Alliance Medical Diagnostic Imaging, Cork University Hospital

Purpose: The clinical indications and demand for 18F-FDG PET CT is increasing and novel tracers such as 18F-PSMA-1007 are being incorporated into routine clinical practice. Adherence to radiation safety principles is key as PET CT is considered a high radiation-dose procedure. Newer technologies allow lower CT exposures and reductions in administered radiotracer activities due to greater sensitivity and technology such as automatic tube current modulation and deep learning algorithms.

The aim of this study was to retrospectively estimate the effective dose received by patients in a newly commissioned PET CT scanner during the first 3 months of operation. Calculating the effective dose will allow comparison of PET CT radiation exposures with other imaging modalities and allow for more effective communication with patients and referring clinicians when weighing up the benefits and risks of radiation exposures.

Methods: Radiation dose information (administered activity in MBq, CT dose index mGy, and DLP in mGy/cm) was collated for 100 patients. Patient information including height, weight, BMI was also collected. Four different PET CT scanning protocols were evaluated (18F-FDG Brain, 18F-FDG Standard skull base to thighs, 18F-FDG vertex to feet, and 18F-PSMA-1007 PET skull base to knees). The estimation of total effective dose was determined by the sum of the effective dose from the radiopharmaceutical administration, calculated by the product of the administered activity and effective dose coefficient added to the calculation determined for the CT scan portion which was done using DLP to effective dose conversion factors.

Results: The results of this study are still under evaluation and will be reported at the time of the meeting.

Conclusion: Effective dose measurement in modern PET CT scanners is important to determine to ensure compliance with international standards, and aid communication with patients and referring clinicians in discussions about the risks of ionizing radiation exposure.

Correlation analysis between radioactivity concentration and radiation dose rate of Naturally Occurring Radioactive Material (NORM) : Zircon Industries

Junghwan Jang [1]*, Kyeongjin Park [1], Hanchang Seo [1], Jaekook Lee [1]
[1] Korea Institute of Nuclear Safety, Daejeon, Republic of Korea

In Korea, naturally occurring radioactive materials (NORMs) are managed according to their radioactivity concentration and amount under the Domestic Act on Action Guidelines against Radiation in the Natural Environment. Gamma spectroscopy using secular equilibrium is the predominant method for the analysis of radioactivity concentrations of the U-238 or Th-232 series. However, given the time and cost of analysis, analyzing all NORMs by gamma spectroscopy can incur significant operational or regulatory costs. In this study, the correlation between radioactivity concentration and radiation dose rate was analyzed to determine the feasibility of developing dose rate-based screening levels that are easy to measure. In this study, the radioactivity concentration and dose rate of zircon (and zirconia), a major NORM in Korea, were compared and analyzed. Radioactivity concentrations and dose rates were measured and computationally simulated for a total of 38 cases. A compensated GM survey-meter (RadEye B20-ER, Thermo Scientific) was used to measure the dose rate of the packaged zircons by distance, and samples were taken for gamma spectroscopy using secular equilibrium. The dose rate measurement results were compared with the results of simulation of the field measurement situation using a radiation transport code (MCNP6.2-EXE, LANL). Zircons were analyzed for radioactivity concentrations in the range 1.2-7.3 Bq/g and 0.18-1.2 Bq/g for the U-238 and Th-232 series, respectively, with dose rates in the range 0.13-2.47 μSv/hr at 10 cm distance. The coefficient of determination (R2) was found to be greater than 0.95 when comparing the linear correlation between the measured and simulated values at distances of 5 to 30 cm from the zircons. At a distance of 5-10 cm, the relative error between the measured and simulated values was within 30%. The results of this study will contribute to the basis for the development of screening levels for the NORM industry.

Methodology for assessment of radiological impact of former metallic mining sites in Extremadura (Spain)

J. Guillén [1*], J.L. Figueredo [1], P. Rodríguez-Oliver [1], J.G. Muñoz-Muñoz, A. Salas [1], J.J. Tejado [2]
[1] LARUEX, Dpt. Applied Physics, Faculty of Veterinary Sciences, University of Extremadura, Avda. Universidad, s/n, 10003 Cáceres, Spain
[2] INTROMAC, Avda. Universidad, s/n, 10003 Cáceres, Spain

There were many metallic mining sites (Cu, Ni, Zn, Pb, Ag, Fe, Sn, W, etc.) in Extremadura up to the midst of the 20th century, when this industrial activity was largely abandoned. Although it is essentially a non-radioactive industry, the generated wastes may present enhanced concentration of naturally occurring radionuclides. The abandonment of these mining activities generated many legacy sites with tailings which may have a potential radiological impact on the environment because of the naturally occurring radionuclides associated with them. In order to establish a methodology, we selected three different mining sites with tailings and carried out sampling campaigns in different seasons (mainly wet and dry), considering the main pathways: external dose rate, transfer into foodchain, association of radionuclides with soil particles and radiological impact on non-human biota. As these are legacy sites, with no working activity and no underground accesses at the moment, the inhalation pathway was considered negligible. In each site, external gamma dose rates were used to generate isodose maps generated. Soil and vegetation samples were collected to derive local transfer factors. Bioavailability of radionuclides in soil was assessed via sequential extraction procedures. Finally, the radiological impact on non-human biota was assessed via Erica Tool.

Acknowledgments: This work was financed by Junta de Extremadura through the project "" Evaluación del impacto radiológico ambiental de la minería metálica en Extremadura "" (IB20060).

Status of regulations on the use of radiation in Korea

Lee Sang-Min[1], Kim Woo-Ran[1], Kim Ji-Young[1]
[1] Korea Institute of Nuclear Safety

Introducing the current status of institutions using radioisotopes and radiation generators in Korea and introducing the current status of the periodic inspection system

In Korea, regulations are applied to institutions using radioisotopes by dividing them into reporting agencies or licensing agencies.

For licensing agencies, radiation safety management is checked periodically through inspections as prescribed by law.

As a method of periodic inspection, on-site inspection or written inspection is based, and remote inspection is introduced and conducted after COVID-19.

Determining external doses from artificial gamma emitting isotopes in soil: Cs-137

Concepción Olondo[1], Saroa Rozas[1], Raquel Idoeta[1], Margarita Herranz[1]
[1] Energy Engineering Department, University of the Basque Country (UPV/EHU), Plaza Ingeniero Torres Quevedo,1, 48013, Bilbao, Spain

Purpose: Cs-137, a gamma emitter, is present in the soil due to the radioactivity released during atmospheric nuclear testing. Cs-137 was deposited in the soil at different concentrations depending on the latitude, and therefore the external dose from its gamma emission will be different in different places. The external dose caused by this presence on the Spanish mainland is determined using data on the concentration of the inventory activity in different places along the Spanish Iberian Peninsula.

Materials and methods: The inventory of Cs-137 was analysed, together with the vertical migration profile of the radionuclide in 29 sampling points of undisturbed soils all along the Spanish peninsular territory. The external effective dose in the human body irradiated by gamma photons from Cs-137 deposited in soil is calculated using the RESRAD ONSITE code from the activity inventory data and the depth reached at each site.

Results: From the activity concentration values obtained, which range between 251 and 6074 Bq/m2, the annual effective dose values were obtained and they are found to be between 1.2 microSv/y up to 2.1 microSv/y; the higher value belongs to a site with one of the higher deposit inventory values, reaching up to 30 cm in depth, and the lower value belongs to one of the lower ones, reaching only 12 cm depth.

Conclusions: The annual external effective doses in humans from Cs-137 in soils in Spain are similar to the values from other countries and, as expected, very low, almost insignificant when compared with the external gamma radiation average effective dose of 480 microSv/y observed by UNSCEAR (2000).

MEENAS releases its new webpage

Almudena Real [1]*, Meritxell Martell [2], Sophie Jacob [3], Boris Brkljacic [4], Eymeric Lafranque [5], Veronika Olsovkova [6], Yevgeniya Tomkiv [2]
[1] ALLIANCE
[2] SHARE
[3] MELODI
[4] EURAMED
[5] NERIS
[6] EURADOS

Purpose: MEENAS, the Consortium of the European Research Platforms in Radiation Protection which includes MELODI, EURADOS, EURAMED, NERIS, ALLIANCE and SHARE, has launched a new website https://www.meenas.eu/ , to give more visibility to the MEENAS Consortium, its collaborations and activities.

Materials and Methods: A working group with representatives of the six European Research Platforms in Radiation Protection was created to design the structure of the new MEENAS webpage and to compile updated content for each section of the webpage.

Results: The MEENAS webpage (https://www.meenas.eu/) has the following sections:

• News: includes the latest news from MEENAS and gathers news of the 6 platforms.
• Activities: includes both information on research projects in which MEENAS has participated or is participating, collaborations with other organisations and internal activities organised by MEENAS.
• Events: both European and international, related with radiation protection and other related disciplines.
• Library & Docs: with reports, publications, abstracts produced by MEENAS, but also an archive with all the deliverables produced during the EJP-CONCERT (2015-2020) and the 9 research projects that CONCERT funded. In this section relevant links to radiation protection, European and worldwide organisations can also be found.
• Grants & Positions: collects information on funding opportunities for young researchers and students to attend scientific events, together with funding resources for researchers to organise training courses. It also inform on research positions available in different organizations.

Conclusion: The new MEENAS webpage is a useful tool to search for relevant information on radiation protection, including events, grants and job positions as well as an archive that contains results obtained in past European radiation protection projects, as the EJP-CONCERT.

We encourage you to visit the new MEENAS webpage at https://www.meenas.eu/! Please note that this work is linked to ALL the platforms.

Radiation Safety E-Learning Training for Non-Radiology Doctors and other Staff: Experiences in a Major Academic Teaching Hospital in Ireland

Jose Jr Binghay [1]*, Thomas Heary [1], Aine Matthew[1], Ronan Faulkner [1], Jack O'Shea [1], Barbara Martin [1], Barry Hallinan [1], Hai Lien Thanh [1], Emma Fitzpatrick [1], Ruth Bridcut [1], Lynn Gaynor [1]
[1] Beaumont Hospital, Dublin, Ireland

Purpose: This study explores the implementation and efficacy of an e-learning program for radiation safety training at Beaumont Hospital, an Irish academic teaching hospital. The program aims to enhance relevant staff's radiation safety knowledge in accordance with COUNCIL DIRECTIVE 2013/59/EURATOM, Irish regulations (SI 256 of 2018 and SI 30 of 2019), and regulatory requirements.

Methods: The Hospital's radiation safety governance, Learning and Development, and Human Resources departments collaborated to develop two modules for the Beaumont Online Resource for Interactive Study (BORIS), a Moodle® based Learning Management System. The content was designed for allied health professionals working in controlled areas, as well as referrers and practitioners. A post-training multiple-choice questionnaire assessed learning course material comprehension.

Results: Despite the challenges of the COVID-19 pandemic and high staff turnover, the shift to e-learning demonstrated remarkable success in improving radiation safety training compliance. BORIS was utilised to track completion rates across nine clinical directorates. Overall completion rates increased annually, rising from 63% in 2020 to 77% in the first quarter of 2023. Most directorates impoved their training completion rates year after year.

Conclusion: The use of e-learning for radiation safety training at Beaumont Hospital proved transformative, fostering engagement and compliance. Facilitating access to mandatory upon employment acceptance was critical in increasing completion rates.

Ongoing efforts to improve compliance include regular communication with stakeholders and the transparency of completion data for managerial review. The platform is constantly updated and customised to meet evolving professional and regulatory requirements, thereby setting new standards for radiation safety training in the Hospital. This initiative has contributed to developing a national radiation safety e-learning program within the Irish public health service.

Investigating the ability of radiographers in Malta to recognise the need for repeats in trauma appendicular radiography

Karen Borg Grima[1]
[1] Department of Radiography, University of Malta

Purpose: Radiographers in diagnostic imaging are expected to have knowledge on image evaluation criteria, as this directly effects image quality, the need to perform repeats and eventually patient radiation doses.

The study proposed to evaluate the radiographer's awareness of the need for repeats in trauma images of the appendicular skeleton. The study also aimed to investigate if demographic factors such as age, work experience, and academic qualifications made a difference in the radiographer's ability to evaluate an image.

Materials and Methods: This research consisted of a cross-sectional, prospective, and quantitative approach. A tool was distributed to the participants through a software (ViewDex) that was pre-downloaded on the researcher's personal computer. A self-designed anonymous questionnaire that asked questions on participants' demographics was also distributed. ViewDex was used to showcase a set of normal and abnormal trauma radiographs of the appendicular skeleton, together with questions related to the images. The images were obtained from online freely available websites.

Results: Results from the study were represented by an ability score indicating the ability to evaluate the contrast, spatial resolution, and exposure parameters, of a set of normal and abnormal trauma images. An overall mean ability score of 77.44% was found. The overall mean image repeat score was 70.40%, which represented the correct responses obtained on the reject analysis of the selected images, in comparison to the responses of the gold standard or expert. These results were than compared with the participants' demographic data.

Conclusions: The results from the study suggested that radiographers should pursue further education via CPDs or training regarding image evaluation criteria, to help standardise image rejection in hope of reducing unnecessary repeats, and therefore unnecessary patient irradiation. The data analysis revealed trends in the results obtained however, there was no statistically significant difference in the findings.

Understanding Daphnia pulex' response to ionising radiation

Pierre Techer [1], Frédéric Alonzo [1], Olivier Armant [1*]
[1] Laboratoire d'Ecotoxicologie des Radionucléides, IRSN Cadarache, France

Understanding the long terms effects of low-dose irradiation on an ecosystem and the potential effects on species is one of the many challenges of ecotoxicology. The contaminated environment of the Chernobyl Exclusion Zone (CEZ) represents an archetypical situation to study the effects of rapid environmental changes caused by radionuclide pollutions on wild populations.

My PhD project aims to understand how Daphnia pulex (a keystone species in freshwater ecosystems) populations evolved following the 1986 Chernobyl catastrophe.

Recent studies on population genetics demonstrated that the D. pulex populations found in differently irradiated lakes showed an increase in genetic diversity correlated with dose rate, with no difference in life history traits over one generation (Goodman et al, 2019, 2022).

-Building upon these observations, we study the response of a D. pulex clone (D. pulex TCO) exposed to ionizing radiation in laboratory to better understand how a naïve population performs under irradiative stress. Life history traits (Growth, reproduction, survival) have been monitored over 3 generations at 6 different dose rates. Microsatellite sequencing techniques will then be used to test whether genetic variation is significantly introduced in high dose rate conditions following chronic irradiation.

The results of the first irradiation indicate that D. pulex seems resistant to ionizing radiation, with the only adverse effects being observed on the total number of offsprings at the highest dose rate (35 mGy/h) in the first generation. An hormetic effect can be observed on the 2 lowest dose rate (5 µGy/h and 50 µGy/h) during the first generation, with no apparent consequence in the following generations.

These first results point toward a complex response to ionizing radiation over generations by a species that seems resilient to this type of stressor. Further study is necessary to ascertain the limits and modalities of said resilience.

Evaluation of the effects of ionizing radiation on honeybees (Apis mellifera L.), from the molecule to the population

Margot Crevet [1]*, Béatrice Gagnaire [1], Jean-Luc Brunet [2], Jean-Marc Bonzom [1], Nicolas Dubourg [1], Michel Pelissier [2], Fabrice Daian [3], Gabriel Bon [3], Luc Belzunces [2], Olivier Armant[1]
[1] IRSN/PSE-ENV/SRTE/LECO, Saint-Paul lez Durance, France
[2] INRAE/A&E/LTE, Avignon, France
[3]AMU/IBDM, Marseille, France

The radiocontamination of the environment is a major ecological issue. To better anticipate the consequences of nuclear accidents, it is necessary to improve our knowledge of the environmental impacts and risks of irradiation and contamination related to radioactive elements. In the context of my thesis, the honeybee, Apis mellifera, was chosen as a model to study the effects of ionizing radiation (IR). Becausevery few data exist on this subject, the objective of the research program is to deepen the knowledge of the effects and mechanisms involved in the action of IR on bees.

My thesis will be based on two approaches: field and laboratory. The field part is developed by monitoring hives placed on sites around the Fukushima nuclear power plant during two years. The laboratory part is brought by exposing bees to external irradiation during experiments conducted in controlled conditions. An estimation of the total dose rates absorbed by the bees will be established. A large part of my thesis focuses on the evaluation of the physiological effects induced by IR on bees, as well as the toxicopathological effects. Effects induced at individual and population levels will also be described. Results obtained in field and laboratory experiments will be compared to investigate whether data observed in laboratory conditions could be extrapolated to predict effects in real conditions.

BEECONECT: a connected "flower" to measure the effects of radioactive contamination on the cognitive health of insect pollinators

Olivier Armant[1]
1 Laboratoire d'Ecotoxicologie des Radionucléides, IRSN Cadarache, France

Insect pollinators, such as bees, flies, and butterflies, are declining worldwide. This is alarming since these animals are vital to the maintenance of terrestrial ecosystems and global food security. Pollinators heavily rely on learning and memory to forage on flowers. However, these cognitive abilities can be easily disrupted by a range of environmental stressors, even at low exposure levels (e.g. insecticides, heavy metals). If impairment of brain development and/or learning processes often only has immediate subtle effects on individual behaviour, this can have long-term dramatic consequences on populations, if food supply is compromised.

The aim of BEECONECT is to study the effects of radioactive contamination on the cognitive health of pollinators (honeybees and other wild insects) in the Fukushima Prefecture (Japan). Following the example of recent work on other environmental stress factors (e.g. neonicotinoid pesticides, heavy metals), we hypothesize that exposure to radioactive pollution, even at very low levels, can have sub-lethal effects on individual cognitive abilities with critical consequences on populations.

To assess the cognitive health of pollinators in the field, we will run mass phenotyping of thousands of bees using a newly developed automated and non-invasive method: a connected "flower" in which the insect must solve a task in a Y-maze to obtain a nectar reward. Our system uses on-board artificial intelligence, enabling recognition of individual bees and species. The learning performance of each insect is recorded, then sent to a dedicated server for online data analysis. This device is the first automated cognitive test ever deployed to measure cognition in insects, and more broadly in invertebrates. It is these effects that we want to identify in order to accurately quantify the risks of radioactive contamination of the environment for pollinator populations and their associated ecosystem services.

Do ionizing radiation and soil drought affect earthworm bioturbation?

Olivier Armant[1]
[1] Laboratoire d'Ecotoxicologie des Radionucléides, IRSN Cadarache, France

IRRASOIL aims to quantify the effects of ionizing radiation on soil communities and associated functional processes, in interaction with predicted climate change. To do so, soil mesocosms were constructed using natural soil manipulated in order to remove macrofauna. Then, a selection of epi- and endofauna species known for their effects on soil processes (leaf litter decomposition, recycling of elements, modification of soil structure and texture…) was added to the soil according to different combinations, including controls without any addition. Finally, a mixture of leaf litters was deposited at the soil surface. Soil mesocosms were disposed into climatic chambers in order to control environmental parameters (temperature and humidity). Using the large-scale irradiation facility available at the French Institute for Radiological Protection and Nuclear Safety (IRSN), we were able to expose the soil mesocosms to different dose rates. Bioturbation activity was quantified using complementary X-ray tomography and fluorescent particulate tracer methods. Preliminary results suggested no effect of soil humidity change on bioturbation but effects of ionizing radiation on both the construction of galleries and on particle reworking by earthworms.