RADIATION PROTECTION FOR EVERYONE

CONGRESS PROCEEDINGS

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T01: NIR Non-ionising radiation

IMPORTANCE OF INDOOR LIGHTING FOR WELL-BEING, PHYSICAL AND MENTAL HEALTH

Mariëlle AARTS

Since the last decades, people spend most of their time indoors. As a result, the exposure to natural daylight is reduced enormously. Given the current insights on how light effects people beyond vision, one should not neglect the power of indoor lighting; both from a positive as from a negative perspective. Performance and alertness for daytime people can be impacted by light exposure. The most obvious route, so far, seems to be via circadian alignment. When people's biological clock is not well-aligned with the social clock, it negatively influences their functioning. When assuming that the natural light with all its specific characteristics, is best for people, what are people missing when being indoors most of the time, and how is this relevant for their well-being, and health?

LIMITS OF SCIENTIFIC INSIGHT WHEN UPDATING ICNIRP GUIDELINES

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When developing or updating guidelines it is necessary to establish adverse effects thresholds, so that these can be used as a basis for setting exposure restrictions.

For example, quantitative threshold data for adverse effects of acute exposures to ultraviolet radiation are both comprehensive and reasonably robust for common exposure scenarios. However, the thresholds show a very strong spectral dependence and the recent development of germicidal applications based on excimer lamps has triggered a need to re-evaluate data at very short wavelengths where limits have seen little application in the past. Whilst it is relatively easy to identify limitations in these data, this is not the same as having a robust basis from which to develop revised limits.

Establishing reliable numerical threshold data is particularly challenging in relation to adverse effects of long-term exposure, where evidence for harm to people is inevitably based almost exclusively on epidemiological studies of sun exposed populations. Aside from the inherent uncertainties associated with retrospective estimation of exposure over periods of decades, the absence of spectral dependency data is especially problematic.

A FRAMEWORK FOR NON-IONIZING RADIATION PROTECTION

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Keywords: Non-ionizing radiation, radiation protection, framework, health

No international framework for health protection from non-ionizing radiation (NIR) currently exists. Rather, a number of countries maintain different compliance needs targeting only specific NIR exposure situations. An overarching and coherent framework developed by the World Health Organization will promote a globally consistent approach for the protection of people from NIR. Its goal is to allow governments to respond to policy challenges on how to achieve effective protection of people, especially in a world that is rapidly deploying new NIR technologies. Based on decades of practical experience the framework provides guidance on establishing national health and safety objectives for the public, workers and patients. It supports multisectoral action and engagement by providing a common language and systematic approach for managing NIR. This presentation will highlight the concepts and key features that underpin the framework for NIR protection, along with some examples of implementation.

THE EFFICACY AND SAFETY OF DISINFECTION WITH 222 NM ULTRAVIOLET-C

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Keywords: Krypton Chloride, ultraviolet-C, efficacy, safety, 222 nm

Over the past two years, there has been a dramatic increase in the development of technologies claiming to disinfect surfaces and the air of infectious pathogens. One optical radiation technology making such claims is the Krypton-Chloride (KrCl) excimer lamp. The KrCl lamp emits a narrowband of ultraviolet-C (UVC) radiation at 222 nm, with lower intensity emissions at longer ultraviolet wavelengths. Like other wavelengths of UVC, 222 nm is absorbed by nucleic acids causing photochemical changes that prevent a pathogen from reproducing; effectively inactivating it. However, strong absorption in the skin's stratum corneum and the eye's tear layer appear to result in 222 nm being safer than other, longer UVC wavelengths. This gives potential for 222 nm to be used as an optimal disinfection technology to assist in the reduction of infectious disease transmission.

Our computer modeling demonstrated that it is the longer wavelength emissions from KrCl excimer lamps that were responsible for skin reddening (erythema) and DNA damage, previously observed in a clinical trial. This was supported by *in vivo* self-exposure experiments at high radiant exposures from filtered KrCl lamps, showing no acute reactions in the skin and minimal superficial DNA damage.

Computer modeling has investigated the efficacy of 222 nm for air disinfection in simulated environments. Our results highlighted the importance of adequate irradiation spatially, temporally and in terms of lamp intensity. This was corroborated in a controlled experiment performed in a room-sized chamber, with 92% reduction in pathogen load at current European exposure limits for 222 nm. This was equivalent to 35 air-changes-per-hour (ACH), outperforming a portable air cleaner (15.5 equivalent ACH at 500 m^3h^{-1}).

In this presentation we review our research findings, place them in the context of other published material and present exciting new data from unpublished ongoing research studies.

OCCUPATIONAL EXPOSURE TO ELECTROMAGNETIC FIELDS AND HEALTH SURVEILLANCE OF WORKERS

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Keywords: electromagnetic fields, occupational exposure, health surveillance

Introduction.
Electromagnetic fields (EMF) exposure is a diffused occupational risk: a large number, possibly the majority, of workers are potentially exposed. The opportunity of an effective Health Surveillance (HS) of such workers is recognized and in some Countries is mandatory. Nevertheless, specific criteria for an effective HS of EMF exposed workers are hitherto scarcely defined.

Materials and Methods.
In the European Union an obligation for the HS of EMF exposed workers is provided by the Directive 2013/35/EU, also providing Exposure Limits Values (ELVs) for occupational exposures. Considering the legal obligation introduced by this Directive, an outline of the main criteria to be considered for an appropriate HS of EMF exposed workers is discussed.

Results.
The HS is aimed to protect and to promote the workers' health. The EU Directive specifically addresses the prevention of EMF direct biophysical effects (as stimulation of muscles, nerves or sensory organs, or thermal effects) and indirect effects (as interference). Conversely, long-term effects are not addressed as scientific evidence of a causal relationship is considered inadequate. Occupational EMF-exposures lower than the ELVs can be usually considered adequately protective against the direct effects, but the occurrence of groups of "workers at particular risk" (e.g. subjects with active medical devices as pacemakers, and also pregnant women) must be considered, and adequate prevention provided. To date no laboratory tests or specific medical investigations can be considered adequate in terms of validity and performance.

Conclusions.
The HS of occupational EMF exposed workers is mainly aimed at evidence the occurrence of direct biophysical and indirect effects of EMF, while, at least in EU Countries, long term effects are not addressed. Another aim of HS is to screen conditions possibly inducing an increased susceptibility ("workers at particular risk"), and to adopt appropriate preventive measures.

COMPARISON OF EXPOSURE TO RADIOFREQUENCY ELECTROMAGNETIC FIELD EMITTED BY RTV AND MOBILE COMMUNICATION TRANSMITTERS IN URBAN ENVIRONMENT

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Keywords: electromagnetic field, measurement, exposure, public health, environmental engineering

In the urban environment, due to the large number of users, there is the highest density of radiocommunication antennas and the electromagnetic field (EMF) with the most complex frequency spectrum. The main sources of exposure are base stations of mobile communication networks and terrestrial radio and television broadcasting transmitters. Our investigations covered recordings of electric field strength, recorded simultaneously in narrowbands harmonized with frequencies of emissions from the above-mentioned types of sources located in Warszawa, Poland (Gryz et al., 2021).

A comparative analysis of the recordings showed that currently the strongest component of the total urban exposure is related to the use of wireless Internet (component of exposure from various LTE signals) and, to a lesser extent, voice calls (component of exposure fromr GSM signals) as part of mobile communication services. Our results correlate with observed continuous increase in the use of mobile networks and changes in the structure of telecommunications services used by mobile communication users. Inside office buildings the total level of recorded EMF exposure was significantly lower than 10%of general public reference limits (Council Recommendations 519/1999/EC).

Gryz, K., Karpowicz, J., Zradziński, P. 2021. Electromagnetic field emitted by radiocommunications systems – changes in Warsaw in the 21st century. Bezpieczeństwo Pracy 7(598), 5-9 (in Polish).
Gryz, K., Karpowicz, J., Zradziński, P. 2021. Empirical assessment of the electromagnetic effects of the development of urban radiocommunication networks from the perspective of a clinical hospital (2014-2021). Inżynier i Fizyk Medyczny. 5(10), 363-367 (in Polish).

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TRANSCRANIAL ELECTRIC AND MAGNETIC STIMULATION

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Transcranial magnetic stimulation (TMS) and transcranial electric stimulation (TES) are non-invasive techniques to trigger and modulate neuronal activity. Application areas are the treatment of various neurologic and psychiatric diseases such as stroke or depression as well as neuroscientific research on normal and abnormal brain function. The development and application of new approaches in TES and TMS, e.g. multi-channel stimulation, requires verification and validation approaches. We propose a new concept for a physical head phantom to address the verification and validation of these techniques. Compared to simulations, physical phantoms consider real-world influences, such as environmental noise or 3D positioning errors. At the same time, physical phantoms allow for a representation of the ground truth, because of their well-known structure and function. We present a phantom concept and a characterization study of phantom materials. The phantom consists of three conductivity compartments and interior components for measurement purposes. Our results show that agarose, gypsum, and NaCl solution can serve as stable representations of the three main conductivity compartments of the head, i.e. scalp, skull, and intracranial volume.

TMS and TES protocols are often applied in a one-size-fits-all fashion, using a fixed stimulation configuration for all subjects participating in an interventional study. This disregards individual differences concerning anatomy and physiology. Thus, inhomogeneous subject groups or the transfer of stimulation protocols to different age groups might result in considerable effect variation. Simulation of current flow based on individual head models can help to individualize stimulation parameters and contribute to the understanding of the causes of this response variability. We review studies that show a relationship between the presence of behavioral/neurophysiological responses and features derived from individualized current flow models. We highlight the potential benefits of individualized current flow modeling.

COMPARISON OF LIMITS IN ICNIRP GUIDELINES AND IEEE C95.1 STANDARD

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Keywords: radio-frequency guidelines, standardization, exposure limit, comparison

Recently, two international exposure guidelines and standard mentioned in World Health Organization (ICNIRP, 2020; IEEE, 2019) have been revised. The guidelines for human exposure set restrictions based on classical heating mechanisms, because all adverse effects are avoided by avoiding adverse effects related to temperature rises above 100 kHz.

There are two primary changes in these revised guidelines at frequency band where the 5th generation (5G) wireless communication system is used; new metrics for continuous exposure and brief exposures. First, New physical quantity named absorbed or epithelial power density averaged over the area of 4 cm^2 is introduced for human protection from continuous (almost sinusoidal) exposures at frequencies above 6 GHz. This averaging area was designed to match the face of averaging volume (10 g in cube) of the specific absorption rate (SAR). For practical assessment, the limit is conservatively derived from the absorbed power density in terms of incident power density averaged over the same area (4 cm^2). The second one is new limit in terms of absorbed energy density/fluence which prevent instantaneous skin temperature rise for exposure to pulses much shorter than thermal time constant of biological tissues (typically several minutes). The rationale for these new metrics and trend of standardization will be reviewed. In this presentation, additional changes and remaining differences are summarized.

ICNIRP, 2020. Guidelines for Limiting Exposure to Electromagnetic Fields (100kHz to 300 GHz). *Health Phys. 118,* 483-524.
IEEE-C95.1-2019. Standard for Safety Levels With Respect to Human Exposure to Electric, Magnetic and Electromagnetic Fields, 0 Hz to 300 GHz.

EMF DOSIMETRY AND ASSESSMENT ABOVE 6 GHZ

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Keywords: 5G wireless communication system, safety assessment, power density

International guidelines and standards for human protection from radiofrequency fields have been revised recently, especially at frequencies higher than 6 GHz. This frequency range will be used for new wireless communication systems, i.e., 5G wireless communications system. Above 6 GHz, a new physical quantity "absorbed or epithelial power density" has been adopted as a dose metric. Then, the permissible level of external field strength or power density is derived for practical assessment in a conservative manner. The limits were explicitly designed to avoid excessive increases in body surface temperature, based on electromagnetic and thermal modeling studies but supported by experimental data where available. Another aspect to be considered is how to conduct compliance assessment for wireless terminals, especially for continuous exposures. This issue has been discussed in the IEC Technical Committee 106. This talk first reviews the studies on the computational modeling or dosimetry which are related to the revision of the guidelines and standard. The trend of standardization for product assessment is also reviewed briefly.

EMF-RISK ASSESSMENT – SUPPORTING GERMAN SME WITH TECHNICAL RULES

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Keywords: electromagnetic fields, occupational exposure, German transposition of 2013/15/EU, risk assessment in SME

The European Directive 2013/35/EU came into force in 2013, defining minimum health and safety requirements regarding the exposure of workers to the risks arising from electric, magnetic and electromagnetic fields (EMF). Similar to all other European member states, the Directive 2013/35/EU had to be implemented into German occupational safety and health legislation. It was open to the member states whether to implement 2013/35/EU into national legislation directly or to amend to existing regulations. Germany has chosen to transpose the requirements of Directive 2013/35/EU on the basis of the EMF OSH legislation already in force since 2001. The German OSH Ordinance on EMF eventually came into force in November 2016. It is a binding labor regulation for any risks arising from the exposure to EMF at workplaces. To support particularly small and medium sized enterprises (SMEs) with an elaborated but applicable safety approach, Technical Rules will improve the comprehensibility and usability of the German EMF Ordinance. With Technical Rules, Germany's OSH legislator supports employers in fulfilling their obligations arising from the German EMF Ordinance and the Directive 2013/35/EU, respectively. Applying Technical Rules entails presumption of conformity with the related German OSH Ordinance; comparable with harmonized standards regarding product safety regulations. It is planned to make the Technical Rules on EMF available in English language additionally, once they have been published.

The proposed presentation provides insight into the safety concept of the German Technical Rules, their structure and content, as well as the procedure for risk assessments for workers and workers at particular risk.

PEROSH WORKSHOP "EMF EXPOSURE OF ELECTRONIC ARTICLE SURVEILLANCE SYSTEMS AT WORKPLACES"

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Keywords: electromagnetic fields, occupational exposure, electronic article surveillance

Introduction

Electronic article surveillance (EAS) systems are widely used in retail and logistics, e.g. to prevent thievery or to locate and monitor numerous products automatically at the same time. EAS-systems use different frequency bands ranging from static magnetic fields, over intermediate to radio frequencies. Depending on their functioning principles, selected EAS-systems emit intense electromagnetic fields, that in some practical situations may even exceed maximum exposure level at the workplace. Hence, EAS-systems exceeding permissible exposure levels may be of concern for workers, workers at particular risk (e.g. with active implanted medical devices such as cardiac implants), and pregnant workers. Customers may be affected as well as.

In addition, it proved challenging for operators/employers of such systems to obtain sufficient information about safe and healthy operation of EAS-systems from manufacturers or distributors.

Scope of the Workshop

The major intention of the information sharing workshop is to connect stakeholders with a background in occupational safety and health as well as market surveillance across Europe, in order to bundle attention to the potential problems arising from EAS-systems. Therefore the workshop will:

– discuss problems with EMF exposure of EAS-systems at workplaces on a PanEuropean perspective and
– evaluate the necessity to initiate a PanEuropean research- and information dissemination-approach to enable safe and health working conditions.

Content of the Workshop

In order to facilitate a thorough discussion in the second part of the workshop, three presentations focusing on technical issues, application, and standardization will provide an introduction of relevant information to EAS-systems' safe and healthy operation. In the second part of the workshop, the necessity to initiate a PanEuropean research- and information dissemination-approach to enable safe and health working conditions will be discussed, including brief reports on experiences with EAS-technology by workshop participants.

Presentation 1: "Technical Issues"
The presentation introduces the different types of EAS-systems and their range of application. To complete the technological background, the framework of exposure assessment for different possibly exposed persons such as workers, workers at particular risk (pregnant workers and those with implanted medical devices, such as e.g. cardiac implants), and members of the general public will be outlined.

Presentation 2: "Challenges in Application"
Building upon the knowledge introduced in presentation 1, the second presentation elaborates on the typical exposure levels at workplaces with EAS-systems. The workers' Directive on EMF 2013/35/EU offers two different approaches to show compliance with its exposure limits as of annex 2 and 3 and in consequence to deduct mitigation measures. One alternative is to show compliance with Action Levels by field measurements directly at the workplace, the second alternative is to show compliance based on Exposure Limit Values derived by computational dosimetry.

Presentation 3: "Reasonably foreseeable use of EAS and product safety"
Irrespective of compliance with Action Levels, EAS-systems available and operated at the European Single Market may be deemed as safe by a declaration of conformity by their manufacturers or distributors with respect to relevant EU product Directives, e.g. Low Voltage Directive 2014/35/EU, Radio Equipment Directive 2014/53/EU, or Electromagnetic Compatibility Directive 2014/30/EU. Concerning EMF and state-of-the-art EAS-systems, compliance at the workplace is then usually shown by dosimetric simulations of exposure situations and evaluation via Exposure Limit Values. Profound choice of exposure setups and reliable numerical simulations are key to the validity of this approach. The scope of presentation 3 is to contrast reasonably foreseeable use conditions based on harmonized product standards to declare conformity with those use conditions to be found at real world workplaces. Giving some examples of discrepancies, it will become obvious, why products with CE certification are not necessarily operated safely under any condition and thus frequently require further attention.

Discussion
The concluding discussion invites all attendees to contribute their experiences, views, and thoughts about the safe and healthy operation of EAS-systems.

INVITED ABSTRACT: CHALLENGES OF 5G NR EXPOSURE ASSESSMENT

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As the roll-out of the fifth generation (5G) of mobile telecommunications is well underway, standardized methods to assess the human exposure to 5G NR base station radios are needed. The 5G mobile networks being rolled-out consist of 5G new radio (NR) technology and Massive MIMO (MaMIMO) where the base stations will in most cases use beamforming. MaMIMO as 5G technology enables benefits such as excellent spectral efficiency and superior energy efficiency. The main concept is to use large base station antenna arrays to simultaneously serve multiple user equipment. Challenges and a method for in-situ assessment of radiofrequency (RF) electromagnetic field (EMF) exposure from fifth generation 5G NR base stations is presented and applied in test sites and in a commercial NR network.

Up to now, only limited research and methods are available on how to conduct in-situ 5G exposure measurements. An important challenge is to obtain correct realistic exposure and avoid unrealistic overestimations by assuming continuous beamforming. Therefore, the first in-situ the first assessment of downlink exposure to fifth generation (5G) New Radio NR base stations will be presented. The fields are determined in-situ using a novel assessment method for downlink exposure to fifth generation NR base stations. Realistic exposure levels with and without active user equipment have been determined by measurements and simulations.

During the measurement campaign, four base station sites were investigated and the exposure was assessed at different positions and distances from the base stations. Extrapolation to the maximum exposure level can be done without prior knowledge of the radiation patterns. The impact of the NR network on the total environmental RF will be discussed for average and maximal values, with and without user device.

NUMERICAL MODELING OF OCCUPATIONAL HAZARDS RELATED TO ELECTROMAGNETIC EMISSION FROM SURGICAL DIATHERMY

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Keywords: environmental engineering, occupational exposure, public health, surgical diathermy units, numerical simulations, electromagnetic field

Performing medical procedures with the use of surgical diathermy units (SDU) all members of treatment team experience exposure to electromagnetic field (EMF) emitted by SDU. Our study is focused on the analysis of biophysical effects of EMF influence in the treatment team members, by means of advanced computer simulations, using realistic models of exposure scenarios in many-persons (1-10 people) treatment teams (modeled using a single-body, homogeneous models of humans, in realistic spatial organization in the treatment room), as well as models of localized exposure near to active electrode handle or cable, for example operated by surgeon (modeled using a heterogeneous posable models of surgeons body, including detailed models of hands).

The results of numerical simulations are analyzed with the use of parameters characterizing electromagnetic hazards in accordance with the requirements of the labor law (i.e. the EMF parameters in the SDU environment and metrics of its impact on humans - the SAR coefficient and the strength of the electric field induced in the body, E-ind).

Next factors influencing strongly on the exposure effects level and spatial distribution in surgeons body are: the number of members of treatment team present next to a patient, the dimensions of the surgeon's body and a way, how the handle of active electrode is kept. Numerical simulations of next realistic cases of exposure are on-going to find the most influencing factors and to evaluate the possible protection measures. So far due to the technical difficulties of the computer modeling required in such study, mentioned problem was insufficiently recognized to fully meet the requirements of labor law.

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MACHINE LEARNING-ASSISTED ANTENNA MODELLING FOR REALISTIC ASSESSMENT OF HUMAN EXPOSURE REFERENCE LEVELS AT FREQUENCIES ABOVE 6 GHZ

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Keywords: non-ionizing electromagnetic radiation, mmWaves, 5G mobile telecommunication technology, human exposure, incident power density

Oversaturation of frequency spectrum, increased need for higher data rates, transmission security and connection reliability have all led to the development of the fifth generation (5G) mobile telecommunication technology, currently in the deployment phase world-wide. Given the fact that operating frequencies of 5G hand-held communication devices often fall into the mmWave frequency range, hitherto poorly researched from the perspective of human exposure to radio-frequency (RF) non-ionizing radiation (Hirata et al. 2021), it is necessary to reevaluate the interaction with the human body and define appropriate dose metrics. The only prominent negative effect of this type of radiation is manifested through the surface heating of the exposed surface of the skin, thus, through standards and/or guidelines, various international bodies have defined dosimetric reference limits and corresponding exposure reference levels, correlated with the increase in tissue temperature (Foster et al. 2018).

This study is based on the assessment of the incident power density - exposure reference level for frequencies above 6 GHz (Hashimoto et al. 2017), through an illustrative example of the near-field exposure of a simple human skin model to high frequency RF radiation. Machine learning and associated techniques such as automatic differentiation have been utilized to improve the overall accuracy of the simulation by eliminating the numerical artifacts inevitable in the standard modelling of a realistic antenna. The discussion on the current state and future directions of differentiable computing in computational electromagnetic dosimetry is outlined.

Foster, K.R. et al. 2018. Modeling tissue heating from exposure to radiofrequency energy and relevance of tissue heating to exposure limits: Heating factor. *Health Phys. 115(2),* 295-307.
Hashimoto, Y. et al. 2017. On the averaging area for incident power density for human exposure limits at frequencies over 6 GHz. *Phys. Med. Biol. 62,* 3124-3138.
Hirata, A. et al. 2021. Assessment of human exposure to electromagnetic fields: Review and future directions. *IEEE Trans. Electromagn. Compat. 63(5),* 1619-1630.

5G AND HUMAN HEALTH: CURRENT KNOWLEDGE AND IMPORTANT KNOWLEDGE GAPS

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”5G frequencies” are found in two different frequency bands, named FR1 and FR2, the first of which is already in use for mobile telecommunications. The possible health effects of these have been regularly evaluated by expert bodies appointed by public authorities. The overall assessment is that RF fields emitted from mobile phones and other mobile communication devices, or the associated transmitters do not pose a risk to human health if exposures are below the limits developed by ICNIRP. However, effects on biological systems and in particular health effects have been studied to a very limited extent for FR2. The studies that have been done are few and are not necessarily suitable for risk assessments. Thus, the basis for a specific risk assessment is insufficient. Similarly, possible effects on environmental organisms (e.g., insects, plants, fungi, bacteria) are insufficiently investigated. Particularly relevant is the question of temperature increase in very small organisms, as the penetration depth of millimetre waves belonging to FR2 can heat up the whole organism.

POTENTIAL CONTRIBUTION OF THE TRANSCRANIAL STIMULATION LITERATURE TO EMF EXPOSURE STANDARDS

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Keywords: non-ionizing radiation, transcranial current stimulation, electroencephalography, EMF exposure standards

Current EMF exposure standards in the extremely low-frequency range (ELF, < 300 Hz) are based on replicable acute effects on human neurophysiology occurring at the lowest known levels of *in situ* electric field, namely the perception of magnetophosphenes (visual perception occurring in the absence of visual stimulus, due to a sufficiently strong electric field at the level of the retina). In their current form, those EMF standards do not take into account results from the literature in the field of transcranial current stimulation (tCS). tCS is a brain stimulation technology consisting in applying a weak electrical current (typically 2 mA maximum) to the scalp using skin electrodes to induce a modulation of the underlying cerebral cortex activity. tCS can be applied using a DC or an AC current (termed tDCS / tACS, respectively). Over the last 20 years, the tCS literature has seen growing and replicated evidence that low-magnitude *in situ* electric fields (on the order of 1 V/m or lower) can modulate electrical oscillations of brain tissue, and result in a modulation of associated cognitive performance, after a duration typically greater than 10 minutes. The mechanisms of action of tCS are being gradually elucidated, and are more complex than the outdated view of triggering action potentials by a sufficiently large electrical stimulation, notably because those effects are not acute but require lasting exposure. Therefore, we will discuss the potential implications of the tCS literature for EMF exposure standards. Overall, considering lasting effects of electric fields at lower levels than those currently considered for acute effects might be a challenging but inevitable task, given the considerable volume of literature arguing for the existence of such effects.

COMMUNICATION WITH THE PUBLIC OF EMF HEALTH EFFECTS: CREATION OF A NON-IONIZING RADIATION TASK GROUP AT IRPA

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Keywords: non-ionizing radiation, public health, International Radiation Protection Association (IRPA), scientific communication

The issue of potential adverse effects of non-ionizing radiation (NIR) on health remains a major concern for the general population. The ongoing deployment of 5G infrastructure and smart meters is a key driver for those concerns. However, there is a lack of information accessible to the general public regarding the known biological effects of NIR. In order to address this issue, IRPA has created a Task Group specifically aiming at coordinating and disseminating knowledge on the effects of NIR for the general public. The NIR TG includes members from national radioprotection societies around the world, to bring a global response on this topic and maximize its impact. In this talk, we will present the members of this new TG and the current plan of actions. This work will be conducted in collaboration with the World Health Organization (WHO), the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the International Commission on Electromagnetic Safety (ICES) of the Institute of Electrical and Electronics Engineers, Inc (IEEE).

INVESTIGATION OF EXPOSURE TO ELECTROMAGNETIC WAVES BY USING UNMANNED AERIAL VEHICLES

Dr. Szilvia NAGY

The article presents measurement options, changes, and results for electromagnetic exposure for NR mobile base stations. I explain the frequency-selective and code-selective measurement procedures. In the case of the new technology, the continuously broadcast channels have changed, and I have also observed their effect. Summarizing these, I present the NR extrapolation formula to be used to evaluate the measurements and its differences from the extrapolation formula used to measure the EMF of 4G technology. I will mention the measurement procedure currently used to measure the electromagnetic exposure of 4G base stations. I will detail this through a measurement I made. The aim of my work is to present the measurement procedures that are currently only recommended. Also illustrate the extent to which the exposure levels of NR systems differ from those measured for LTE systems.

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MEASUREMENT OF RADIOFREQUENCY (RF) EXPOSURE AROUND A 5G BASE STATION

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Keywords: radiofrequency, exposure measurement, 5G technology

The fifth generation (5G) mobile system, similarly to previous mobile phone telecommunication technologies (2G, 3G, 4G, Wi-Fi), uses electromagnetic waves. The 5G service to be introduced will partly use the same radio frequency (RF) bands as the previous technologies, while new frequency bands have also been designated on the basis of international conventions. In Europe, including Hungary, the 5G service was already launched in the 3.6 GHz frequency band. With the use of beamforming and MIMO (Multiple Input Multiple Output) technology in 5G technology and optimised service, the ambient RF exposure, will change, the peak exposure could be increased, but the expected average ambient electromagnetic exposure will remain below the exposure limit.

The aim of this study was to evaluate the "bystander" RF exposure of a 5G base station used beamforming antenna in the 3.5 GHz band. For this purpose RF measurement devices were fixed at 134 m distance in front of a building deployed a 5G base station while a test mobile phone which generated standard data traffic was moved step by step away from the measurement point. The electric field strength was measured with three devices: (i) RF spectrum analyser (Narda SRM-3006, Narda-STS, Germany); (ii) broadband RF field monitor (Narda NBM-550); (iii) band selective RF exposimeter (ExpoM-RF, Fields at Work GmbH, Switzerland). All RF measurement devices were set in data logging mode. Two minutes of mobile data was generated by the test phone every five metres moving away from the measurement devices. The results show that at the fixed point the electric field strength of the 5G band (3.4-3.8 GHz) is decreasing with the distance the mobile phone generates the traffic. The field level decreased around 50% while the test mobile distance reached 25 meters. The background of this phenomenon is the "beamforming" technology of 5G systems, which means that the RF beam of base the station antenna focuses and follows the active mobile device.

HEALTH EFFECTS OF LIGHTING: THE GOOD AND BAD

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Keywords: non-ionizing radiation, light, health, wellbeing

Humans, and most other species on earth, have evolved with a 24-hour light/dark cycle. For most of evolution, the source of light has been the sun during the day and light reflected from the moon during the night (at least when it is not cloudy). Artificial light was originally provided by flames and would have been resource intensive for humans. Therefore, nighttime would usually have been very dark. Life revolved around the local timing of dawn and sunset.

As the availability of oil, gas and then electric lighting increased, the day became artificially extended. Benefits were seen by at least some of the population. For example, factories could be operated for more hours per day. However, the detriment of being indoors all day were eventually recognized.

In modern societies, daily activities involve exposure to a range of artificial sources of optical radiation. Generally, this provides benefits. However, it is necessary to consider the exposure of different people to this optical radiation, including light. We need to consider effects beyond vision.

Taking a holistic approach to light exposure, it is necessary to take account of the amount of exposure, including the spectrum, time and duration of exposure, prior light exposure history, the individual's age and other parameters that may alter or compromise the transmission of optical radiation to the retina, and what the task is.

A considerable amount of research has been carried out to provide guidance on the light exposure required for optimum wellbeing and performance. As a result of this, how far are we from providing specific advice for an individual person – or will any advice always be a compromise?

The outcome of two international workshops in Manchester, UK, and a standard developed by the International Commission on Illumination will be discussed, along with guidance from the International Commission on Non-Ionizing Radiation Protection to ensure there is no direct harm to the eyes.

LASER SAFETY FOR HIGH POWER AND HIGH INTENSITY EMERGING LASER APPLICATIONS

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In recent years, the average laser power available for industrial lasers has steadily increased by an order of magnitude, from a few tens of watts for ultrafast lasers to tens of kW or a few kW for cw lasers to more then 100 kW. This enables new manufacturing processes and new opportunities for laser processes in industrial manufacturing. Nevertheless, in order to enable safe use of these laser sources, the newly available laser power has to be taken into account in the design of laser manufacturing systems and especially in the work in research facilities. In this paper we will present the latest results and considerations on laser safety for new high power and high intensity laser applications.

PUBLIC EXPOSURE TO ARTIFICIAL OPTICAL RADIATION IN THE AESTHETICS AND THE ENTERTAINMENT SECTOR IN GREECE. RISK MANAGEMENT ACTIONS

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Keywords: risk assessment, laser, IPL, LED, optical radiation, aesthetics, entertainment, public exposure, risk management

Lasers, IPLs and LEDs are routinely used in a wide range of aesthetic procedures. Commercially available IPLs and LEDs for home-use are becoming increasingly popular. Laser light shows are widespread and consumers extensively use laser projectors and laser pointers of various output powers and wavelengths.

Internationally, public exposure to artificial optical radiation in the aesthetics and the entertainment sector has been marginally regulated. In Greece, no relevant legislation exists and systematic investigations regarding the public exposure to such applications have never been performed. Greek Atomic Energy Commission (EEAE), the competent national regulatory authority for radiation protection, assessed the general public exposure to lasers, IPLs and LEDs used in the aesthetics and the entertainment sector.

The ISO 31000:2018 guidelines were followed in order to manage the risk from exposure to: 1) lasers, 2) IPLs and 3) LEDs in aesthetic procedures, 4) commercially available IPLs and LEDs for home-use, 5) lasers for laser shows, 6) laser projectors and 7) laser pointers. For all applications, at first, risks were identified, analyzed and evaluated based on relevant risk matrices. Risk treatment plans were proposed and the new risk levels, after implementing risk treatment and monitoring measures, were re-assessed. Finally, risk monitoring and recording measures were proposed.

In brief, the exposure risk to lasers and IPLs in aesthetic procedures and to laser pointers was assessed as intolerable. The exposure risk to laser shows was assessed as substantial, and the exposure risk to laser or LED projectors, LEDs in aesthetic procedures and home-use IPLs or LEDs was assessed as moderate. Training of the lasers / IPLs / LEDs operators and raising public awareness regarding the lasers / IPLs / LEDs hazards in aesthetic procedures and the use of laser pointers, are considered as top priorities among the proposed risk treatment measures.

ASSESSMENT METHODS FOR RADIATION OF 5G SYSTEMS

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Keywords: human exposure, incident field dosimetry, electromagnetic-thermal dosimetry, 5G mobile communication systems

Human exposure to mobile communications systems of fifth generation (5G) may result in a local temperature elevation at the body surface (skin, ear and eye in particular). According to ICNIRP 2020 guidelines, this surface heating is quantified by absorbed power density (S_{ab}) above transition frequency of 6GHz, while for the frequencies below 6GHz well-known quantity specific absorption rate (SAR) is used. Also, transmitted power density (TPD), an alternative dosimetric quantity and metric providing an estimation of skin temperature increase for human exposure to electromagnetic fields at GHz frequency range is used. This paper reviews some recently reported incident and internal dosimetry methods for the assessment of humans to radiation from 5G mobile systems.

Thus, the paper first deals with simple incident dosimetry procedures to assess the electric field radiated by 5G systems. Some efficient techniques to estimate irradiated field from *m*MIMO (massive multiple input multiple output) adaptive antenna systems, taking into account beamforming, are outlined.Then, some deterministic internal dosimetry procedures for an analytical assessment of S_{ab} and TPD in tissue, due to exposure to 5G radiation sources in GHz frequency range, are presented. The case of Hertz dipole and horizontal dipole antenna radiating in the presence of a lossy half-space are considered (D.Poljak et al, 2021). Next topic of interest is the calculation of incident power density (IPD) and related temperature increase in multilayer tissue model using different numerical methods based on the paper prepared by IEEE ICES working group and recently published in IEEE Access (Li, K et al. 2021).

The last part of the paper tackles a stochastic-deterministic electromagnetic-thermal dosimetry in lower portion of GHz frequency range featuring the use of anatomically based realistic multilayered model of the human head exposed to radiation from 5G communication systems (A.Susnjara et al. 2021).

ICNIRP (2020), "Guidelines for limiting exposure to electromagnetic fields (100kHz to 300 GHz)," *Health Phys*, March 2020.
Li, K. et al., 2021. Intercomparison of Calculated Incident Power Density and Temperature Rise for Exposure from Different Antennas at 10-90GHz. IEEE Access.
Poljak, D. et al., Absorbed Power Density at the Surface of Planar Tissue due to Radiation of Dipole Antenna. Proc. SpliTECH 2021.
Susnjara, A. et al., Stochastic-Deterministic Thermal Dosimetry Below 6 GHz for 5G Mobile Communication Systems, IEEE Trans EMC, No 6, Oct 2021.

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ASSESSMENT OF ABSORBED POWER DENSITY IN MULTILAYER PLANAR MODEL OF HUMAN TISSUE

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Keywords: human exposure, mulitilayer tissue model, absorbed power density, 5G mobile communication systems, dipole antenna

Exposure of humans to mobile communications systems of fifth generation (5G) may lead to local temperature elevation at the body surface, as stated elsewhere, e.g. in (Li et al. 2021) and (Poljak et al. 2021). According to IEEE 2019 and ICNIRP 2020 guidelines, this surface heating is quantified by absorbed power density (S_{ab}) above transition frequency of 6GHz, while for the frequencies below 6GHz well-known quantity specific absorption rate (SAR) is used.

In this work an analytical/numerical assessment of S_{ab} in the multilayer planar model of the human tissue due to radiation of horizontal dipole antenna in GHz frequency range has been carried out. This paper extends the work reported in (Poljak et al. 2021) pertaining to homogeneous tissue model for the assessment of S_{ab} and in (Li et al. 2021) dealing with incident power density (IPD) and temperature elevation in multilayer tissue model.

First step in this work is to determine the current distribution along the wire. The analysis is performed for the case of assumed sinusoidal current distribution, and for the current obtained by numerically solving the Pocklington integro-differential equation using the Galerkin Bubnov Indirect Boundary Element Method (GB-IBEM). The influence of the multilayer medium (properties of the tissue) is taken into account via the corresponding Fresnel reflection/transmission coefficient. Once the current distribution is known the irradiated electric and magnetic fields are determined by evaluating the corresponding field integrals via boundary element formalism.

The last step is to calculate S_{ab} at the tissue surface. According to ICNIRP 2020 guidelines S_{ab} is averaged over area of 4cm^2 and 1cm^2, respectively, depending of the frequency range of interest. The case of the two-layer and three-layer model, respectively, of human tissue is considered and the results S_{ab} are obtained for frequencies: 6 GHz, 10 GHz, 30 GHz and 60 GHz. The results obtained via assumed and calculated current distribution are compared to the results available from the relevant literature.

Li, K. et al., 2021. Intercomparison of Calculated Incident Power Density and Temperature Rise for Exposure from Different Antennas at 10-90GHz. IEEE Access.
Poljak, D. et al., 2021. Absorbed Power Density at the Surface of Planar Tissue due to Radiation of Dipole Antenna. Proc. SpliTECH 2021.
IEEE-C95.1 (2019), IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz, IEEE, Ed. NY, USA.
ICNIRP (2020), "Guidelines for limiting exposure to electromagnetic fields (100kHz to 300 GHz)," *Health Phys*, March.

THE ICNIRP 2020 RF GUIDELINES – WHAT IS NEW?

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Keywords: electromagnetic fields, radiofrequency, non-ionizing radiation

In 2020, the International Commission on Non-Ionizing Radiation Protection (ICNIRP), published an update of the guidelines for exposure to radiofrequency electromagnetic fields. These guidelines replace the ones from 1998. They are based on a review of the scientific database, and new insights in the dosimetry. As a consequence, the new guidelines contain a large number of small and larger modifications relative to the old ones, but are still mainly based on the prevention of heating of the body and of body parts. The main features and differences between the old and new guidelines will be presented.

ICNIRP 2020. Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). *Health Phys 118(5):*483-524.

THE ICNIRP 2020-2024 WORK PLAN

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Keywords: non-ionizing radiation, electromagnetic fields, visible light, ultraviolet radiation, ultrasound

The work of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) covers the entire non-ionizng radiation spectrum, from static fields up to ultraviolet radiation, but also ultra- and infrasound. ICNIRP provides guidance on exposure limits for all frequencies in this range. ICNIRP is currently working on a large range of projects in the non-ionizing radiation area, which will be presented.

OCCUPATIONAL EXPOSURE TO OPTICAL RADIATION

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Keywords: optical radiation, occupational, skin cancer, exposure assessment

Exposure to natural and artificial optical radiation in the wavelength range between 100 nm and 1 mm is almost unavoidable in the occupational sector. It occurs for example during welding processes, at high temperature processes in the glass or metal industry or simply when working outdoors. Wellknown effects of optical radiation are injuries of the eyes and the skin such as erythema, corneal irritation or cataract. The Institute for Occupational Safety and Health performs measurements of optical radiation at various workplaces. The gathered data can firstly be used to make workplaces safer. Furthermore they can provide valuable information that can be used for prevention or as basis for further research. One example that illustrates the importance of workplace mesurements are the GENESIS-UV measurement campaigns that aimed to determine occupational and leisure time UV exposure. These measurements provide a huge data basis that drives knowledge about the mechanisms of skin cancer development and the design of specific prevention concepts for vulnerable groups.

A METHODOLOGY TO ASSESS THE EMF EXPOSURE OF 5G SIGNALS

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Keywords: 5G, new radio, EMF exposure assessment, radio frequency electromagnetic fields

The fifth-generation new radio (5G NR) system is quickly being implemented in Italy, such as in most European countries. Unlike pre-5G systems that use passive antennas with static radiation pattern, the NR uses active antennas and beamforming techniques to shape the radiation lobes.
The exposure assessment of EMF generated by active antennas is challenging: some techniques are currently being developed on vector analysis and demodulation of 5G signals or on scalar measurement such as zero span. Especially the vector analysis requires new instruments, or at least new demodulation tools, which however may require to force data traffic.

Arpa Piemonte implemented a methodology to assess the EMF exposure forcing data download on 5G NR signals. This procedure requires a server able to generate high data flow and a 5G user equipment, in this case a commercial 5G mobile phone. The data flow is transmitted over the 5G signal using the User Datagram Protocol (UDP), a connectionless protocol which does not require interactions between server and client. An UDP server has been implemented in Arpa network, which is bound to the 5G mobile phone. The data flow is generated via a commercial (and free) application which calls the UDP server and, using several configuration parameters, it starts the data flow. The mobile phone access the 5G network using the SIM card of the carrier whose 5G EMF exposure is being assessed.

In order to test the procedure, Arpa Piemonte conducted several measurement campaigns on 5G NR signals from different carrier in the 3.6-3.8GHz band, which is the only band in which 5G signal are currently being transmitted. Due to the low amount of 5G users, the data traffic forcing is able to fill the 5G signal frame and to focus the radiation beam to the measurement point. The results show that, using 400Mbits for 20MHz signal span and 800Mbits for 80MHz signal span, the signal channel power, acquired by a signal analyzer able to sweep at about 10ms, is the maximum EMF that can be generated by the 5G signal over six minutes in the measurement point.

Therefore, the procedure demonstrated very good performances to assess the maximum EMF exposure generated by 5G NR signals. Compared to other methodologies, such as vector measurements, the proposed procedure has an infinitesimal cost (the 5G mobile and carriers' data plans) and it is easily implemented by other control agencies.

GENERATION OF SOFT X-RAYS DURING LASER MATERIALS PROCESSING WITH ULTRASHORT LASER PULSES

Rudolf WEBER

Materials processing with so-called ultrafast lasers with pulse durations below about 10 ps allows very precise materials processing with mechanical and thermal accuracies in the micrometer range. However, due to the high irradiances $>10^{11}$ W/cm^2 a hot plasma is created, where electron temperatures > 1 keV might occur. At such high temperatures both, thermal and line emission in the soft x-ray region >5 keV can be generated.

In the talk the basic properties of the soft x-ray emission during industrial laser processing will be discussed, also with respect to future laser developments.

EVALUATION OF PHYSIOLOGICAL EFFECTS OF THE ELECTROMAGNETIC FIELD CAUSED BY FULLY ELECTRIC AND HYBRID DRIVES IN THE PASSENGER COMPARTMENT

Prof. Dr. habil. György WERSÉNYI

The paper presents a modular simulation methodology to investigate the radiated electromagnetic field of hybrid and fully electric drive inside the passanger compartment. Firstly, the standards related to the human exposure of electromagnetic fields, and the measurement method are shown. Secondly, a novel modular simulation technique to evaluate electromagnettic field caused by electric drive is presented. The proposed method deals with the computational challenges of simulating electrically large and complex system by breaking down the full simulation setup into subsystems. On one hand, this approach helps to drestically decrease the computational time required to analyze the system. Ont he other hand, the modularity of this technique enables the interchangeability of subsystems, therefore makes it easy to apply changes in the system, while maintaining computational speed, and accuracy.

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T02: Education and training

DEVELOPING (EDUCATION AND TRAINING IN) RADIATION PROTECTION IN SURINAME AND BEYOND – THE ROLE OF THE DUTCH SOCIETY FOR RADIATION PROTECTION

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Keywords: Radiation Protection in developing countries, education & training, IRPA

In 2020, the Dutch Society for Radiation Protection (NVS) established a chapter 'Radiation Protection in Suriname and the Dutch Caribbean' as a follow up of a mission of the NVS to Suriname in November 2019 (Adhikari et al., 2021). With the new chapter, the NVS intends to promote organised radiation protection in Suriname and the Caribbean area.

In its mission report, the NVS provided recommendations on a regulatory infrastructure including a limited system of education and training in radiation protection to the government of Suriname. In its first meetings the members of the chapter decided to focus on raising awareness on radiation and radiation protection. This contribution will first of all focus on the activities in Education and Training in Radiation Protection. We will report on the basic instructions already provided to various target groups in Suriname, but also discuss the current status of a possible system of Education and Training in radiation protection in Suriname.

The limited scope of the applications and/or the limited number of inhabitants make it difficult for many countries like Suriname to establish and maintain a radiation protection organisation. It is for that reason that the authors are developing a plan to cooperate with other IRPA Associate Societies in establishing similar chapters in the Caribbean area, that might ultimately lead to a new IRPA Associate Society in this area. In our contribution, we will elaborate further on these initiative.

Adhikari, K.P., Boersma H.F., Coates R., Coulor W., Gallego E., Omrane L. Ben, Suarez R.C. and Tsegmed U. 2021. Radiation protection infrastructure—challenges in developing countries. *J Radiol Prot.* 41, S171-S180.

INCREASING THE NUMBER OF STUDENTS IN RADIATION PROTECTION AND MEDICAL PHYSICS - FINDING A FORMULA THAT WORKS

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Keywords: radiation protection, medical physics, curriculum development

In many countries in the world the radiation-protection and medical-physics professions face an acute shortage of entrants owing to the irregular number of physics/engineering graduates and low popularity of two year masters programmes. Under such conditions of uncertainty the professions would not only fail to grow but inevitably decline. A formula needed to be found to: (a) ensure that the potential stock of entrants to the professions would be independent of erratic student numbers in physics/engineering (b) address the paradox of having to reduce the masters programme to one year at a time when the knowledge-skills-competences required for modern radiation-protection/medical-physics practice are expanding rapidly. A survey of radiation-protection/ medical-physics education programmes and documentation was carried out and elements of best practice identified. The latter were used to guide the curriculum development process. Stakeholders were consulted and their suggestions implemented. It was considered that the best way forward would be to opt for an undergraduate inter-faculty programme that combined physics and radiation protection/medical physics. The resulting four year programme consists of 5 parallel strands namely physics/mathematics/statistics, radiation-protection/medical-physics, basic-medical-sciences, research and hospital placements. The physics/mathematics/statistics component is sufficiently strong to ensure a strong scientific foundation whilst the radiation-protection/medical-physics is sufficiently comprehensive to permit the reduction of the Masters in Medical Physics from two years to one. We are pleased to report that the innovative curricular experiment has been a great success. The combination of pure and applied physics, the inter-faculty nature of the programme (where students share lectures with both physics and healthcare professions students) together with the element of clinical practice have been found to be the most attractive features of the programme. The programme has provided a welcome boost for both the radiation-protection/medical-physics professions and indeed even physics itself.

UK EXPERIENCE OF PROFESSIONAL REGISTRATION IN RADIATION PROTECTION

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Keywords: professional registration; Radiation Protection Council

The UK Radiation Protection Council (RPC) was established in 2018, under the Royal Charter of the Society for Radiological Protection. The RPC holds the Registers for three grades of professional registration – Chartered, Incorporated and Technical Radiation Protection Professional. Individual radiation protection practitioners may apply for registration through any Society or Organisation that has been accepted as a licensee of the RPC.

Criteria for registration at each level have been developed for five generic areas: application of general and specialist knowledge; analysis and solution of radiation protection challenges; personal responsibility; interpersonal skills; and professional practice.

The benefits of registration for individuals include evidence of expertise, competence and continuing professional development; demonstration of professional attitude; enhancement of status within an organisation and the profession; greater influence within organisation and industry; improved career prospects and employability. For employers, there are also benefits, such as increased credibility with customers, auditors and regulators; assurance of employees having satisfied a thorough assessment of their radiation protection competence; indication of commitment of staff and their adherence to a code of professional conduct; and a positive impact on recruitment and staff retention. The registration system also raises the profile of the profession and provides a mechanism by which third party organisations and the public may find reassurance as to the status of individual practitioners from whom they may wish to seek advice.

This presentation will share the experience of establishing the RPC, identifying key issues and potential pitfalls for other Societies wishing to go down this route, and discuss future expectations for professional registration.

RADIATION PROTECTION EDUCATION AND TRAINING: INITIATIVES FROM THE SCK CEN ACADEMY

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Keywords: education, training, competence building, CPD

Thanks to its experience in the field of nuclear science and technology, its innovative research and the availability of large and unique nuclear installations, SCK CEN is an important partner for education and training in Belgium as well as at international level. In the broad domain of radiation protection (RP) science and applications the SCK CEN Academy transfers basic knowledge and recent findings from its R&D towards students and professionals dealing with ionizing radiation.

Towards students, we offer the possibility to make use of our installations and expertise to guide them in their studies. On average (in non-pandemic times) about 50 bachelor and master students per year prepare a thesis or perform an internship at SCK CEN in a topic related to RP. About 45 PhD students are currently performing their research in the Institute for Environment, Health and Safety.

SCK CEN plays a major role in academic collaborations such as the master-after-master BNEN program and the post-graduate Radiation Protection Course which partially or fully deal with RP issues. Next to initiatives for students, we also offer customized training for professionals working in the nuclear industry, healthcare, research organizations or governmental bodies. When building competences for professionals, face-to-face classroom training is often complemented by practical exercises in dedicated training facilities, e-learning, instructional videos and VR gamification.

Radiation protection remains an important pillar in the majority of training courses of the SCK CEN Academy. Related to the research of SCK CEN, dedicated training courses are also offered in emergency management, radiation biology, decommissioning, radioactive waste management and disposal.

Furthermore, support is provided to RP policy makers and end-users in the E&T implementation of the EU BSS requirements, and via the organization of networking possibilities via the EUTERP Foundation and the ETRAP conferences.

This presentation will highlight the current and future initiatives of the SCK CEN Academy in support of competence building in radiation protection.

EFFECTIVENESS OF ONLINE TRAININGS ON RADIATION PROTECTION IN THE CONTEXT OF THE COVID-19 PANDEMIC

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Keywords: radiation protection, education and trainings, online trainings

During the Covid-19 pandemic, like all over the world, a number of restrictions were imposed in Georgia, which significant reflected in the field of education and training. In particular, face-to-face trainings have been replaced by online trainings. It should be also noted that the pandemic has led to an increase in the workload of personnel who are required to undergo periodic training in radiation safety in accordance with national legislation. In these circumstances, we have developed an online training system that allows us to properly assess both the students' daily progress as well as the effectiveness of the overall training.

Each online training, lasting up to 10 working days, is accompanied by mandatory Google Form-based questionnaires, which includes daily key questions about each lecture as well as pre- and post-training tests and provided to participants. In addition, the ability to conduct a dialogue with patients about radiation risks, group discussions, as well as a special module for RPOs were assessed online. The trainings also allow participants to focus on the most important issues from their point of view in their daily work, indicating them in pretests, allowing the trainers to conduct lectures more adequately for each group of participants.

Analysis of daily as well as pre- and final tests have shown that online training is not inferior in efficiency to face-to-face training and national regulatory body received an improved opportunity to indirectly assess this efficiency. We believe that in the future, the experience gained with online training and some of its elements will have a significant impact on efficiency of face-to-face trainings once the restrictions caused by the pandemic are removed.

INFORMATION ON COSMIC RADIATION RECEIVED BY BELGIAN AIRCREW: A SURVEY

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Keywords: aircrew, cosmic radiation, workers information

Exposure of aircrew to cosmic radiation had already been identified as an issue of concern in the European BSS of 1996 which requested airlines to assess the exposure of the crew and to inform their workers of the health risks their work involves. These requirements have been implemented in Belgian regulations in 2001 and updated with the transposition of the 2013/59/Euratom directive. Dosimetry data show that aircrew is the group of workers which contributes the most to the collective dose of occupationally exposed workers in Belgium.

In order to verify the extent of the information received by Belgian aircrew regarding their exposure to cosmic radiation, FANC, the Belgian radiation protection authority, launched in 2019 a large survey in collaboration with the Belgian Cockpit Association (BeCA), the professional association representing airline pilots in Belgium. The survey included 8 questions regarding the information of aircrew on cosmic radiation in general, on the individual dose level and on the risk related to exposure during pregnancy.

A total of 400 responses to the survey were received. Overall, the survey reveals that aircrew members in Belgium receive too little information about the potential risks, that they are not sufficiently informed about their own exposure and that female staff members are insufficiently informed about the hazards for the unborn child in case of pregnancy.

66% of the respondents answered that their employer has never informed them about their exposure to cosmic radiation. However, most are aware of this phenomenon, either because they have looked up information or because they have discussed the topic with colleagues and professional associations. The results also showed that 17% of female crew continued to fly while being pregnant. Finally, the survey also allowed to identify differences and similarities between different groups of workers: cockpit and cabin crew, men and women. For instance, cabin crew was even less informed about their individual exposure than cockpit crew.

The presentation will give an overview of the results of the survey and the lessons learnt.

A TEACHING CONCEPT FOR SCHOOL EXPERIMENTS ON RADIOACTIVITY USING AUGMENTED REALITY METHODS

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Keywords: AR, augmented reality, app, education, visualization

Digital media are becoming increasingly influential in society, especially among the younger generation. Therefore, an augmented reality (AR) app was developed that simulates experiments with radioactive sources. In addition to increasing student's motivation, the app offers the chance to make radioactivity more accessible by visualizing ionizing radiation.

The app can currently run experiments on the range and penetration power of alpha, beta, and gamma radiation. It assigns radiation sources, shielding materials or detector to QR codes, and superimposes them on the camera image. There are four sources and five shielding materials to choose from. The detector displays the measured count rates.

Alpha, beta and gamma radiation are clearly distinguishable by choosing different visualizations. On the one hand, the emitted particles or waves are displayed. On the other hand, a colored background shows the decreasing intensity of the radiation as a function of the distance from the source.

The app can be used in a variety of ways in school. Here, a concept for a teaching unit in grade 10 was developed. The app can be used in sequential lessons to work out the characteristics of ionizing radiation. Alternatively, the app can serve for repeating and consolidating the entire unit on radioactivity.

A prototype of the app was tested in several classes and the learning progress from working with the app was investigated. It is shown that the students were able to develop and strengthen important concepts about radioactivity through the AR experiments. Furthermore, an evaluation of the app revealed a lot of positive feedback on the visualization of the radiation and the display of devices. Suggestions for improvement were given as well, which shall be fixed in subsequent releases of the app. The most recent version of the app can be found here: https://seafile.projekt.uni-hannover.de/d/dd033aaaf5df4ec18362/

WORKING TOGETHER ON E&T IN RADIATION PROTECTION

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Keywords: education, training, liaison

The EUTERP Foundation was formally launched at the 3rd IRPA European congress in Helsinki in June 2010. The main aims of the Foundation are to act as a central focus for the collection and dissemination of information and resources, and to promote the development of standards and good practice in radiation protection training. Currently, EUTERP has 25 Associate members whose contribution is fundamental to EUTERP's ongoing success.

However, in addition to working with our Associate members, EUTERP has also established good liaisons with the main international radiation protection organizations including, amongst others, IAEA, ICRP, HERCA and, of course, IRPA. These liaisons include not only mutual exchange of information regarding activities and areas of interest but also, where appropriate, collaborations on conference organization and programme committees. EUTERP values these connections as they provide opportunities to share information, highlight issues and keep abreast of developing themes. In this presentation the wider benefits of EUTERP's engagement with liaison partners will be explored, with particular consideration being given to how best to a) ensure a common "voice" within E&T in radiation protection, and b) optimize the opportunities for working together.

A REMOTE RADIATION PROTECTION TRAINING INITIATIVE IN THE UK

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These unprecedented times of pandemic restrictions have had a significant impact on our ability to travel to and attend professional events such as annual conferences and training meetings. This in turn has meant that many of radiation protection professionals have struggled to obtain developmental training and collect Continuing Professional Development (CPD) points. This situation has been, and potentially will be, exacerbated by many organisations (particular universities and the health service) attempting to financially economise by restricting training budgets to only what is 'absolutely essential'.

In the UK, the Society for Radiological Protection (SRP) and the Association of University Radiation Protection Officers (AURPO) have been collaborating for many months to develop and deliver a programme of free on-line training webinars. This is to support the needs of our members and the profession as a whole both nationally and around the rest of the world, thereby acting to support CPD and promote international knowledge exchange.

The webinars are hosted using the MS Teams Live Events software facilities and so far have included a variety of topics provided by a number of different experts and aimed at two basic cohorts: (a) those persons requiring introductory or refresher training on a certain subject, and (b) those who wish for more advanced treatment of a specialised area. Topics have included non-ionising radiation protection, liquid scintillation counting, decommissioning, gamma spectroscopy, how to read the radiation legislation, proton beam therapy, risks assessments, and medical exposure legislation. and decay calculations.

Over the last 15 months, these webinars have proved to be very successful with a regular attendance of over 200 participants from around the world.

It is acknowledged that remote on-line training does not obviate the necessity for practical training in some circumstances (e.g. the rehearsal of contingency plans). However, experience gained from running these training webinars has highlighted that they can be a valuable method and resource that could conveniently and cost-effectively have a role to play moving forward – even after the pandemic is over. SRP and AURPO aspire to continue this programme of training webinars indefinitely.

This presentation will describe the reasoning behind this series of webinars and the techniques developed to deliver them.

ONLINE RADIATION PROTECTION COURSES - LESSONS LEARNED DURING THE CORONA CRISIS

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Keywords: Radiation Protection courses, online courses, education, training

Before the time of the Corona pandemic, the implementation of 100%- online radiation protection courses without a presence phase was not permissible according to the German Radiation Protection Ordinance. This changed abruptly as of April 2020, when, due to the pandemic, the Federal Ministry for the Environment allowed for the first time the implementation of 100% online refresher-courses. In December 2020, this rule was extended to all courses for the duration of the Corona crisis, as long as they do not include practical exercises. Many course providers took advantage of this new option in order to be able to maintain course offerings even in pandemic times. This in turn led to an enormous increase in competence and experience in the use of digital media and methods in radiation protection courses, which could also be used in the post-pandemic period. This paper reports on which digital media and methods have proven successful in this area, where their limitations lie and how these experiences could change the design of future courses.

AUGMENTED COOPERATION IN EDUCATION AND TRAINING IN NUCLEAR AND RADIOCHEMISTRY

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Keywords: radiochemistry, education, training, virtual reality

In order to maintain European nuclear operations, expertise in nuclear and radiochemistry (NRC) is of strategic relevance. NRC contains key knowledge and techniques needed by a modern society in order to address many societal challenges including amongst others the energy sector, medical treatment and diagnosis, material sciences and dating. The A-CINCH project is the latest of four CINCH-based project aiming on cooperation in education in nuclear chemistry and radiochemistry. In the first three projects[1], CINCH, CINCH-II and MEET-CINCH minimum requirements for bachelor, master and postgraduate programs to achieve approved NRC curricula were defined, a number of theoretical and practical courses were developed using hands-on and e-learning approaches and platforms. MEET-CINCH counteracted the massive lack of NRC expertise by building teaching package for high schools and a MOOC on NRC for the general public in order to attract young persons to the NRC field and convey them its fascination and relevance. New education and training approaches based on remote teaching, remote controlled RoboLab experiments, interactive screen experiments[2] and the flipped classroom concept were developed and implemented. ECVET course modules are offered in an e-Shop adapted to the needs of end-users. The current project A-CINCH makes use of state of the art virtual and augmented reality tools. It implements a highly innovative Virtual Laboratory and wraps it all up into a user-friendly and easy-to-navigate single page interface. The wide mix of e-learning and presence teaching in nuclear and radiochemistry education aims to increase the number of students and trainees in the field. To address the new target groups directly and efficiently attract the attention of the secondary school students, new didactical tools, suitable for today's youth, are used. These newly developed courses and tools and all previous CINCH results are accessible via the newy set up CINCH Hub platform.

[1]https://www.cinch-project.eu/cinch-series
[2]http://ibe.irs.uni-hannover.de/ibes/en/index.html

T03: Medical applications

DYSFUNCTION OF THE SALIVARY AND LACRIMAL GLANDS AFTER RADIOIODINE TREATMENT: PRELIMINARY RESULTS OF A SELF-CONTROLLED STUDY IN FRANCE

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Keywords: Salivary dysfunctions, lacrimal dysfunctions, radioiodine, thyroid cancer, epidemiology

Following radioiodine (^{131}I) therapy of differentiated thyroid cancer, salivary and lacrimal glands may become inflamed, leading to dysfunctions. The incidence of these dysfunctions after ^{131}I-therapy is poorly known, and no clinical or genetic factors have been identified to date to define patients at risk. The aims of this study are 1) to characterize the dysfunction of salivary and lacrimal glands after ^{131}I-therapy, 2) to identify risk factors of salivary and lacrimal dysfunction.

START (**S**alivary dysfunc**T**ion **A**fter **R**adioiodine **T**reatment) is a prospective study including 139 patients, candidates for a ^{131}I-therapy in the context of their differentiated thyroid cancer (45 and 94 patients in 1.1GBq and 3.7GBq groups respectively).

The follow-up was based on 2 scheduled visits: immediately before ^{131}I-therapy (T0) and 6-months after (T6). At each visit, questionnaires on salivary disorders (validated French tool) and dry eye (OSDI© Questionnaire) were administered, and individual salivary flow measurements (without and with salivary gland stimulation) were performed. Descriptive analyses and paired comparisons tests between T0 and T6 were computed.

The T6 follow-up started in March 2021, and is still ongoing. Complete information was provided for 122 patients (71% women, mean age=47.4 (±14.3) y). At 6 months after ^{131}I-therapy, stimulated saliva flow rate decreased (from 6.98 (±3.35) to 6.07 (±3.15) mL/min, $p<0.01$), as well as the difference between stimulated and unstimulated saliva flow rates (from 1.40 (±0.67) to 1.21 (±0.63) mL/min, $p<0.01$). Also, after ^{131}I-therapy, 19% and 21% of the study population reported dry eye or dry mouth feeling, respectively.

This work presents preliminary results of the START study, showing a decrease in salivary and lacrimal gland activity after ^{131}I-therapy. Further analyses will be performed, including saliva biochemical composition, genetic and epigenetic variants, and dose-response relationships (using dosimetric reconstructions).

THREE-DIMENSIONAL DOSE CALCULATION IN CT / SPECT TREATMENTS WITH INTERNAL EMITTER LU-177 USING MONTE CARLO TECHNIQUES

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Keywords: Monte Carlo, MCNP, SPECT, CT, NEMA, lutetium

The particularity of this work is to demonstrate the possibility of establish Monte Carlo code as an accurate dose calculation technique in lutetium-177 (177Lu) clinical therapies. This radionucleide is used in endocrine tumors, where gamma photons emited are used for targeting visualization by external imaging and beta particles are used to kill cancer cells. The combination of these two kinds of radiation characterizes 177Lu as an excellent treatment, but there is no manner to specify the accurated dose received in tumor lesions and adjacent tissues.

The experimental part of this work was performed at the Hospital Universitari I Politècnic la Fe de València, with a body phantom NEMA with six spheres and a computer tomography (CT) Philips Brightview XCT SPECT/CT scanner. Spheres where filled with a 177Lu solution emulating hot lesions in a warm background. Absolute activity concentration in the spheres at the beginning of the scan was 36.45mCi/l, and sphere-to-background concentration ratio was 9.4.

The geometry of the phantom included in the simulation is based on the CT image acquired. Segmentation process generates volumes from segmented slices based on gray-level pixel values, dividing the image into different density groups labeled as an independent structure. After segmentation, Abaqus/CAE software was used to generate an 3D unstructured mesh geometry of the NEMA phantom.

Monte Carlo code simulates the transport of particles emitted by the sources and the interactions of these through the different materials, having the ability to record results of such interactions particles. The code used in this work is MCNP6.1.1 (Monte Carlo N-Particle).

Using Paraview software for 3D geometry and results calculated by MCNP, visualization is a major improvement and advantage over other Monte Carlo codes.

This work has proved that the feasibility of Monte Carlo dose calculation methodology for internal emitter therapy, making this technique attractive for clinical applications.

Wesley E. Bolch, The Monte Carlo Method in Nuclear Medicine: Current Uses and Future Potential J Nucl Med. 2010;51:337-339
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DEVELOPING A RADIATION SAFETY PROGRAM IN COUNTRIES WITHOUT LEGISLATION IN RADIATION SAFETY – A REPORT ON CARIBBEAN COUNTRIES

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Keywords: radiation protection in developing countries, medical applications, education & training

The International Basic Safety Standards (IAEA et al, 2014) require the presence of a regulatory framework for radiation safety for the protection of people and the environment from harmful effects of ionizing radiation. The regulatory framework includes the presence of a competent regulatory body and established regulations to ensure, among other principles, that there is a positive balance between the beneficial use of ionizing radiation and the risk of harm to patients, workers and members of the public. In 2019, a survey was conducted to gather information on the current status of the regulatory infrastructure for radiation safety in the Caribbean. The results from the survey demonstrated that many Caribbean countries do not have national legislation on radiation safety implemented. In addition to the lack of or outdated regulatory infrastructure in radiation protection, Caribbean countries also lack a structure for radiation safety for medical applications and a system for education and training in radiation protection. As a result, there is a great shortage of experts in radiation protection with required knowledge, skills and competences. An example of this is that most countries do not have medical physics experts nor radiation protection experts. The observed shortage leads to poor implementation of radiation safety practices and thus may pose danger to the safety of patients, workers and the environment against harmful effects of ionizing radiation. The Pan American Health Organization (PAHO) recently started with a program to aid Caribbean countries in the establishment of a radiation protection program for medical applications. A questionnaire was developed in 2020 to assess the current status of radiation safety for medical applications in a subset of medical clinics in seven Caribbean countries. Based on the results, a gap-analysis was created and a customized radiation protection manual was developed tailored to the applications in the medical sector. In this contribution we will report on the outcomes of this project and the identified gaps in the establishment of an institutional program for radiation safety in Caribbean countries with no national infrastructure for radiation safety.

European Commission, Food and Agriculture Organization of the United Nations, International Atomic Energy Agency, International Labour Organization, OECD Nuclear Energy Agency, Pan American Health Organization, United Nations Environment Programme, World Health Organization. 2014. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. International Atomic Energy Agency

KV-CBCT DOSE LENGTH PRODUCT AND EFFECTIVE DOSE ESTIMATION ON HALCYON LINEAR ACCELERATOR

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Keywords: Halcyon, kV-CBCT, DLP, effective dose

Acquiring the exact patient dose information is important; it is prescribed by both Hungarian national regulations and the EU BSS.

The new generation Varian Halcyon linear accelerator based Image Guided Radiotherapy requires the daily use of Cone Beam CT (CBCT) which means extra doses for patients. We need to know the accurate Cone Beam Dose index (CBDI) to calculate the Dose Length Product (DLP), and the Effective Dose (ED) according to anatomical region.

In our study, to calculate the DLP and ED values we used the CBDIs set by the manufacturer multiplied by both the scan range and the longer side of the longitudinal field of view (LFOV). We also conducted free air and point based CBDI measurement, over different CBCT protocols: Head low, Head, Breast, Thorax, Pelvis.

We found 12% difference on average between the reference and calculated DLP values when we used the scan range, based on the equation of definition, independently from the CBCT protocols. However, with LFOV we received the reference DLPs. Free air and point measured DLP values with LFOV constantly overestimated the reference DLPs. The range of difference was [-26.41%, -0.47%] with an absolute average of 14.5% for free air and 11.3% for point measurements. The calculated DLPs with scan range were overestimated using low kV and mAs CBCT protocols but underestimated with higher kV and mAs. The range of difference was [-11.33%, 11.78%] with an absolute average of 4.8% for free air and 8.4% for point measurements. The ED estimation was calculated based on ICRP 103 guideline where anatomical regions weight factors (k) are defined. The EDs were calculated by DLP multiplied by the "k" factor. The percentage deviations from the references remained as before, because we used only a constant multiplication factor (k). Therefore, we found a wide range of difference between the effective and reference doses meaning that the chosen methods for DLP and ED calculations are not negligible for dose estimation.

STUDY OF ACTIVATION OF AIR, WATER AND SOIL IN COMPACT PROTON THERAPY CENTERS (CPTC)

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Keywords: compact proton therapy centers, operational radiation protection, neutron radiation area monitoring, MCNP6

The present work is part of the dosimetry and neutron spectrometry activities in proton therapy centers carried out by the Polytechnic University of Madrid (UPM). Proton therapy has recently arrived in Spain with two centers in operation since the end of 2019 and the beginning of 2020, respectively. The objective of the work has been to carry out the study, using both, Monte Carlo codes and analytical methods collected in international recommendations, of the induced activation of the air, the water (present in ancillary facilities and the water table), and the natural soil of compact proton therapy centers. The results achieved with analytical calculations using international guidelines underestimate the ^{41}Ar concentrations about three times while ^{15}O concentrations are overestimated about ten times when compared to Monte Carlo results. However, ^{13}N concentrations estimated by both the methods are in good agreement. Analytical calculations ignore the significantly large contribution of ^{41}Ar formation by the neutrons above thermal energy. The overestimation of ^{15}O is caused by the large cross-section value assigned in the analytical calculations. The cooling circuits of the equipment that run through the acceleration rooms and the gantry are susceptible to activation of water. The expected activation products in water are ^{14}O, ^{15}O, ^{13}N, ^{11}C, ^{18}F, ^{7}Be, and ^{3}H. Considering the self-shielding factors of water, and that dose rate from activation will always be lower than metallic components of pipes, it is almost negligible. The main problem is not the activation of the water, but this effluent can transport radioactivity out of the facility. Soil characterization before building is a key task to prevent and limit the activation of the natural layer of the ground. Developments in proton therapy could have a huge impact in the operational radiation protection in this centers. New delivery modes could dramatically change some inputs and workload of the facility.

IMPACT OF NEW DELIVERY METHODS ON THE OPERATIONAL RADIATION PROTECTION OF COMPACT PROTON THERAPY CENTERS (CPTC)

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Keywords: compact proton therapy centers, operational radiation protection, Proton Arc Therapy, Proton Flash Therapy

Proton therapy is in continuous ever evolving to improve its performance. Some prominent current trends involve cutting-edge delivery methods or building compact proton centers. New developments have direct impact in radiation protection of facilities. The main goal of this work has been to carry out the comparative analysis, using Monte Carlo codes and experimental measurements, of the impact on the shielding of different proton dose delivery modes with greater projection and development. The current and new proton delivery methods compared were Intensity Modulated Proton Therapy (IMPT), Proton Monoenergetic Arc Therapy (PMAT) and proton flash-therapy with protons (PFT). On the one hand, PFT involves irradiation for less than 500 milliseconds of a dose greater than 40 Gy/s, that is, pulsed fields of high energy and intensity. On the other hand, arc therapy uses monoenergetic fields with lower energies than conventional ones, but for a longer time. For PMAT, both experimental measurements and simulations have been reached. These results show that with PMAT higher neutron fluences are generated, but with lower energy, therefore, its impact is greater on activation, but not so much on the ambient dose. For PFT, results have only been obtained with Monte Carlo simulations. With PMAT the shielding requirements could be reduced since the energy of the protons used is lower than the conventional IMPT modality. For PFT, the current shields should be reviewed since the energies used are the maximum, but for a fraction of the time, therefore, the instantaneous doses outside the barriers could exceed the legal limits in some clinical cases. The main challenge is to convert the different treatments into a real workload of the facility. Meantime parametric and Monte Carlo methods could help to quantify the proton load. Other mitigation actions could be limiting orientation of beam and occupancies in some spaces, using special concretes in different areas of proton therapy facility, or introducing changes in the design and situation of treatment control room. Experimental measurements could help to achieve more precise assumptions, always in the conservative side.

THE DOSE INDEX OF KILOVOLTAGE CONE BEAM COMPUTED THERAPY FOR VARIOUS IMAGING PROTOCOLS

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Keywords: Halcyon, kV CBCT imaging, dosimetry, CTDI

Varian Halcyon 2.0 with software version 3.1 is one of the new generation radiation therapy machines. This linear accelerator (LINAC) requires kilovoltage (kV) cone-beam CT (CBCT) for all the patients before all treatment fractions. The imaging involves additional dose for the patient, but image guided radiotherapy (IGRT) increases the accuracy of the set-up and the effectiveness of the treatment. The aim of this study is to assess the additional imaging dose of various available protocols with different calculation and measurement methods.

CT dose index (CTDI) (measured in mGy) is a measure of the radiation dose output of a CT scanner, but if we have a wide beam width (>40 mm) as in CBCT, the measured values have to be corrected. We can determine the volumetric CTDI which represents the patient's dose during the imaging process. The CTDIs were calculated based on the measured values following the IEC 60601-2-44 recommendations.

For the measurements we used the Radcal pencil ionization chamber with 10 cm active length in free-air and in PureImaging CTDI phantom for five different imaging protocols of Halcyon LINAC: Head-low dose, Head, Breast, Thorax, and Pelvis.

In the case of a point measurement, we found large deviations between reference and calculated low CTDI values: 26.6% and 27.1% at Head-low dose and Breast protocol, respectively. In the other cases when we used the corrections of wide beam length the largest discrepancy was found at Head protocol with 19.6%, higher than the reference value. The calculated values were always larger than the reference values for all protocols and measurement setups.

For the point measurements we found similar results as in the international literature, where the reference values underestimated the real CTDIs. However, if we apply the wide beam correction there are still deviations between our results and the reference values, but with less degree.

DESIGN AND DEVELOPMENT OF A NATIONAL PATIENT DOSE REGISTRY

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Keywords: patient dose, DRLs, registry, optimisation, machine learning

The increasingly widespread and generalised use of diagnostic and treatment modalities that employ ionising radiation has led the institutions responsible for Radiation Protection, both national and international, to establish increasingly complex mechanisms for the review, monitoring and auditing of the patient absorbed doses.

The Centro Nacional de Dosimetría (National Dosimetry Center) is a Spanish public health institution part of the National Institute of Health Management (INGESA) belonging to the Ministry of Health. Together with several scientific and technological institutions, we aim to create a National Dose Registry (NDR) that collects patient dose indexes from regional dose registries into a unified patient medical record. Among other features, this will allow the development of dose reference levels (DRLs) and will constitute an important tool for research through the application of machine leaning tools.

Standardization criteria includes HL-7, IHE RAD and DICOM RDSR for all communications within the NDR and between the NDR and the regional dose registries. Integration with private institutions will be addressed in a future step.

To start the project, a survey was conducted to identify what dose management systems currently exist in Spain. Next, the architecture of the platform was defined and the relevant dose indexes that will be recorded were established. Finally, a proof of concept that integrates different dose registries has been developed to start evaluating the functionalities and scope of the project.

The incorporation of the data from the different regions will be carried out incrementally. At the present time, work has begun to define the requisites in order for the first regions to join. Once completed, the NDR will be a decisive tool for the radiation protection of patients in Spain and maybe in the rest of the world too.

NUCLEI ACTIVATION IN PROTONTHERAPY TREATMENTS

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Keywords: protontherapy, activation

It is well known the fact that protontherapy maximizes dose deposition at the end of its range in tissue because of Bragg peak deposition, thus reducing doses to surrounding healthy tissues. However, nuclear reactions taking place in tissues can generate radioactive nuclei. Nevertheless, there is little knowledge about patient and material activation and its impact in terms of radiological protection. In this work, we aimed to study radionuclides and dose rates that may affect protontherapy staff because of activation during clinical treatments and daily procedures at these facilities.

Several dose rate measurements in terms of H*(10) were performed in patients immediately after irradiation in order to assess decay rates and identify nuclei activation. Additionally, we evaluated dose rate and spectrum obtained in PMMA as a surrogate of human tissue. We used a MiniTRACEg-Saphymo multipurpose meter for dose rate measurements and a RIIDEye-M-G (Thermo Scientific) spectrometer to identify the radionuclides.

Patient measurements were performed for a 20' time span following irradiation, showing two different decay curves contributions presumably associated to ^{11}C and ^{13}N. Further studies performed with PMMA mimicking tissue reactions showed ^{15}O presence, not visible in patient measurements due to the difficulties of measuring such short-term decay (2' half-life) and an additional peak (479keV) due to ^{7}Be in the long-term measurements (24h after irradiation). The latter was not visible in previous measurements due to its longer half-life (53d). The maximum dose rate value measured was 144μSv/h following an unfavourable irradiation (E_{max}=228.7MeV, 336.2MU, 10x10cm^2) of PMMA.

Patient and PMMA activation after clinical irradiations were evaluated, showing the presence of ^{11}C, ^{13}N, ^{15}O and ^{7}Be. Further measurements using different materials and irradiation conditions are planned in order to better assess activation in protontherapy facilities.

MEDAUSTRON – RADIATION PROTECTION FOR AN ION THERAPY CENTER IN AUSTRIA

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Keywords: ion therapy, synchrotron, high energy Radiation Protection

MedAustron is an accelerator facility with a synchrotron for cancer therapy and research located in Wiener Neustadt, 50 km south of Vienna. The facility provides protons up to kinetic energies of 250 MeV and carbon ions up to 400 MeV/u for medical applications. Additionally, protons up to 800 MeV kinetic energy can be used for non-clinical research purposes in a dedicated room.

The research branch of MedAustron is directly connected to three university professorships in the fields of radiation physics, medical physics and radiation biology.

The concept of the MedAustron particle accelerator was developed in cooperation with the European Organization for Nuclear Research CERN. Since 2016, the MedAustron Particle Therapy Accelerator MAPTA is a CE-labeled medical product in accordance with the European medical device directive. The system is comprised of active beam scanning on fixed beam lines, as well as a proton gantry.

In 2016, treatment of tumor patients, as well as research with protons, commenced and so far, more than 1000 patients have completed their treatment. Recently, the last room to be commissioned – containing a proton gantry – was certified and taken into operation. Commissioning of Helium beams has started in parallel.

Radiation Protection plays a crucial part since the beginning of the project for authority approval as well as for daily operations.

UNIQUE IN-VIVO NON-INVASIVE MULTIMODALITY IMAGING BASED TRANSLATIONAL RESEARCH LABORATORY ESTABLISHED AT MEDICAL IMAGING CENTER OF SEMMEWEIS UNIVERSITY

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Keywords: image based translational research, triple modality imaging, in-vivo non-invasive imaging

Multimodality imaging has great impact in the in-vivo non-invasive functional & morphology imaging diagnostic and research as well as plays important role in the functional biology. **M**edical **I**maging **C**enter (MIC) of Semmelweis University covers the entire imaging field by the integration of Radiology, Nuclear Medical and MRI disciples.

An AnyScan™ PET/CT (Mediso Ltd. Budapest) multimodality imaging system was formal handed over at 2021. at MIC. The system was financed by VEKOP program to be supported by both EU and domestic funds. AnyScan™ PET/CT imaging system has been extended by a triple detectors SPECT system by a collaboration contract with the manufacturer in order to obtain a unique triple modality AnyScan™ TRIO SPECT/CT/PET imaging system. AnyScan™ TRIO turned into the fundament of the „Innovative large animal models for clinical therapeutic research project" to be implemented at the Department of Nuclear Medicine of MIC -**Translational Research Lab** - under the leadership of the Department of Biophysics and Radiation Biology. Hereby became entirely completed the application of new therapeutic products and diagnostic procedures from pre-clinical trials into human use i.e. the **M**3 (**M**olecule-**M**ouse-**M**an) at the university. Behind the clinical research activities several other disciples are involved, such as the multimodality, multi-dimensional image reconstruction (4D recon.), novel image acquisition procedures (4D–5D dynamic, LIST mode), deep analysis of signal/noise ratio on the acquired data set. The latter has serious significance in the patient dosimetry, since the noise elimination effect including the detection sensitivity-resolution relations have large influence to the radiation dose level. TRIO-SPECT has organ specific (brain, cardiac) **MPH** (**M**ulti-**P**in**H**ole) collimator set providing ~1mm voxel-size imaging with artifact free results for both physical phantoms and human cases. TRIO-SPECT with parallel projection - LEHRHS (**L**ow **E**nergy **H**igh **R**esolution **H**igh **S**ensitivity) - collimator set has almost three times higher sensitivity comparing to the conventional double detector SPECT system by LEHR collimators with comparable depth dependent PSF (**P**oint **S**pread **F**unction) distortion.

The established laboratory may serve high level image based translational research, as well as it is a suitable environment to design, implement unique imaging procedures and to assure outstanding research and development circumstances for the related scientific fields as well.

LIPOSOMAL FORMULATIONS OF NEW DECORPORATION MOLECULES FOR THE TREATMENT OF INTERNAL STRONTIUM/COBALT CONTAMINATIONS

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Keywords: decorporation, cobalt, strontium, bisphosphonate, liposome

Nuclear/radiological incidents or accidents involving internal contaminations with radioactive cobalt or strontium compounds occur regularly. In this case, the current recommended therapeutic options (calcium salts of DTPA and cobalt gluconate in case of internal cobalt contamination and ammonium chloride and calcium gluconate in case of internal strontium contamination) are of low specificity, and their effectiveness remains modest. There is therefore a crucial need to design new modalities of administration and/or new molecules based on drug discovery or already marketed drugs for decorporation.

Our team is developing new liposomal formulations to deliver strontium/cobalt potential chelating agents to the main radionuclide retention organs. In a first step, we have identified and selected bisphosphonates (BP) molecules that can form stable complexes with cobalt and strontium. For that purpose, we have developed different approaches such as UV/Visible spectrophotometry and ion chromatography coupled with ICP-MS detection to screen our preselected candidates. These techniques have enabled the effective visualization of the BPs and divalent cations but compelling detections of BP-metal complexes have yet to be achieved. Additionally, we are currently developing a new separative analytical method based on capillary electrophoresis that should also be very useful for characterizing complexes.

The further step will be to encapsulate the candidate molecule into liposomes that will be surface functionalized with specific targeting ligands. The molecular targeting should induce a preferential accumulation of the liposomes in the bone compartments as well as in the liver and kidneys, thus enhances the distribution of the BPs in these key radionuclide retention organs. *In vivo* evaluation of the decorporation efficiencies of both the free and liposome-encapsulated molecule will then be performed in a rodent model.

OPTIMIZATION OF PATIENT DOSE IN BRAIN [18F]-DOPA PET/CT

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Keywords: PET/CT, patient dose, optimization

The development of new PET equipment incorporating the time-of-flight (TOF) technique has led to a significant improvement in image quality, allowing to reduce the activity administered to the patient. The aim of this study was to optimize the activity administered to the patient in brain PET/CT studies with [18F]-DOPA, simulating the reduction of activity by means of an equivalent reduction in acquisition time.

In this work, brain PET studies with [18F]-DOPA from 27 patients were included. Mean administered activity was 163 MBq. List mode acquisition was performed in a Biograph mCT TrueV (Siemens) scanner, allowing thus the reconstruction of images with different times: 1200 (reference), 900, 600, 450, 300, 150 and 75 s. Images were reconstructed with OSEM and OSEM+TOF algorithms. Image analysis was performed with the DopaSoft software, which automatically quantifies the concentration in the striatum and occipital regions, the striatum/occipital ratio and the clinically relevant statistical parameter Z score.

The relation of each parameter between the 1200s acquisition and the shorter time ones was studied using: the Pearson's correlation coefficient, the Lin's coefficient of concordance, and the Bland-Altman's analysis.

For both reconstructions, when acquisition time was reduced up to 300s, substantial agreement was found for the mean concentration, the striatum/occipital ratio and the clinically relevant statistical Z parameter, as compared to the reference. Therefore, a reduction of activity by a factor of 4 would be clinically feasible. Considering a dose coefficient of 1.68×10^{-2} mSv/MBq, mean effective dose to the patient would be reduced from 2.74 to 0.68 mSv.

This study demonstrates that the activity delivered to the patient in brain PET/CT studies with [18F]-DOPA scan be optimized. In particular, activity, and consequently patient effective dose, could be reduced by a factor of 4 without losing quantitative diagnostic capacity.

MEETING THE RADIATION PROTECTION CHALLENGES: NOVEL APPROACHES FOR MEDICAL AND OCCUPATIONAL EXPOSURE CONTROL

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Among the IAEA's key publications are its Safety Standards, which provide the fundamental principles, requirements and recommendations to ensure nuclear safety. They serve as a global reference for protecting people and the environment and contribute to a harmonized high level of safety worldwide. Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must be subject to standards of safety. Occupational radiation protection is the backbone for any national arrangements for radiation protection and the total number of monitored workers exposed to ionizing radiation is estimated to be approximately 24 million worldwide. About 52% are employed in the sectors that include exposure to natural sources of radiation (12.6 million workers) and about 48% in the sectors that include exposure to human-made sources of radiation (11.4 million workers). To protect them against such an exposure, some concrete steps can be taken as required by the GSR Part 3 and GSG-7 provides guidance on the control of occupational exposure (technical and operational aspects) based on "exposure situations" and provides information on ORP framework, exposures of workers in different exposure situations, protection of workers in special cases, dose assessment, management system for service providers, control measures as well as health surveillance. GSG-7 offers an itemized step-by-step guidance on how to be vigilant in enhancing safety standards for workers across a range of industries with new approaches for itinerant workers, female workers during and after pregnancy, monitoring of lens of the eye exposure, cosmic ray exposure, Naturally Occurring Radioactive Material (NORM) and radon at workplaces.

Medical use of ionizing radiation is one of the most rapidly developing areas of application of radiation: latest estimates are for around 4.2 billion procedures performed annually worldwide in diagnostic radiology, image guided interventional procedures, nuclear medicine and radiotherapy. Because of the direct benefit for patients from medical exposure, no dose limits apply to patients, and radiation protection is ensured by applying the principles of justification and optimization specific to the medical applications. The basic requirements for ensuring radiation protection in medical exposure are set in the GSR Part 3, and guidance specific to different medical applications is provided in the safety guide SSG-46. The current challenges include justification at individual level when accounting for recurrent imaging, practical use of approaches for optimization, such as quality control, patient dosimetry, diagnostic reference levels, proper use of imaging in radiotherapy, all linked to the need of improved education and training of health professionals with different professions. Another important area is the need of improved safety culture and team approach to radiation protec-

tion, which compliments the safety standards and regulatory actions. Involvement of different key stakeholders is crucial for the successful implementation of the international safety standards.

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[2] INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, Occupational Radiation Protection, IAEA Safety Standards Series No. GSG-7, IAEA, Vienna (2018).
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RISK MANAGEMENT IN SRS TREATMENTS

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Keywords: Risk management; SRS treatments

Purpose:
The purpose of the present work is to build a more robust analysis of the risk assessment already implemented in our department for stereotactic radiosurgery treatments (SRS). The goal is to review the results obtained from the preview analysis and use it as a guideline to write a risk management manual, in order to improve the security and performance of our processes.

Methods:
A representative group of professionals involved in SRS treatments procedures met regularly to perform a new failure modes and effect analysis (FMEA). Preliminary discussions about the scoring and risk prioritization were conducted in order to clarify all the professionals about the methodology adopted in our department. Process map, process steps, and failure modes (FMs) already implemented for this procedure were revised, together with event reports. FMs were rescored by each professional according to the probability of occurrence, the severity, and the detectability, with the corresponding recalculation of the risk priority number (RPN).

Results:
16 process steps were revised with a total of 183 potential associated FMs. Based on the previous analysis the steps corresponding to the treatment CT, validation of the plan and quality control were subjected to a more detailed analysis. Several strategies were discussed to mitigate or reduce the RPN of these FMs.

Conclusions:
By revisiting the SRS risk assessment applied in our department we were able to implement a more robust approach to risk management. This work will help us to extend this methodology to all treatments performed in our department, materialized in a risk management manual.

(Malicki et al. 2015). General guidelines on risk management in external beam radiotherapy. European Commission
(Huq et al. 2016). The report of Task Group 100 of the AAPM Application of risk analysis methods to radiation therapy quality management *Medical Physics* Volume 43 7 4209 4262

NEUTRON DOSE AROUND HIGH ENERGY LINACS IN HUNGARIAN RADIOTHERAPY CENTERS

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Keywords: neutron dosimetry, linac bunker, pulsed radiation field

The aim of the study is to measure neutron dose around high energy medical linear accelerators (linacs) in the bunkers of Hungarian radiotherapy centers.

When high energies are used above threshold for reaction in high Z components of linacs, a significant amount of photoneutrons are produced that needs to be taken into account when planning the shielding. 13 linacs were included in our investigation nationwide. We measured the neutron dose around high energy linacs in certain points along the maze and at the entrance of the bunker. Berthold LB 6411 dosimeter was used to measure neutron dose rate only outside the directly produced out-of-field beam where the high gamma to neutron flux rate in the pulsed beam causes counting difficulties for this device. In addition, closed collimators helped to improve neutron to gamma flux ratio by increasing the produced photoneutrons while decreasing the scattered photons. The investigated linacs were as follows: Varian TrueBeam, Clinac iX, Novalis, Elekta Synergy, VersaHD, Siemens Artiste and Primus, the used energies were either 15 MV or 18 MV. Bunker designs also differed according to the turns from the bunker entrance door to the end of the maze and the optional use of the inner wall.

For all the investigated linacs at 15 MV photon energy the neutron dose rate was a few times higher than photon dose rate up to 8 m along the maze from the treatment room opening while for some cases the ratio went below 1 at further distances. At 18 MV the neutron dose rate was higher along the whole maze. In one case at the entrance of the bunker a very high neutron dose rate with one order of magnitude higher value than for the rest of the centers was found. This linac operating at 15 MV energy was placed in a bunker with a maze containing only one turn from the treatment room opening to the entrance of the bunker.

We recommend to design or use bunkers with at least two turns in the maze for high energy linacs if their energies are above 15 MV.

T04: Measurement and standardisation

ENERGY CALIBRATION OF PULSE-HEIGHT SPECTRA IN PLASTIC SCINTILLATORS FOR CLEARANCE MONITORS USING MONTE CARLO SIMULATIONS

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Keywords: plastic scintillators, energy calibration, clearance monitors for decommissioning

Nowadays spectroscopic information in the form of pulse-height spectra can also be retrieved in plastic scintillator based clearance monitors, which represents a challenge for calibration, given the lack of photopeak presence for these particular materials. In past years, several publications provided methods for energetically calibrating such detectors (Siciliano et al., 2008; Byoungil et al., 2019), typically involving cumbersome determinations of the positions of the Compton edge's and optimization techniques (χ^2, genetic algorithms, etc.).

In this work, a simple method for calibration of the pulse-height spectra obtained in clearance monitors was investigated, aimed at simplifying the procedure in the case where up to 24 plastic scintillators are measuring simultaneously. Monte Carlo (MC) calculations were performed to simulate the irradiation conditions and adjust the corresponding response of the clearance monitor to the experimental data. In the present case, MC simulations are also globally optimized to resemble the experimentally obtained spectra, but using a convenient set of parameters. Preliminary results show good agreement in the high-energy range, but the simulations underestimate the count rate in the low energy region. The optimal set of parameters, as well as the folding (resolution) function used for the broadening of the simulated spectra were investigated and will be discussed.

This procedure will help not only to determine the conversion factors from count rates to activity for non-standard nuclides/geometries, but could also provide a means to perform nuclide identification.

Byoungil, J., Jongyul, K., Myungkook, M., Gyuseong, C. 2019. Parametric optimization for energy calibration and gamma response function of plastic scintillation detectors using a genetic algorithm. *Nucl. Instrum. Methods Phys. Res. A.* 930, 8-14.

Siciliano, E.R., Ely, J.H., Kouzes, R.T., Schweppe, J.E., Strachan, D.M., Yokuda, S.T. 2008. Energy calibration of gamma spectra in plastic scintillators using Compton kinematics. *Nucl. Instrum. Methods Phys. Res. A.* 594, 232-243.

REPRODUCTION OF SHIELDING CONCRETE ACTIVATION MEASUREMENTS BY SIMULATIONS

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Keywords: radioactive waste, concrete, neutron activation, MCNP, Cinder, FISPACT

With the increasing number of shut-down nuclear reactors, decommissioning-related research activity become more and more important. In case of shielding concretes, developments in radioactive waste assessment provides more precise radioisotope inventory estimations, hence tons of lower category radioactive waste, which also means huge amount of spared money.

The appropriate use of simulation tools could support this process, however, results of measurements and simulations in the scientific literature still show remarkable differences. Žagar et al. (2004) for example achieved 2-5-times higher simulation results when they tried to reproduce the measurement results of their shielding concrete activation experiments.

In our study, it was aimed to reproduce the measurement results of Žagar et al. with different simulation tools: MCNP code was used coupled with Cinder1.05 and FISPACT-II - partly to compare them. In case of some isotopes, like ^{65}Zn and ^{134}Cs, similar measurement-simulation differences were achieved to that of Žagar et al., however, ^{54}Mn showed much higher differences. On the one hand, latter could partly be explained by the less accurate fast neutron activation cross section libraries applied for the generation of ^{54}Mn. On the other hand, the tendencies in the differences between measurement and simulation results of different radioisotopes suggest that the energy distribution of the applied neutron source was not exactly accurate either.

Žagar, T., Božič, M., Ravnik M. 2004. Long-lived activation products in TRIGA Mark II research reactor concrete shield: Calculation and experiment. *Journal of Nuclear Materials.* 335, 379-386.

THE NOVEL EUROPEAN METROLOGY NETWORK (EMN) FOR RADIATION PROTECTION

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Keywords: network, stakeholder involvement, regulation, EURAMET

The European regulation on 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, which lead to new standards, technological innovations, and improved capabilities. It is therefore of vital importance to create a network that acts 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 and platforms. The EMN for Radiation Protection was officially launched on 16 September 2021. One of the most important tasks of this EMN will be to give a strong voice to the field of radiation protection metrology in Europe, so that it can provide responsible guidance and support to future technological development.

https://www.euramet.org/european-metrology-networks/radiation-protection/

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SELECTION TOOL OF IN SITU MEASUREMENT TECHNIQUES FOR RADIOLOGICAL CHARACTERIZATION IN D&D PROCESSES

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Keywords: in situ measurements, radiological characterization, decommissioning and dismantling

Radiological characterization is a key element of the planning, controlling and optimizing of decommissioning and dismantling (D&D) activities. This characterization aims at knowing the list of radionuclides present, as well as their location and concentration in a nuclear facility. It is usually done by using in situ measurements techniques under constrained environments. To successfully accomplish such an objective, an analysis of the suitability of existing methodologies for in-situ measurements in constrained environments is needed beforehand. This analysis has been done in the framework of the INSIDER project (H2020-Euratom) and already published in the journal Progress in Nuclear Energy (Aspe et al, 2020; Amgarou et al, 2021). Using the information gathered in these two papers, as well as along the INSIDER project, a decision-helping tool for the selection of the suitable detector in the different D&D phases has been developed.

The work presented here is an online tool, easy to use, intuitive and freely available. Just answering to a specific questionnaire related to the purpose and situation of the in situ measurements, the tool offers the best solution. After establishing the phase of the D&D program we are in, the purpose of the radiological investigation must be chosen. In the next step, one must select the type of particular installation under study as well as the specific area we want to control. Based on the impacts of the different environmental constraints (radiological, accessibility, materials and other environmental constraints) to which the chosen area may be subject to, the tool finally recommends some detectors, detailing their strengths and weaknesses as well as where to use it.

RADIATION PROTECTION CHALLENGES IN THE UPGRADE, AUTOPSY AND DISPOSAL OF THE LHC BEAM DUMP

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Keywords: FLUKA, Monte Carlo simulation, LHC, beam dump, radioactive waste

The Large Hadron Collider (LHC) beam dump allow for a safe and controlled extraction of the 7 TeV proton beams circulating in the ring. The LHC is equipped with two external beam dumps (TDE) located in two caverns ~750m downstream the Interaction Point 6. The TDE core is composed of a cylindrical ~8.5m long and 700mm diameter stainless 318LN vessel, enclosing several blocks of graphite of different densities. The core is surrounded by a shielding made of iron and concrete.

During the last LHC physics period (Run 2), several problems arose related to excessive vibrations of the TDE. These problems obliged to a modification of the TDE layout by upgrading the available spare dumps. In addition, this upgrade allowed inspecting for the first time of the two operational dumps, which showed signs of damage on some graphite blocks. Therefore, it was decided to conduct an in-house autopsy and a Post-Irradiation Examination to extract information essential for the next operational Run 3, the production of new spare dumps and the future design of a new TDE for High-Luminosity LHC operation. Following the autopsy, the dumps will be disposed as radioactive waste accordingly to the eliminations paths in place at CERN.

The spare dump upgrade and the TDE autopsy required to perform several activities in high radiation environment posing significant Radiation Protection (RP) challenges, due to the high residual activation of the TDE core. To ensure high safety standards and to respect the ALARA principle, these challenges were addressed by using advanced Carlo techniques to predict the residual ambient dose equivalent rate and radionuclide inventory at different stages of the interventions. The CERN RP group makes use of the FLUKA and ActiWiz codes to produce accurate estimates.

This work aims to provide an overview of the RP studies and the technical solutions found in order to optimize the interventions (ALARA) and to reduce the radiological risk for personnel and environment.

CITIZEN MONITORING OF AMBIENT DOSERATE: THE SAFECAST PROJECT

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Keywords: ambient dose rate, Citizen Science, SAFECAST, quality assurance, Citizen Monitoring

Citizen Monitoring is a discipline of Citizen Science (CS) [1], which means scientific research performed by citizens who are not professional scientists.

A very successful CS project is SAFECAST [2]. It has been founded in Japan after the Fukushima accident in 2011, motivated by distrust in the perceived biased information by Japanese authorities and the NPP operator about the radiation situation. Measurements of ambient dose rate (ADR) performed by citizens were intended to verify and to complement official data. A standard instrument called "bGeigie Nano" was designed for the purpose. It records ambient dose rate (ADR) together with GPS coordinates and date/time, allowing projection onto digital maps. The data can be submitted to the project team, which projects them on a world map freely accessible for viewing and downloading data. The project soon expanded internationally and by late 2021, about 170 million measurements are included in the database.

Benefits of CS are, shortly, the large amount of data which can be generated, making it a valuable source for science; the educational value; and communication between citizens and professionals. The problem consists in quality assurance (QA), because citizens are no trained metrologists and usually are only little familiar with notions of representativeness, measurement protocols and uncertainty, which are among central QA topics. Metrological QA has two levels: the one of the instrument itself, which must be metrologically characterized; and of instrument handling and data interpretation, particularly relevant in the CS.

For this contribution, we chose to discuss two topics which pertain to both levels: variability of the response of instruments of the same kind (bGeigie Nano) under same ambient conditions and isotropy of response under field conditions. Both contribute to the uncertainty budget; the latter adds to uncertainty due to instrument handling, hence is an uncertainty component typical for CS monitoring.

[1] https://en.wikipedia.org/wiki/Citizen_science; Vohland K et al. (eds.) The Science of Citizen Science. 2021, Springer International Publishing, DOI 10.1007/978-3-030-58278-4, www.springer.com/gp/book/9783030582777 (open access; accessed 14 August 2021)
[2] https://safecast.org/ (accessed 11 August 2021)

T05: Radioecology

INTEREST OF ECOSYSTEM SERVICES CONCEPT FOR ENVIRONMENTAL RADIATION PROTECTION

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Keywords: environmental radiation protection, ecosystem services

The emerging concept of ecosystem services (defined as the benefits people obtain from ecosystems) (MEA, 2005; TEEB 2012) is not yet reflected in the current approaches for protecting people and the environment against radiation by the International Commission on Radiological Protection (ICPR) or other similar approaches (Rhodes and al., 2020). Yet some recent thoughts from international organizations lead us to believe that an eco-based approach could be promoted in the coming years in the environmental radiation protection community.

IRSN has identified possible fields of application of the concept of ecosystem services to environmental radiation protection, in line with its integrated approach of radiological risks management. The concept of ecosystem services makes it possible to highlight biophysical/ ecological and socio-economic approaches of the impacts of ionizing radiation on ecosystem. Such developments require a multidisciplinary approach and multi-criteria analysis, currently being developed at IRSN. IRSN's ecosystem services approach will be developed in our communication along two axes:

- interests of biophysical characterization of ecosystem services for environmental radiation protection : review of works in progress and R&D perspectives,
- socio-economic assessment methods of ecosystem services : advantages for radiation protection and methodological limits.

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TEEB, 2012. The Economics of Ecosystems and Biodiversity in Business and Enterprise, Earthscan, Routledge.
Rhodes O.E. and al. 2020. Integration of ecosystem science into radioecology: A consensus perspective. *Science of the Total Environment* 740:140031.

DOES THE USE OF REFERENCE ORGANISM IN IMPACT ASSESSMENTS PROVIDE AN ADEQUATE PROTECTION OF SITE-SPECIFIC SPECIES IN ROUTINE RELEASE? CLARIFICATION AND REASSURANCE

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Keywords: radiological risk assessment, non-human biota, reference organism, terrestrial, absorbed dose rate

Wildlife protection has become of regulatory interest since the International Commission on Radiological Protection (ICRP) developed an approach to assess the level of radiological protection specifically for animals and plants. Pragmatically, an assessment cannot take account of all living species and populations within an area of interest. An international consensus was achieved [IAEA, 2018; ICRP, 2014] where the diversity of wildlife requires the use of a limited set of modelled organisms that facilitates standardisation of the models which are implemented in different codes and associated data used (e.g. ERICA, EA R&D128, CROM, RESRAD-BIOTA…). This set of organisms is known as Reference Organisms (ROs) [Larsson, 2004] or Reference Animals and Plants (RAPs) as were defined by the ICRP [ICRP, 2003, 2008]. However, for endangered or protected species in the field area, individual considerations in a risk assessment could be taken, but there is no explicit guideline to deal with such endangered species. Adding site-specific species to that set of surrogate species can respond to various interests, such as demonstrating to stakeholders the actual level of protection of the environment. Moreover, there is a need to question whether the use of the set of surrogate organisms is conservative enough to cover a wider range of biodiversity. Previous studies partially answered this question (Charrasse et al., 2019) and this paper adds a range of test cases for which dose rates are evaluated to determine the greatest difference between dose assessments for site-specific species and those for reference organisms, considering the radionuclides potentially discharged from different nuclear facilities. The dose coefficients were recalculated with the last version of the dose coefficient calculator supplied by the ICRP: BiotaDC tool. Maximal dose rate differences between a site-specific organism and a RAP or a RO were estimated from a set of radionuclides and sorted according to atmospheric releases of several facilities (NPP, research center, waste disposal, hospital). The global methodology and conclusions of those studies are presented.

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METHODOLOGIES TO ASSESS RADIOLOGICAL IMPACT OF A NUCLEAR FUSION TEST FACILITY

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Keywords: radiological impact assessment, nuclear fusion

With regard to environmental radiological impact, nuclear fusion facilities present peculiarities compared to nuclear fission reactors, mainly concerning the kind of radionuclides present at the facility that can be released both during normal operation and in case of accidents. Similar methodologies can be used for both kind of facilities, but some specific radionuclides, mainly tritium and some activation products, may require ad-hoc models and data.

In this paper, we present our experience in modelling the potential radiological impact of assumed gaseous discharges, chronic and acute. The main radionuclides for normal operation discharges in this case are H-3, C-14, Ar-41, between others. To assess the impact caused by normal operation discharges, the models used were PC-CREAM 08, CROM 8.4.1 and GENII-V2.10, and NORMTRI specifically for H-3. With regard to accidental discharges, we have assessed the impact of H-3 and Be-7 with the GENII-V2.10 and UFOTRI v4 for H-3. These codes were contrasted with the methods described in the US NRC Regulatory Guides 1.111 and 1.109 for routine releases, and Regulatory Guide 1.145 for accident discharges. To facilitate comparisons, simplified atmospheric conditions were considered, calculating doses at different distances for three representative persons, infant, child and adult.

A conclusion is that models are reasonably well established, but they give significant differences for some radionuclides and exposure pathways that should be better studied. Also, between the tested computer codes, some are obsolete from the informatics point of view. Their improving with regard to user friendliness and capacity to perform uncertainty and sensitivity analysis would be desirable. The influence that an adequate assessment of the radiological impact on the population and the environment may have on the design and licensing of these facilities would justify the efforts to improve the available models.

A REVIEW ON 60 YEARS RADOECOLOGICAL RESEARCH OF THE DANUBE RIVER

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Keywords: freshwater radioecology, Danube, environmental contamination, ^{137}Cs, ^{90}Sr, natural radionuclides, public exposure

Elevated levels of radionuclide concentration in rivers lead to increased health risks for the public drinking processed river water or consuming water animals. The use of contaminated river water for irrigation can also increase health risks by consumption of the agricultural products produced in the irrigated areas. Very early, also naturally occurring radionuclides such as ^{210}Pb, ^{210}Po, ^{226}Ra, ^{228}Ra, ^{228}Th and ^{238}U originated from industrial plants processing natural materials (e.g. mineral raw materials, building materials) were also included in the environmental monitoring programmes.

In this paper, a systematic review on radioecological research and radioactivity monitoring carried out in the Danube freshwater ecosystem in the past 60 years is presented. The essential objective of the spacious and long-term radioecological monitoring is the protection against harmful ionising radiation public exposure to manage sustainable use and conservation of the Danube freshwater resources. Therefore, it is of importance to monitor the radioecological status of the Danube River ecosphere and to evaluate the impact of artificial and natural radionuclides on the public health.

Results of radiometric analysis of Danube water and bottom sediment, collected continuously by sediment traps and additionally by grab sampling during Danube research cruises, are given and discussed. Sample collection techniques, sample preparation and radio-analytic methods, developed and applied in radioecological studies on the Danube River, are shown comprehensively.

Additionally, this paper aims to evaluate and visualise the spatial and long-term temporal development of natural and man-made radionuclides e.g. ^{40}K, ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{238}U and ^{210}Pb in Danube riverbed sediments. Finally, the public health risks on the population due to the radioactive contamination of the Danube ecosystem is assessed.

INFLUENCE OF EARTHWORMS ON THE BIOAVAILABILITY OF RADIUM AND METALS IN SOIL

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Keywords: earthworms, microcosm system, soil-to-plant transfer

Soil is an important medium for the dispersion of pollutants and their transfer into the food chain, potentially causing risk to man and non-human biota. Abiotic soil characteristics such as pH, cation exchange capacity and organic matter are known to influence the mobility and bioavailability of radionuclides and their co-pollutants such as metal(loid)s. However, soil is also one of the most diverse habitats on Earth and soil life is essential for ecosystem processes including nutrient cycling and plant growth. When pollutants are present in a bound unavailable form in the mineral or organic fraction, they can be made available for uptake by plants through bio-weathering and decomposition of organic material, which is the role of decomposers such as bacteria and earthworms. However, the influence of soil biota on radionuclide and metal bioavailability is often not considered in assessment models. Within this study, we aim to evaluate the influence of earthworms (*Lumbricus terrestris*) on the bioavailability of ^{226}Ra and metals present in soil. We used Belgian soil historically contaminated with a mixture of radionuclides (^{226}Ra, ^{137}Cs) and metals (Cd, Zn). Microcosm systems were used to mimic the natural interactions between soil, earthworms and vegetation. ^{226}Ra and metal concentrations were determined in pore water, soil and grass to determine their solid-liquid distribution and transfer to vegetation. To evaluate possible direct effects of earthworms on radionuclide and metal bioavailability, soil pH, the ionic composition of pore water and dissolved organic carbon were determined. In addition, possible indirect effects of earthworms on the bacterial community are being studied using next generation sequencing to refine our understanding of how earthworms shape them and if they in turn influence radionuclide and metal bioavailability. At this moment, analyses are ongoing and results are being processed. The results will be presented at the conference.

T06: Personal dosimetry

BIOKINETICS OF HIGHLY ENRICHED URANIUM IN A FEMALE NUCLEAR WORKER

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Keywords: enriched uranium, female, biokinetic modeling, tissue dosimetry

A female whole-body donor to the United States Transuranium and Uranium Registries, was employed at a nuclear defense facility for 27 years and was exposed to enriched uranium (EU) via inhalation. She died 31 y post-exposure at age 86. A total of 129 tissue samples from the right side of the body was analyzed for uranium by alpha spectrometry. ^{236}U was measured in 20 tissue samples using mass spectrometry. Analysis of the lung tissues confirmed that the inhaled material was EU with 67.2% of ^{235}U, 31.9% of ^{238}U, 0.7% of ^{234}U, and 0.2% of ^{236}U by weight. At the time of death, 27.1±0.6 Bq of uranium was retained in the respiratory tract, 0.29±0.01 Bq in the kidneys, 0.056±0.005 Bq in the liver, and 26.7±0.1 Bq in the skeleton. Bioassay data including urine and chest measurements and post-mortem activities in the lungs, liver, skeleton, and kidneys were simultaneously fitted using IMBA Professional Plus® to estimate the intake and the radiation dose. A combination of chronic inhalation and two acute inhalation intakes best describes the bioassay data. This individual was a heavy smoker that reflected in compromised particle clearance from the lungs to the thoracic lymph nodes. The models recommended by the International Commission on Radiological Protection (ICRP), with the adjustment for smoking status, adequately describe the biokinetics of inhaled EU except retention in the liver and kidneys. ICRP systemic models are mostly based on data from males and may not reflect female physiology. The best fit (p = 0.739) to all data including post-mortem tissue retention was achieved when the transfer rate from the liver to blood was increased by 10 and that from the kidneys to blood decreased by 2.1. The total intake was estimated to be 48.3 kBq, and the committed effective dose was 225 mSv with 97% contributed by ^{234}U. Of this dose, 96.8% was delivered to the respiratory tract tissues followed by red bone marrow (0.8%), bone surfaces (0.6%), and liver (0.4%).

MODIFIED HUMAN RESPIRATORY TRACT MODEL TO DESCRIBE THE RETENTION OF PLUTONIUM IN SCAR TISSUES

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Keywords: plutonium; internal dosimetry; human respiratory tract model; scar tissues

The Human Respiratory Tract Model (HRTM) described in Publication 130 of the International Commission on Radiological Protection (ICRP) provides some mechanisms to account for retention of material that can be subject to little to no mechanical transport or absorption into the blood. One of these mechanisms is 'binding', which refers to a process by which a fraction of the dissolved material chemically binds to the tissue of the airway wall. Because this parameter 'bound fraction' – the value of which is given as 0.2% for plutonium (Pu) in ICRP Publication 141-- has a significant impact on the radiation doses imparted to different parts of the respiratory tract. To properly evaluate – and quantify – bound fraction, one would need information on long-term retention of Pu in individual compartments of the respiratory tract. Such data on regional retention in the respiratory tract of four workers – who had inhaled materials with solubility ranging from soluble nitrate to very insoluble high-fired oxides – were obtained at the United States Transuranium and Uranium Registries. An assumption of bound fraction alone was found to be inconsistent with this dataset and also with a review of the literature. Several studies show evidence of retention of a large amount of activity in the scar tissues of humans and experimental animals, and accordingly, a model structure with scar-tissue compartments was proposed. The transfer rates to these compartments were determined using Markov Chain Monte Carlo analysis of the bioassay and post-mortem data, taking into account the uncertainties associated with deposition, dissolution, and particle clearance parameters. The models predicted that a significant amount – between 20-100% for the cases analyzed – of plutonium retained in the respiratory tract was sequestered in the scar tissues. Unlike chemically-bound Pu that irradiates sensitive epithelial cells, Pu in scar tissues may not be dosimetrically significant because the scar tissues absorb most, if not all, of the energy from alpha emissions.

TRANSITIONING TO RADIOPHOTOLUMINESCENCE (RPL) DOSIMETRY FOR ENVIRONMENTAL AND AREA MONITORING: THE PAUL SCHERRER INSTITUTE'S EXPERIENCE

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Keywords: radiophotoluminescence, environmental dosimetry

Radiophotoluminescence (RPL) dosimeters have been employed for individual monitoring at the Paul Scherrer Institute (PSI) since 2016. The RPL system was thus approved and accredited for personal dosimetry by the competent Swiss supervisory authorities, as part of the Dosimetry service's routine, itself accredited by the Swiss Accreditation Service following the ISO 17025:2005 norm. In an effort to simplify the dosimetry workflow, and replace an aging Al_2O_3:C- and LiF:Mg,Ti-based thermoluminescence (TL) system, formerly used at PSI for environmental and area monitoring, the RPL system was investigated and adopted for this purpose.

In this contribution, we will present the results of tests of the RPL systems carried out to demonstrate to the Swiss authorities that RPL dosimeters also fulfill the criteria specific to environmental and area dosimeters, whether it is in terms of detection range, energy and angle dependence, and reproducibility. Furthermore, the compliance to these criteria has been confirmed by the performance of RPL dosimeters in inter-comparison exercises for environmental dosimetry, at national and international levels (Swiss national inter-comparison 2019, EURADOS IC2019prep), that yielded satisfactory agreement between RPL and TLD systems. These results have led to the RPL system being approved by the competent authorities, and it has since replaced the TLD system for environmental and area monitoring at PSI, since 2021.

Finally, we will discuss practical problems encountered when RPLs for environmental and area dosimetry were first implemented at PSI, as well as advantages and disadvantages compared with the previously used TLD systems.

RENEB INTER-LABORATORY COMPARISON (2021): BIOLOGICAL DOSIMETRY BASED ON DICENTRIC CHROMOSOMES

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Keywords: RENEB, inter-laboratory comparison, biological dosimetry, dicentric chromosome assay

Regular quality-controlled inter-laboratory comparisons (ILCs) are important to allow the comparison of laboratories and to identify needs to optimize international networking in the field of biological dosimetry. ILCs are regularly performed in the frame of the European legal association RENEB (Running the European Network of Biological and Physical retrospective Dosimetry) to validate and improve the procedures for various assays. The dicentric chromosome assay (DCA) is considered as the "gold standard" for radiation biodosimetry and is an important tool for dose assessment in small and large-scale radiation accidents. For a large-scale accident, where many individuals are potentially exposed to ionizing radiation, the scoring procedure has to be adjusted to handle the large amount of samples in a reasonable amount of time and it is crucial to test the performance of the laboratories under conditions simulating a real accident situation. 33 laboratories from 22 countries participated in the current RENEB ILC (2021) for the DCA. The study design included the irradiation of blood samples, blood shipment, sample processing, analysis of chromosome aberrations and dose assessment. Blood was irradiated in vitro with X-rays and three blind coded blood samples were sent to each participant. The task was to culture samples, to prepare slides and to assess radiation doses based on the observed dicentric yields. The main aims were to test the response time of the participants, to determine whether the estimated radiation doses of the participating laboratories were in good agreement with the reference doses and to identify potential needs for further training and harmonisation. The participation of laboratories from countries around the world gave the opportunity to compare the results on an international level. The results of the ILC for the DCA will be presented and the potential and limits of the DCA in the case of a large-scale accident will be discussed.

PYMCGPU-IR MONTE CARLO CODE FOR OCCUPATIONAL DOSIMETRY IN INTERVENTIONAL RADIOLOGY

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Keywords: Monte Carlo simulations, MCGPU-IR, interventional radiology

Computational dosimetry is an extended alternative to estimate dose values in patient and personnel for interventional radiology techniques without the need for physical dosimeters. It provides immediate dose results for the entire body which increases the information for medical staff.

Monte Carlo (MC) radiation transport codes have been proved to provide precise dose distribution estimations. In particular, MCGPU-IR is a fast MC code that provides dose values with low uncertainties for both patient and operator in less than two minutes of simulation time. The main characteristic is the optimized use of several GPUs in parallel. It allows to calculate equivalent of personal dose, absorbed dose in organs and effective dose values.

This code has been validated comparing results with the standard multipurpose code PENELOPE and with experimental values measured in physical phantoms for both patient (Bosman et al., 2021) and operator (Balcaza et al., 2021).

Here is presented the MCGPU-IR validation in real occupational dosimetry conditions for different medical interventions and the validation of the protection shielding located in front of the operator, comparing personal dosimeter doses with simulated values.

The installation and use of MCGPU-IR and the posterior analysis of obtained data is a laborious issue. That is why the wrapper PyMCGPU-IR is created. It reads the RDSR from the C-arm and the camera tracking files that provide operator positions and transform them into MCGPU-IR input files. Then it performs the simulations and retrieve the dose values from its output files.

Bosman, D.F. 2021. Validation of the MC-GPU Monte Carlo code against the PENELOPE/penEasy code system and benchmarking against experimental conditions for typical radiation qualities and set-ups in interventional radiology and cardiology. *Physica Medica.* 82, 64-71.

Balcaza, V.B. 2021. Fast Monte Carlo codes for occupational dosimetry in interventional radiology. *Physica Medica.* 85(2), 166-174.

EXPERIMENTAL RECONSTRUCTION OF AN ACCIDENTAL EXTERNAL EXPOSURE: HOW THE DOSIMETRIC METHODS COMPLEMENT EACH OTHER?

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Keywords: radiological accidents, external exposure, dosimetric methods, dose assessment

The feedback from past irradiation accidents and the risk of malevolence make it necessary to be prepared to a possible event involving many irradiated victims. In this case, it is essential to know the dose distribution within the body in order to sort the victims and take them to the most suitable medical facilities according to the severity of the irradiation. The dose assessment can be performed using clinical dosimetry (observation of the early-phase radiation-induced signs), biological dosimetry (mainly based on the analysis of cytogenetic damage in peripheral blood lymphocytes) and physical dosimetry (retrospective dosimetry and experimental or numerical dosimetric reconstruction).

With the aim of validating a numerical dosimetric reconstruction tool called SEED (Simulation of External Exposures & Dosimetry) developed in collaboration between the French Defense Radiation Protection Service and the Institute for Radiation Protection and Nuclear Safety (Entine *et al.*, 2021), an exposure of a realistic irradiation scenario was performed at a military site in 2019. An anthropomorphic dummy filled with thermoluminescent dosimeters and water phantoms equipped with personal Hp(10) dosimeters were exposed to a high activity Ir-192 source. Blood samples and a mobile phone (used as a fortuitous dosimeter) were also placed at different locations. Several dosimetric techniques were used to assess the dose: thermoluminescence (TL), optically stimulated luminescence (OSL), cytogenetic dosimetry and Monte-Carlo simulation.

This work gives a detailed description of the experimental setup and includes the comparison of the results obtained by the dosimetric methods. This experiment involving several dosimetric techniques highlights their complementarity, their advantages and their drawbacks.

Entine *et al.* 2021. SEED: an operational numerical tool for dosimetric reconstruction in case of external radiological overexposure. *Health Physics Journal,* accepted.

CADOR*med:* A TOOL FOR INTERNAL DOSE ASSESSMENT

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Keywords: occupational exposure, committed effective dose assessment, Occupational Intakes of Radionuclides, software tool

CADOR*med* is a free home-made Excel tool for committed effective dose assessment using latest dose coefficients from ICRP OIR publications. It allows user to import data from OIR Data Viewer with a safety procedure. The procedure for entering data and testing the different models is very simple and user friendly.

Calculations are made according EURADOS guidelines principles (EURADOS report 2013-1). Chi-squared test for goodness of fit is made with scattering factors type A and type B provided by EURADOS report. Four different types of analysis, 2 in vivo measures and 2 in vitro measures, may be used simultaneously. Goodness of fit may also be tested according French recommendations: no more than a factor three between various estimates of intake. Intake is calculated with maximum likelihood method. Measures below detection limit may be used with allocated value equal to half or quarter of detection limit. Identification of rogue data may easily be done.

Advanced options may also be used: mixed ingestion and inhalation, mixture of default absorption types, correction for DTPA treatment, calculation with new intake, adjustment when date of intake is unknown.

A detailed user's manual is available.

The validation of the tool has been included in the work plan of EURADOS WG 7. The validation plan has been defined and the validation tests completed. All changes are traced in Quality Assurance document.

The next step for the final validation is the participation of CADOR*med* in international intercomparison dose assessment exercise.

OCCUPATIONAL RADIATION DOSE AND RADIATION PROTECTION TO THE EYE LENS OF INTERVENTIONAL PROFESSIONALS FROM DEPARTMENTS OF INTERVENTIONAL RADIOLOGY AND INTERVENTIONAL CARDIOLOGY

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Keywords: $H_p(3)$, eye lens dose, interventional radiology, interventional cardiology, radiation protection, lead glasses

In 2012, International Commission on Radiological Protection (ICRP) had revised the equivalent dose to the eye lens for occupational exposure from 150 mSv/year to 20 mSv/year, averaged over five consecutive years, with a maximum of 50 mSv in a single year. Lately, several studies on clinical measurements, either with limited cases or with specific procedures, of the eye lens dose using dedicated eye lens dosimeters have been reported in interventional radiology and interventional cardiology (Vanhavere et al., 2011). However, a comprehensive eye lens dose assessment for different kinds of procedures from these departments in multiple hospitals has not been reported. Furthermore, for countries that have not established the calibration system for 3-mm dose equivalent $H_p(3)$, and the $H_p(3)$ monitoring system, or for interventional professionals who forget to wear the dedicated eye lens dosimeters when performing interventional procedures, an optional method for $H_p(3)$ assessment from the existing dosimetry system, especially from the whole body dosimeter, is crucial but has not been reported either. Lead glasses are the most fundamental equipment for protecting the eye lens in clinical operations and could distinctly reduce the lens dose for interventional professionals (Seals et al., 2016). Nevertheless, we observed that when the radiation protective lead glasses have lateral shielding, increasing the thickness of the lead equivalent material shows no better performance in radiation protection efficiency in clinical measurements. In this study, we provided the dose estimation models for $H_p(3)$ assessment from the whole body dosimeter for interventional professionals from departments of interventional radiology and interventional cardiology and assessed the effectiveness of the lead glasses for radiation protection of the eye lens.

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IS THE ISO SLAB PHANTOM APPROPRIATE FOR CALIBRATIONS OF THE NEW ICRU 95 OPERATIONAL QUANTITY PERSONAL DOSE?

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Keywords: personal dosimetry, personal dose, metrology, calibration, Monte Carlo

The metrologically correct calibration of personal dosemeters is crucial for the safe radiation protection of persons exposed to radiation. According to the latest recommendations by the International Commission on Radiation Quantities and Units (ICRU) and International Commission on Radiological Protection (ICRP) in ICRU Report 95, dosemeters intended to assess the new operational quantity personal dose shall be calibrated using the ISO slab phantom. It is assumed that the ISO slab behaves like the human trunk regarding backscatter from the incident radiation to the dosemeter position. However, no metrological validation of this assumption was found in the literature yet.

The proposal that the ISO slab should continue to be used as calibration phantom for personal dose can be legitimated by simulations and measurements for the determination of backscatter factors on the ISO slab and, comparatively, on a human-like Alderson Rando phantom. An ionization chamber was used to determine backscatter factors for standardized X-ray spectra in the energy range of 20 keV to 120 keV. For the validation of measurement results on the ISO slab, the Monte Carlo code MCNP was used. Additionally, the influence of shifting the detector position on the Alderson Rando on the backscatter factor was determined by measurements of relative backscatter factors.

Since backscatter factors on the ISO slab differ only up to ± 5 % from those on the human-like Alderson Rando, it could be concluded that it is not necessary to develop a new calibration phantom for assessment of personal dose. An additional uncertainty contribution may be considered taking also the variable dosemeter carrying position into account. The shifting of the detector by only few centimeters on the surface of the Alderson Rando caused similarly large deviations. These results can be used for the new international recommendations of IEC and ISO standards for dosemeter performance requirements, testing and calibration.

PRELIMINARY STUDY ON INDIVIDUAL RADIATION DOSE RECEIVED BY MEDICAL STAFF FOR DOSE CONSTRAINT DETERMINATION

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Keywords: eye lens, extremity, dose, TLD, occupation dose, medical application, intervention, nuclear medicine, safety culture, MTS-N, RadPro

The staff of the Radiation Protection Service of Semmelweis University measured the radiation dose suffered by the medical staff to assess the effectiveness of current procedures and equipment for further optimalisation, prompted by the requirements EU BSS 2013.

Thermoluminescent dosimeters (TLDs) were handed out to participants, who wore them on their chest, finger and head (or glasses) and evaluated to determine whole body (Hp(10)), upper extremity (Hp(0.07)) and eye lens (Hp(3)) equivalent dose, respectively. The collected TLDs were evaluated by TLD (MTS-N, RadPro) system.

Kálmán Pándy Hospital in Békés County provided data regarding their Departments of Nuclear Medicine, Invasive Cardiology and Radiology (Section of Angiography), including nurses and doctors. In addition, data of the Medical Imaging Centre of Semmelweis University personal were collected from assistants working in nuclear medicine, and both from doctors and radiographers in the Angiography Laboratory.

The data revealed high deviance in dose suffered resulting from habitual differences (9 cases, average of 2.09 μSv/GBq, with 2.30 μSv/GBq st. dev for Hp(10)). New yearly dose restrictions, namely 6 (from 2) mSv for whole body effective dose, 15 (from no value) mSv for eye lens dose and 300 (from 50) mSv for extremity dose, were also implemented.

The data also show high eye lens doses during certain procedures (e.g. 6.03 mSv in a 34 day period), that would lead to exceeding the yearly dose limits if the trend continues. The participant also suffered high eye lens to whole body dose ratio (e.g. 9 cases, average of 121.89 % with 29.48 % st. dev in classical nuclear medicine).

Task-dependent personal monitoring could be used to pinpoint personal practices that should be elevated into general use or be corrected, thus improving safety culture. The need for individual eye lens dose monitoring for nuclear medicine and angiography staff seems to be also essential.

ESTIMATION OF PLUTONIUM CONCENTRATION IN SKELETON FROM OCCUPATIONALLY EXPOSED INDIVIDUALS

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Keywords: plutonium, skeleton, principal component regression

Purpose: The skeleton is a major plutonium retention site in the human body. The estimation of the total plutonium activity in the skeleton is a challenging problem. For most tissue donors at the United States Transuranium and Uranium Registries, a limited number of bone samples is available. The total skeleton activity is calculated using plutonium activity concentration (C_{skel}) and skeleton weight. If limited number of was bone samples analyzed, C_{skel} could be estimated using multiple linear regression (MLR) of data from whole-body donors, where C_{skel} were estimated based on the analysis of the half of the skeleton. The caveat of MLR is that individual bone sample concentrations are correlated. Multicollinearity can be addressed by principal component regression (PCR).

Methods: A case with eight analyzed bone samples: vertebral arch, vertebral body, sternum body, patella, skull, femur middle shaft, femur distal end, rib, was used to demonstrate the application of PCR for prediction of C_{skel}. For each combination of these eight bone samples, PCR was performed using data from 14 non-osteoporotic whole-body donors, and C_{skel} was predicted for each combination. The predicted 95% confidence intervals were compared.

Results: The lowest relative width of confidence interval (6.5%) was achieved for the following four-bone combination: vertebral arch, vertebral body, patella, and skull. The widest confidence interval (90%) was observed for the combination of three bone samples: patella, skull, and femur middle shaft.

Conclusion: PCR was used to estimate C_{skel} for various bone sample combinations. Analysis revealed that a proper selection of bone samples significantly reduced the width of the 95% confidence interval of estimated C_{skel}.

PERSONAL ONLINE DOSIMETRY USING COMPUTATIONAL METHODS: THE PODIUM PROJECT

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Keywords: personal dosimetry, interventional procedures, computational dosimetry

Individual monitoring of workers exposed to external ionizing radiation is essential to allow application of the ALARA principle and follow up of the official dose limits. However, large uncertainties still exist in personal dosimetry, especially for neutrons and for inhomogeneous fields. Also, many practical problems exist for personal dosimetry, with many dosemeters getting lost and the reluctance of many workers to wear one or more dosemeters.

The objective of the PODIUM project is to improve personal dosimetry by an innovative approach: the development of an online dosimetry application based on computer simulations without the use of physical dosemeters. Operational quantities, protection quantities and radiosensitive organ doses will be calculated based on the use personal tracking devices, flexible individualized phantoms and scanning of geometry set-up. When combined with fast simulation codes, the aim is to perform personal dosimetry in real-time. Parallel to this, a different approach was planned with pre-calculated fluence to dose conversion coefficients.

We applied and validated the methodology for two situations where improvements in dosimetry are urgently needed: neutron workplaces and interventional radiology. We use input from dose monitors in the neutron workplace and radiation dose structured reports (RDSR) from the x-ray machine used in interventional radiology and we capture real movements of exposed workers and transfer this to the calculation application.

This paper will describe the achievements of the PODIUM projects in this new approach for personal dosimetry. We will show the results from the validation and test measurements in different hospitals, and in 2 workplace fields with significant neutron exposure.

MEDICAL RADIATION EXPOSURE DURING CONE-BEAM COMPUTED TOMOGRAPHY (CBCT) GUIDED PULMONARY INTERVENTION

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Keywords: augmented fluoroscopic bronchoscopy (AFB), entrance surface dose (ESD), effective dose, $H_p(3)$

Augmented fluoroscopic bronchoscopy (AFB) is a technique combining cone beam computed tomography (CBCT), fluoroscopy and bronchoscopy to provide real-time images for detecting small pulmonary lesions, which can be used for lesion biopsy or localization. Medical teams have begun to use CBCT examination room and hybrid operating rooms to perform pulmonary interventions such as transbronchial and percutaneous methods. However, the radiation exposure of patients and medical staffs during procedures has not yet been evaluated. Therefore, the purpose of this study investigated and analyzed the radiation dose, precise patient's entrance surface dose (ESD), effective dose and physician's $H_p(3)$ during AFB procedures by using DICOM data and clinical measurements.

For the direct measurement of ESD, 20 thermoluminescence dosimeters were attached around to patient's body throughout the AFB procedure. DICOM data were also collected for effective dose calculation using PCXMC, a computer program based on Monte Carlo method. To measure their $H_p(3)$, the physicians wore an EYE-D near their eye while performing the procedure.

In this study, a total of 45 cases were analyzed in 2 hospitals, with 25 and 20 cases in Hospitals A and B, respectively. The peak ESD varied from 2.5mGy to 220.5mGy, with a median of 47.8mGy, which is significantly lower than the threshold of skin erythema significantly. The effective dose ranged from 2.1mSv to 31.1mSv, with a median of 8.1mSv, having a slightly lower dose level comparing with other procedures with similar imaging techniques. Furthermore, 49 over 86 $H_p(3)$ data were below 4μSv per procedure, which is lower than the lower limit of our measurement system and will not exceed the annual dose limit mentioned by ICRP 118 (20mSv).

In conclusion, CBCT provided a more efficient and precise workflow for AFB, facilitating thorough preoperative preparation. Patient's doses measured throughout the procedure were determined to be safe for clinical practice, and physician's $H_p(3)$ remained significantly low. This study devised a measurement system for clinical radiation procedures, and the findings can serve as a guide for routine AFB procedures under the principle of radiation safety, that is, as low as reasonably achievable (ALARA).

T07: NORM & Radon

THE APPLICATION OF THE ALARA PRINCIPLE FOR RADON AT WORK: FEEDBACKS FROM THE EUROPEAN ALARA NETWORK

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Keywords: radon at workplace, ALARA principle, radiation protection culture, European survey

National regulations for the protection against radon at the workplace have recently evolved in Europe with the implementation of article 54 from Euratom Directive 2013/59 in national regulations. In general, the scope potentially concerned by the radon regulation has widen; including organizations not previously aware of radiation protection. Furthermore, the practical application of a graded and step-by-step approach including, when necessary, radon measurement, radon remediation, delineation of radon areas and exposure assessment of the personal, can be foreseeably challenging in practice, raising questions from employers, employees and other affected parties.

In this context, the European ALARA Network (EAN) has set up in 2021, a working group to investigate the practical implementation of the ALARA principle in relation to exposure from Radon At the Workplace (the A-RAW working group).

The objective of the working group is to gather a sample of practical experiences in Europe (the objective is 1~2 case studies per country). A questionnaire template has been developed to assist in the collection of an overview of the national regulations and the description of suitable case studies. The questionnaire has been designed to help provide practical details on the controls taken and the measures implemented at the different steps of the regulation. A particular focus is given to the application of the ALARA (optimization) principle.

The questionnaire can be filled in by employers and/or organizations supporting employers in the implementation of the regulation. Following the distribution in June 2021, the first feedbacks are being collected.

The working group aims to present a synthesis of the cases studies, consolidated with an analysis reflecting, notably:

- Commonalities and differences in regulations between countries,
- Feedbacks of the implementation of the regulation, at the different steps, with practical experiences and good practices,
- Difficulties in application, questions that could arise in the future,
- How is the ALARA principle implemented in this exposure situation,
- Actions (ex. guidance, training, sharing of experience etc.) that could be needed and developed in the future at national or European levels.

RADONORM - TOWARDS EFFECTIVE RADIATION PROTECTION BASED ON IMPROVED SCIENTIFIC EVIDENCE AND SOCIAL CONSIDERATIONS – FOCUS ON RADON AND NORM

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Keywords: radon, NORM, radiation protection, multidisciplinary research, E&T, stakeholder involvement

The EU-funded RadoNorm project initiates and performs research and technical development in support of European Union's effort to improve protection of people from radon and naturally occurring radioactive material (NORM). The project is highly inclusive and transdisciplinary and targets all relevant steps of the radiation risk management cycle for radon and NORM exposure situations. It aims at reducing scientific, technical and societal uncertainties by initiating and performing research and technical developments, to integrate E&T in all research and development activities and to disseminate project achievements through targeted actions to the public, stakeholders, and regulators. The inclusive character of RadoNorm is given by 1) targeting research and development of the management cycle, 2) combining biomedical and ecological research with mitigation development and social science research, and 3) integrating researchers from national radiation protection institutions, research centers, universities, SMEs and citizen scientists. In addition, education and training actions are integrated as well as stakeholder involvement in project activities. Thus, dissemination efforts are linked directly to knowledge achievements and new recommendations for improved radiological protection.

An overview of planned activities and first results will be presented addressing (1) radon and NORM exposures, (2) improvement of dosimetry, (c) assessment of effects and risks for humans and the environment, (d) refinement of mitigation technologies, (e) raising and encouraging the understanding societal aspects, and (f) dissemination of achievements. In addition, an ambitious pan European E&T programme contributes to competence building and sustainability of the project findings.

OCCUPATIONAL EXPOSURE IN INDUSTRIES INVOLVING NORM: SPECIAL CASE OF THE INADVERTANT INGESTION

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Keywords: NORM, occupational exposure, inadvertent ingestion

Industries involving naturally occurring radioactive material (NORM) belong to a large variety of industrial sectors with very diverse processes. As a result, the raw materials, products, residues and wastes are very varied in terms of radionuclides and associated chemical forms as well as in terms of physical nature (sludge, dust, sand, scraps, scales...).

Workers may thus be exposed by external irradiation, by inhalation and by inadvertent ingestion of NORM. The exposure depends on the physical nature of the handled materials among other hypotheses (workplace geometry, postures and actions performed).

If exposure by external irradiation and inhalation can easily be estimated using measurements in the working environment (ambient dose rate, airborne dust…) or by individual measurements (passive or operational dosimeters, individual air sampling), exposure by inadvertent ingestion cannot be directly measured and must be estimated on the basis of different models. This contribution presents existing models, compares them and makes recommendations for their use.

CLASSIFICATION OF NORM AS A BASIS FOR DOSE ESTIMATION

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Keywords: NORM, radionuclides, inhalation dose, classification

The determination of dose from a radiation source is the basis for radiation protection. In the case of NORM, the radiation sources are always a mixture of naturally occurring radionuclides. Usually, in solid geological materials (ores, minerals) the decay series of U-238, U-235, and Th-232 are in an activity equilibrium. The chemical and thermal treatment of such materials in industrial processes can significantly change the composition of the radionuclide mixture. Gamma spectrometry has proven itself as a preferred measurement method for characterising NORM. With this method, the long-lived radionuclides Ra-226, Ra-228, Th-228, K-40 can be determined sufficiently well from the gamma lines of the short-lived daughter nuclides with simple spectrometric devices (NaI detectors). With high-resolution detectors, measurements of U-238 (via the gamma lines of Th-234, Pa-234m) and Pb-210 are also possible. But U-234, Th-230, Th-232, Po-210 cannot be determined via gamma-spectrometry or only with high detection limits. Generally, Ac-227 can be determined via gamma-lines of its decay products, but due to its very low activity concentration it is usually not detectable with NaI-detectors and is frequently not determined in high-resolution measurements. However, due to the high dose coefficients, the thorium isotopes and Ac-227 are of high importance in determining the inhalation dose. As a practical method for deriving complete information on radionuclide composition of NORM, a classification based on knowledge of the processes in which the materials were produced, can be used. This paper makes a proposal for such a classification and discusses its application in practice.

EXPERIENCE WITH NORM-WASTE DISPOSAL IN DIFFERENT EUROPEAN COUNTRIES

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Keywords: NORM, waste, disposal, landfill, notification, authorization, acceptance

Mining and industrial processes generate NORM waste in different amounts. Large quantities of NORM waste result from the processing of raw mineral materials, e.g., bauxite and phosphate. For practical reasons, this waste usually has to be disposed of close to the site of production. However, in many other industries, NORM waste that can not be reused or recycled has to be disposed of in landfills or even treated prior to disposal in special facilities, e.g., by incineration. NORM waste that exceeds a certain level of activity concentration is under regulatory control. Any disposal of such waste requires approval from the authorities, which may restrict the disposal options, requiring additional effort and time.

This contribution summarizes the experience from different European countries regarding the disposal of NORM waste. Special attention is paid to the aspect of acceptance of radioactivity by the waste management industry.

INDOOR GAMMA RADIATION AND RADON RISK ASSESSMENT IN HUNGARIAN DWELLINGS

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Keywords: dwellings, gamma radiation, radon concentration, radiation exposure, risk assessment, slag

People spend the biggest part of their time within buildings. Generally the indoor environment is more radioactive comparing to the outdoor environment. For this reason the indoor environment is the main contributor to our natural originated exposure. At the same time, the public interest grows rapidly in indoor hazard risk factors including the radiation burden.

Indoor and outdoor gamma radiation and radon measurements were started in 1980's in our institute. Detailed radiohygiene examinations were carried out in dwellings from 2000. These examinations stated from detailed gamma dose rate survey and indoor radon concentration measurements. Around 460 buildings were surveyed until 2021. Additional information was recorded regarding the building structures and materials. Extensive statistical analysis was made from the results.

Based on our results, the average dose rate of outdoor and indoor gamma radiation is around 100 and 150 nSv/h in Hungary. We noticed that, the indoor dose rate values vary within wide range (50–1000 nSv/h) opposite of outdoor value's narrow range (50–150 nSv/h). According to our observations, only the slag within floor space or the slag concrete walls caused the enhanced indoor gamma radiation in dwelling. We developed a practical guideline for in-situ examination and evaluation of the indoor gamma radiation as well.

The long term and short term radon measurements have also long tradition in our institute. The previous are made by passive detectors. The latter are made by active method. We analyzed the available results of both methods and compared them to each other. The long term measurements are preferred generally, but sometimes it is needed to make a quick decision, e.g. before real estate transaction or during renovation. The estimation of potential radon risk can help in this situation. Using our experience, we worked out a concept for criteria of short term radon measurements and calculation method for indoor radon potential (IRP) value.

ASSESSMENT OF UNCERTAINTIES AFFECTING DOSIMETRIC CALCULATIONS FOR INTAKE OF RADON AND NORM

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Keywords: uncertainties, dosimetry, radon, NORM

Uncertainties in dosimetry of inhaled radionuclides are arising from different sources. Biokinetic models are used to describe the behavior of the radionuclide and its progeny in the human body. These models are also used to calculate the number and localization of decays in the body. Dosimetric models are used to calculate the doses to the target organs by the radiation emitted during or following the decays. The uncertainties of the calculated doses will be studied by propagating the uncertainties of the model parameters through the dose assessment. Fixed parameter values will be replaced by samples from distributions of those and used to estimate the dose. In the project the model parameters will be studied and distributions for the initial parameters based on physiological considerations will be derived and used in an uncertainty assessment. Software tools will be developed to allow the use of the distributions (e.g. by sampling out of those) in the calculations. Besides a global analysis of the uncertainty, these techniques allow also to study the influence of the single model parameters and to identify the most relevant in terms of uncertainty. In this project global uncertainty analyses and sensitivity analyses of exposure scenarios relevant for Radon and NORM (RADONORM) will be performed.

It should be noted that the study and treatment of uncertainties in internal dosimetry is still a topic of scientific interest (Paquet et al., 2015). 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 (Breustedt et al., 2018). From the literature study so far, it has been observed that the parameters that mainly lead to uncertainties in calculated doses for the intake of radon and NORM are mainly the activity size and breathing rate. Other parameters of interest are the unattached fraction of the aerosol, the nucleation fraction and the target cell parameters (Puncher and Harrison, 2012). Sensitivity analysis and the estimation of associated parameter uncertainties in biokinetic models need to be performed to give a better understanding of these models and to estimate the influence of single parameters on the model predictions and hence dose coefficients. The results from this study will provide information about the reliability of assessed doses and indications to sensitive parameters for a better fit of the models to monitoring data; this will be the focus for further studies since this knowledge will be crucial for guiding future epidemiological studies.

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SIMPLE ONE-PARAMETER FUNCTION TO RETRIEVE THE CORRECT EXPOSITION VALUE FROM CR-39 RADON DETECTORS, ALSO VALID IN HIGH SATURATION REGIME. VALIDATION OF THE METHOD WITH TWO DIFFERENT RADON MEASURING SYSTEMS AND IN BFS INTERCOMPARISON

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Keywords: radon, CR-39, PADC, saturation, correction, BFS

Solid-state nuclear trace detectors made with CR-39 polymer are widely used to determine long-term average concentrations of radon activity in indoor air. Normally, the response curve of this detectors is quite linear within 5000 kBqh/m^3 so that a simple calibration factor can be used for many measurements. However, it is known that for higher exposures there is an increasing saturation effect which can also lead to a significant underestimation of the measured value. The observed value could then also have direct consequences on health, especially in cases where the calculation of the dose is required to limit worker exposure.

Generally, to partially obviate saturation, a response curve can be determined by interpolating two or more "calibration points". Alternatively, self-correction algorithms usually present in detector reading systems can also be used. However, none of these approximations is able to always efficiently retrieve the correct exposure values in a wider measurement range, that goes from zero to high exposures in saturation regime.

As a useful alternative, a simple and efficient function is here proposed, obtained from completely general considerations and therefore also compatible with any nuclear trace counting algorithm. This feature uses a single experimental parameter which is easily determined for each batch of dosimeters and, for input, only requires the raw trace density provided by the CR-39 detector reading system in use.

To validate the proposed method and appreciate its usefulness both in terms of greater performance and ease of use, the proposed general function was tested on a wide range of controlled radon exposures using two well-known commercial systems: Radosys and Politrack. Exposure retrievals were also assessed in a BFS intercomparison.

ON THE EFFECTIVENESS OF RADON PRIRITY AREAS – A CRITICAL EVALUATION

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Keywords: radon, radon priority areas, hazard, risk, lung cancer

The detrimental health effects of radon have been acknowledged by national and international legislation such as the European Union Basic Safety Standards (EU-BSS Article 103/3) which requires member states to delineate radon priority areas. These radon priority areas are conventionally based on the concept of hazard by using indoor radon exceedance probability of a threshold concentration or geogenic radon potential for delineation of these areas. While this approach is efficient for finding many affected buildings with limited resources and, hence, reducing the individual risk, it is probably inefficient for reducing the collective risk if hazard and risk areas differ. In this study we map collective radon risk for Germany by linking information of geogenic hazard with exposure (residential building stock). The resulting map of affected residential buildings reveals distinct spatial contrasts compared to the hazard-based map. Further, an analysis based on hypothetical hazard zones elucidates that the vast majority of affected buildings (i.e., above threshold concentration) are located outside of areas of high and very high hazard. Consequently, radon policy focusing on areas of very high hazard only and within these areas on high concentration buildings only will presumably have no significant effect on averting radon attributable lung cancer deaths (less than 1 % of annual lung cancer deaths). We conclude that for reducing the collective risk significantly, complementary measures in addition to the current radon policy are required.

RADON MAPPING OF A DIFFERENT KIND: MAPPING ACTIVITIES AND COLLABORATIONS ON RADON OF INTERNATIONAL ORGANIZATIONS AND ASSOCIATIONS

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Keywords: radon, collaboration, activities, international organizations

In many countries, strategies and action plans to control the exposure from radon are in place. However, not only at the national level, but also at the international level many activities are carried out to support countries in designing and implementing their radon policies. Guidance and technical documents are issued, training is provided, research projects are sponsored, and interaction with various stakeholders is encouraged.

In October 2021, the European Radon Association (ERA) invited international organizations and associations to inform about their specific activities with respect to controlling radon exposure and to explore existing collaborations. The workshop also aimed to identify the need for a better collaboration. Presentations were given by representatives from WHO, IAEA, UNSCEAR, EC, HERCA, ISIAQ, ENBRI, RICOMET, EURADOS, EURAMET EMN, ENA, IRMA, and CARST.

This contribution will summarize presentations and panel discussion and present the main conclusions.

The workshop showed that a high number of various activities exist at the international level but that there is a strong need for more collaboration with the medical sector, the indoor air quality community, and the building sector to address all stakeholders involved in radon protection. The focus should be rather on exchanging experience, share capacities and competences than on the harmonization of procedures.

EXPLOTATION OF RESULTS: RADON METROLOGY FOR USE IN CLIMATE CHANGE OBSERVATION AND RADIATION PROTECTION

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Keywords: radon, metrology, radiation protection, climate observation

Radon gas is the largest source of public exposure to naturally occurring radioactivity, and concentration maps based on atmospheric measurements may help European Countries to comply with EU Safety Standard Regulations. Radon can also be used as a tracer to evaluate atmospheric dispersion models important for identifying greenhouse gas (GHG) origins. One of the recently most applied technique for indirect retrieval of GHG fluxes is being the Radon Tracer Method (RTM). To increase the accuracy of radon measurements used both for radiation protection and GHG budget goals, traceability to SI units for radon exhalation rate from soil, its concentration in the atmosphere and validated models for its dispersal are needed. Thus, an overlapping need exists between the climate research and radiation protection communities for improved traceable low-level outdoor radon measurements, combining the challenges of collating and modelling large datasets, with setting up new radiation protection services.

The EMPIR project 19ENV01 traceRadon[1] works on these aspects. Actually, it provides the necessary measurement infrastructure and uses the generated data to correctly apply the RTM which is particularly important for GHG emission estimates that support national reporting under the Paris Agreement on climate change.

First results in the development of new activity standards as well as in the application of new approaches in the data analysis for calibration procedures will be presented. By these results smaller uncertainties in field measurements can be achieved, while the calibration in field becomes traceable to the SI system for the first time. The project has already developed new technology and looks to implement this in new standards and support the uptake of new services by calibration labs. In summary the so far available exploitable results will be presented including new prototypes, procedures and software.

[1] This project 19ENV01 traceRadon has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme. 19ENV01 traceRadon denotes the EMPIR project reference.

RAISING AWARENESS THROUGH CONTINUOUS RADON MEASUREMENTS IN INDOOR WORKPLACES

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Keywords: continuous radon measurement, radon exposure

Since 1988, radon is classified as a human carcinogen and it is recognized as a major risk for human health. Relevant documents such as the Directive 2013/59/EURATOM and IAEA GSR Part 3 have established strategies for reducing the health impact of radon and for raising public awareness about the consequences of radon exposure. When radon is taken out of the scientific context in order to be understood by the public, through mediatic approaches, the materials distributed are more than often prone to sensationalizing and radon exposure is classified by the public as just another scandal news.

Communicating risk in a clear and effective manner was never easy and communication of radon risk poses serious challenges because radon is not widely known and specialists need to be more involved in engagement activities and campaigns to inform about radon exposure.

In this paper we present the continuous radon measurements performed in more than 50 institutions for raising awareness among workers occupationally exposed to ionizing radiation. Radon measurements were made using Airthings Wave monitors that continuously measure radon, temperature and humidity and the measured values are recorded hourly. The studies were performed with no costs for the institutions. Measurement periods were between 3 to 9 months and most of the institutions were hospitals.

The measurements put in evidence the temporal variation of radon, its increase with the decrease of outdoor temperatures and also highlight the periods when the rooms were less ventilated. The soundness of data correlated to real-time visualization of the maximum radon levels provided convincing evidence that led to increased interest for radon exposure among exposed workers.

The main outcomes will be discussed in the present work.

T08: Radioactive waste management and geological disposal

REMEDIATION OF A CONCRETE UNDERGROUND ARTIFACT CONTAINING RADIFEROUS PREPARATIONS OF RA-226 AND DISPOSAL OF THE RADIOACTIVE OR CONTAMINATED MATERIAL UNTIL COMPLETE RESTORATION OF THE AREA AT THE HOSPITAL FACILITY OF BORGO TRENTO

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Keywords: radiferous preparations, remediation, radioactive waste management, clearance

At the hospital facility of Borgo Trento (VR) a concrete artifact containing radiferous preparations of Ra-226 was located underground. Most of the radium was contained in two safes and a cylindric lead container. Other contaminated material was contained in a wooden box and in a plastic wrap. These items were put inside a sarcophagus and embedded in a concrete matrix. Campoverde was appointed for the remediation of the artifact, the management and disposal of all the radioactive or contaminated material, and restoration of the area. The activity presented multiple challenges, related to radiation protection and construction aspects.

A soldier pile wall was installed to correctly insure soil retention during excavation. Above the foreseen excavation area a confinement structure was constructed, equipped with a ventilation system with absolute and activated charcoal filters, as well as a dose rate and air monitoring system.

The material coming from soil excavation and sarcophagus demolition was retrieved in big bags. Samples of each big bag were collected in special radon gas-tight containers and analysed immediately, for a preliminary screening, and after 30 days, after onset of secular equilibrium. The material was cleared as special waste only if the second measurement revealed levels of radioactivity statistically undistinguishable from the blank reference samples with a significance level of 99%. Analyses were performed in the Campoverde laboratory installed on site, equipped with HPGe gamma spectrometry systems.

The radioactive items were inserted in suitable containers to be directly transported to the radioactive waste repository of Campoverde.

The remediation activities involved the manual removal of more than 140 tons of material, and lead to the recovery of 69 radium needles and other items containing radium salts, for a total activity of 10.858 GBq of Ra-226.

All the activities were carried out under constant supervision of a Radiation Protection Expert.

OPERATIONAL RADIATION PROTECTION CHALLENGES FOR THE LHC EXPERIMENTS

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Keywords: LHC, radiation protection, Monte Carlo, FLUKA, radioactive waste

The Large Hadron Collider (LHC) at CERN, the largest particle accelerator existing at present, aims to accelerate and collide proton or ion beams up to energies of 6.5 TeV and 2.56 TeV/u at the four main experiments ATLAS, ALICE, CMS and LHCb. At these energies, the interaction of collision secondaries with materials produces unique high-energy and mixed fields that induce radioactivity in detector and infrastructure components.

Proper optimization during maintenance and upgrades is required to ensure that the exposure of personnel to radiation and the radiological impact on the environment are as low as reasonably achievable (ALARA). Reliable estimates of residual dose rates for interventions are needed at several locations and for the possible configurations in which the complex experiments will be during stop periods. Additionally, any material that is removed from a radiation area is always subject to radiological control: since the procedure applied for the radiological control depends on the activation levels, the estimation of residual activation in detector components and infrastructures is essential.

Due to the complexity of the facilities and the uniqueness of the radiation fields, Monte Carlo codes for the interaction and transport of particles in matter are used to simulate prompt radiation fields and residual activation. Specific tools based on the FLUKA Monte Carlo code have been developed at CERN to tackle the complex problem of estimating residual dose rates for shutdown detector configurations. More recently, an on-line weighting method to convert particle fluences to relevant radiological hazard factors has been employed for efficient residual activation zoning. The capabilities of this method with respect to radioactive waste characterization and minimization will be demonstrated by the assessment of the activation of the 600 tons of austenitic stainless steel in the CMS High Granularity Calorimeter (HGCal) that will be installed in 2026.

APPLICATION OF CATION-EXCHANGED BENTONITES IN NUCLEAR WASTE TREATMENT

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Keywords: Modified-bentonite, Nuclear waste, Sorption experiments

One of the important goals of the 21th century is to improve the environment. The emission of pollutants can have adverse effects on the environment and public health. Therefore, it is necessary to develop treatment processes that isolate and remove contaminants from their environment. Thus, the aim is to sorb long-lived radioactive isotopes on modified bentonite clay. Since these pollutants are anions, they do not sorb onto natural clays to a significant extent and therefore they can relatively quickly migrate with water in the environment. The modifications create sorbing sites in the clays where anions can also be sorbed or precipitated in the form of weakly soluble salts, thereby reducing migration. The sorption of $^{36}Cl^-$, $^{131}I^-$ isotopes was investigated on Ag-bentonite, while the sorption of ^{99m}Tc isotopes as pertechnetate ions (TcO_4^-) was studied on Mn-, Cr-, Sn-bentonites.

The successful cation exchange was confirmed by X-ray fluorescence spectroscopy and X-ray diffraction. Kinetic studies were carried out to determine. The sorption of iodide ions on Ag-bentonite is rapid and the equilibrium is reached within a few minutes so the rate constant could not be determined by the batch technique. In the case of iodide ion, the sorption was influenced by iodide carrier solution. Increasing the concentration of the inactive iodide ion reduces the sorption due to the formation of a soluble silver diiodide complex. The modified bentonites can sorb ^{99m}Tc ions fast and in a high degree. On the basis of the redox potential and the relative sorption values, it can be stated that the Cr-, Sn-modified bentonites showed the most effective sorption, the removal of Tc was 100% after 5 minutes. These results show that modified clays can be suitable for the construction of waste containers as anion sorbents.

PREPARATION OF A SORBENT SUITABLE FOR SORPTION OF ANIONIC AND CATIONIC RADIOACTIVE CONTAMINANTS

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Keywords: layer double hydroxide (LDH), bentonite, structure analyses, radioactive contaminants

Interfacial reactions of clay rocks play an essential role in describing the interfacial processes in the rocks and in mapping the consequences of environmental pollution. Inhibition of anionic radionuclides is still a problem in the management of radioactive waste. Our research group (DE TTK Department of Physical Chemistry, Imre Lajos Isotope Laboratory) has studied the sorption properties of bentonite in recent decades. According to our research results, natural and modified bentonites are able to sorb cationic radionuclides, while anion sorption is only possible with appropriate modification due to the negative layer charge. A few years ago, our research team began producing positively charged layered double hydroxides for the sorption of anionic impurities. The problem, however, is that cationic and anionic radionuclides occur together in an aqueous medium. Thus, with this work, we attempt to form a sorbent material that may be capable of sorbing anionic and cationic contaminants. During this work bentonite hybrid material containing layered double hydroxide (LDH) was produced. The structure of the produced hybrid material was investigated by Scanning electron microscopy (with energy dispersive detector) (SEM-EDS), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS) and Fourier- transform infrared spectroscopy (FT-IR). Structural analyses have shown that LDH-containing bentonite hybrid material has successfully produced. Gamma spectrometry was used to study the migration of the ^{36}Cl isotope, which can be used to determine the chloride ion progresses during migration. Liquid scintillation spectrometry measurement technique was used to monitor the temporal displacement of ^{36}Cl and ^{137}Cs isotopes in bentonite during migration study, which can be used to determine migration coefficient. Migration study shows promising results. Further studies are planned to clarify the conditions of the production of LDH-containing bentonite hybrids.

INTRODUCTION TO THE APPLICATION OF COMSOL MULTIPHYSICS TO RADIONUCLIDE TRANSPORT CALCULATIONS OF MIGRATING SPECIES FROM A REPOSITORY FOR LOW-LEVEL RADIOACTIVE WASTE

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Keywords: COMSOL Multiphysics, radioactive waste, radwaste repository

Portugal does not have nuclear power plants but had a research reactor operational until 2019 and the spent fuel was sent to the USA under a bilateral agreement. Radioactive wastes produced in Portugal, besides future decommissioning wastes, also considers radioactive waste resulting from application of radiations in many fields such as health, industry, research, teaching and training. Therefore, a wide range of radioactive waste arises every year from which the disused radioactive sealed sources are the main concern due to not only safety considerations but also to the implicit security associated. Portugal has a national interim storage facility located at IST, Lisbon University and, according to Directive 70/2013/EURATOM, must develop R&D in order to develop studies related to a future site to receive a disposal facility for the type of radioactive wastes produced in Portugal. Research started between 2008 and 2011 to collect data from different geological materials (FCT Project KADRWaste) and is now moving to the application of models to simulate the possible repositories. In this work, we will present the preliminary results of the application of COMSOL Multiphysics having in consideration geomaterial data collected and the isotope ^{137}Cs.

INVESTIGATION OF THE STRUCTURE OF BINDERS RELATED TO THE FINAL DISPOSAL OF RADIOACTIVE WASTE

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Keywords: NMR, cement stone, geopolymer, rehydration, diffusion, pore structure

The macroscopic properties of nanostructural materials are directly related to their porous structure, the slightest change of which can significantly influence the possible applications. The process that has the most significant effect on the porous structure is the interaction with water. Investigation of interactions with liquid media is especially important for materials such as binders for radioactive waste storage, the structural change of which can also lead to a decrease in the immobilization of waste.

In our work, we investigated the changes during the interaction of cement stone matrices of different compositions and geopolymers with water by liquid nuclear magnetic resonance (NMR) methods. During the NMR relaxometric measurements, we successfully separated the water types with different mobility located in different pores of the cement stone. We drew conclusions about the porous structure from the quantitative distribution and mobility of water types. Comparison of the samples shows the effect of the added components on the properties of the cement stone matrices. In the case of the dried samples, the process of hydration showed a change that could be followed over time. Information on the mobility of water in cement stone was obtained by the H_2O - D_2O exchange diffusion technique. The size of the larger pores in the solid matrix was determined by NMR cryoporometry experiments. In addition, a small, single-sided magnet, the NMR MoUSE, was tested for crushing-free analysis of the samples. Geopolymers are used to solidify waste that is difficult to handle and to improve its solubility properties. The structure of the geopolymers were also investigated by the above-mentioned methods.

Our results effectively supplement the standard dissolution studies with the characterization of the water mobility and the structure formed by hydration, thus providing input information for the modeling processes and the matrix material development.

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NEWLY BUILT CLEARANCE FACILITY AT THE PAUL SCHERRER INSTITUTE, SWITZERLAND

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Keywords: Clearance Facility, clearance measurements, radiation safety

In 2020 a new Clearance Facility has been built at the Paul Scherrer Institute (PSI), where routine free-release and characterization measurements of radioactive waste generated by the institute take place. The introduction of clearance monitors as a part of the management process of waste from controlled areas created a demand for a well-shielded measurement facility, where the influence of PSI's large radiation facilities on the free-release measurements would be minimal. The new Clearance Facility located on the west side of PSI with its 50 cm thick concrete walls provides adequate shielding from external radiation, as evident from the background measurements conducted during a 1-year-long measurement campaign.

The Clearance Facility is comprised of two areas: the sorting room (front) and the measurement hall (rear). The latter holds two clearance monitors: the HWM-1800 Free Release Chamber from Ludlum GmbH and the RTM661/440™ Large Object Monitor from Mirion Technologies, Inc. In the sorting room, two radon detectors and a dose rate detector continuously record background levels of radon gas and dose rate, respectively. Together with the background data from the clearance monitors, the background data are evaluated biweekly to ensure continuous monitoring of the conditions within the building.

The completion of the Facility comprised of: i) the Preliminary Study (2018), ii) Concept Development (2018-2019), and iii) the Construction Phase (2019-2020). The Commissioning of the Clearance Facility (2020-2022) is currently underway, involving the installation and validation of the clearance monitors for routine use. The installation of the NuRAD 8200 Modular Concrete-based Shielding System from Nuvia a.s. is also planned during this stage. The system will provide additional shielding and separate the building into the different measurement stations. After the installation of the NuRAD system, a new measurement campaign evaluating the background level will be conducted.

T09: Radioactivity monitoring and emergency monitoring

CARBON-14 SPECIFIC ACTIVITY IN ATMOSPHERIC AIR IN THE VICINITY OF A PHWR NUCLEAR POWER PLANT IN INDIA

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Keywords: radiocarbon, specific activity

Radiocarbon (^{14}C), a pure beta emitter ($T_{1/2}$ = 5730 y, E_{max} = 156.5 keV), is produced naturally by the cosmic-ray induced reactions in the upper layer of the atmosphere. During the regular operation of nuclear reactors, ^{14}C is produced by the neutron activation of stable isotopes of carbon, nitrogen and oxygen in the fuel, cladding, coolant, moderator and structural materials of the reactor. A fraction of the generated ^{14}C is released to the environment, mainly in two chemical forms; oxidized, i.e. carbon dioxide (CO_2), and reduced, which mostly is in the form of CH_4. The release rates for different nuclear power reactors are in the order CANDU>RBMK>BWR>PWR. For all types of reactors except PWRs, most of the gaseous releases of ^{14}C are in the form of $^{14}CO_2$, which plants assimilate. Considering the biological importance of ^{14}C in the organism and its long half-life, significant importance is given to monitoring its activity in the vicinity of nuclear facilities. In India, the measurements of ^{14}C in the vicinity of a nuclear power plant (NPP) were initiated by the Centre for Advanced Research in Environmental Radioactivity, Mangalore University, in 2015. This paper reports the excess ^{14}C activity in ambient air in the vicinity of the 220x4 MWe Kaiga PHWR NPP (14º51′51.96″N, 74º26′21.84″E) on the West Coast of India. The measurements were performed during 2019-2020. Atmospheric CO_2 was sampled by bubbling ambient air through a bubbling setup consisting of 2N NaOH solution, precipitation of the absorbed CO_2 as $BaCO_3$ and analysis of the activity using a liquid scintillation spectrometer. The ^{14}C specific activity in ambient air in the vicinity of the NPP was in the range 234–451Bq $kg^{-1}C$. The excess activity was evaluated by comparing the specific activity recorded for the clean air region (the region with minimal or no anthropogenic activity) of the West Coast of India. The GM values of excess activity recorded at 7 sampling sites were in the range of 8-96Bq $kg^{-1}C$.

NON-PROPORTIONAL SCINTILLATION RESPONSE MODEL FOR AIRBORNE GAMMA-RAY SPECTROMETRY APPLICATIONS

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Keywords: airborne gamma-ray spectrometry, FLUKA, intrinsic broadening, machine learning, Monte Carlo simulation, NaI(Tl) scintillator

Recent advances in the experimental characterization and mathematical modelling significantly improved our theoretical understanding about the non-proportional relationship between energy deposition and scintillation light yield in scintillators. The objective of this study was to implement a simple and reliable non-proportional scintillation model (NPSM) for the multi-purpose Monte Carlo transport code FLUKA adopting recently developed best-estimate electron response models accounting for free carrier creation, Onsager recombination, Birks annihilation as well as Debye related trapping.

By means of high-performance computing, model parameters of the NPSM were iteratively optimized using a global surrogate solver coupled to the FLUKA Monte Carlo code. Gaussian Process Regression models were trained and cross-validated using machine learning techniques to characterize the intrinsic resolution up to a photon energy of 3 MeV. ^{133}Ba, ^{60}Co, ^{137}Cs and ^{152}Eu radionuclide sources were measured with an airborne gamma-ray spectrometry detector system with four individual NaI(Tl) scintillation crystals at the calibration laboratory of the Paul Scherrer Institute for validation of the NPSM model.

Through the implementation of the developed NPSM model, the detector response simulations show a statistically significant better agreement with the validation measurements results, especially around the Compton edge. The intrinsic resolution contributes up to 60% to the total detector resolution. Furthermore, hypothesis tests together with a descriptive statistical analysis confirmed the conjecture that the intrinsic photon peaks are asymmetric and non-Gaussian according to the adopted NPSM.

The validated methodology presented herein can be utilized for simple and reliable implementations of NPSM using Monte Carlo codes for any inorganic scintillator materials and to derive the detector dependent model parameters numerically without the need for additional electron response measurements.

IDENTIFICATION AND QUANTIFICATION OF ANOMALIES IN GAMMA DOSE RATES OF ENVIRONMENTAL RADIATION MONITORS USING ARTIFICIAL INTELLIGENCE

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Keywords: gamma dose rate, environmental radioactivity, machine learning, artificial intelligence

Gamma dose rate (GDR) monitors are the most widely used tool for continuous monitoring of environmental radioactivity. They are inexpensive to procure and operate, and generally require little maintenance. However, since no spectral information is available, the detection limit for irregularities is correspondingly high; A value around 20 nSv/h is often quoted. Especially precipitation-induced signal peaks determine the alarm limits.

By adding weather data and a suitable sequence of algorithms from the domain of machine learning and artificial intelligence, the detection limit can be lowered, with at least the same reliability. The algorithms need to be designed in such a way that an integrated safety net prevents false negatives, i.e. the probability of classifying real events as normal or overlooking them shall be minimal.

Such a sequence was developed, implemented, and tested in a research project of Scienta Envinet and the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS). The first step consists of merging the GDR data measured by BfS with the associated weather data provided by the German Weather Services DWD. Afterwards, the precipitation-induced GDR peaks from washed-out Raden progeny are removed by means of regression, provided that a check of the regression parameters shows sufficient agreement with past precipitation events at the measurement site.

With the help of the weather data, a neural network then calculates the expected value of the remaining GDR series for the prevailing conditions. An anomaly detection is then carried out on the difference between the nominal and actual value. Here, extreme value theory is used for point values, and hierarchical clustering of subsequences for slower processes. By combining the two detection methods, the spectrum of irregularities is covered as sensitively as possible.

The algorithms were implemented in Python and trained with real measurement data. For verification, the data were enriched with results from JRODOS simulations of nuclear power plant accidents.

Altogether, the presented methodology can lower the detection limit of irregularities to about 4 nSv/h, i.e. about a factor of 5 below the previous consensus value. The algorithm not only detects the anomaly in the GDR, but also quantifies it.

ADAPTATION OF AN ANALYTICAL METHOD FOR RADIUM 226 IN WATER TO URINE MATRIX

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Keywords: radium 226, urine, Ra Nucfilm disks®

The French Defense Radiological Protection Service (SPRA) realizes water and urine analyses in order to ensure environmental and medical monitoring respectively. One of radionuclides that could be targeted by the laboratory is radium 226, a highly radiotoxic radionuclide. In literature, radium analyses often require a lot of steps for chemical pretreatment and radium extraction. The method based on Ra Nucfilm disks® (supplied by Triskem) allows, for water analyses, a direct radium extraction coupling to source preparation without any chemical treatment followed by alpha spectrometry measurement.

Firstly, the water protocol was applied as recommended in the Triskem technical information using barium 133 as tracer: 6h-agitation of disk into the sample and 24h alpha spectrometry measurement. Some measurements of standards were also done to determine the physical yield of alpha spectrometry taking into account the disk thickness. With this technique, six samples could be treated and analyzed in less than two days. The radium adsorption yield is around 50% and the detection limit is lower than 10 mBq/L which respects the recommended value for drinking water analyses (0,04 Bq/L).

Once the water protocol completely available, some optimizations were initiated to extend this technique to urine analyses. SPRA already does some radium urine analyses with calcium oxalate precipitation and gross alpha measurement. A mineralization step after calcium oxalate precipitation was added and Ra Nucfilm disks® were used on mineralization residue dissolved in deionized water. Determination of radium activity was achieved with 24h alpha spectrometry. As water analyses, six samples could be treated and analyzed in two days with a mean yield around 30%.

To conclude, the application of Ra Nucfilm® disks on urine matrix is quite new. Further optimizations should be done to increase adsorption yield but this new protocol is time-saving and easy to apply in the laboratory.

France. Ministère des solidarités et de la santé. Arrêté du 19 octobre 2017 relatif aux méthodes d'analyse utilisées dans le cadre du contrôle sanitaire des eaux. *JORF* n°0251 du 26 octobre 2017.
Triskem. How to use Ra-Nucfilm discs? (v301209). Technical information.

COMPARISON OF RADIOMETRIC AND MASS SPECTROMETRIC ^{90}SR ANALYSIS IN THE CONTEXT OF THE FUKUSHIMA NUCLEAR ACCIDENT

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Keywords: strontium-90, radiometry, mass spectrometry

For ^{90}Sr analysis, radiometric methods have been mainly used, detecting beta particles emitted by the radioactive decay of ^{90}Sr. The beta particles have a continuous energy spectrum, unlike gamma rays with discrete energy. Therefore, efficient separation of interfering beta emitter radionuclides is crucial prior to ^{90}Sr measurement with radiometric methods. In the case of the Fukushima nuclear accident, the radionuclide contamination was dominated by interfering radiocaesium isotopes (^{134}Cs and ^{137}Cs, which emit beta particles that coexist with gamma radiation). The ^{90}Sr/^{137}Cs activity ratio in contaminated samples from Fukushima is around 1×10^{-4}, which corresponds to a Cs decontamination factor of 10^5 - 10^6 (Sahoo et al., 2016).

In recent years, many successful ^{90}Sr determinations have been reported using mass spectrometry instruments. Inductively coupled plasma mass spectrometry (ICP-MS) instruments with collision/reaction cells and thermal ionisation mass spectrometry (TIMS) have primarily been used for ^{90}Sr measurement (Kavasi & Sahoo, 2019). The main advantages of the mass spectrometry method over the radiometric are the shorter analysis time, higher sample throughput and smaller sample intake. However, the low-level ^{90}Sr detection in environmental samples with mass spectrometry instruments is a demanding assignment.

The first critical point is the isobaric interference of ^{90}Zr as a consequence of significant amounts of the Zr element in environmental samples. The second critical point is the peak tailing on the higher mass side from ^{88}Sr. Although there exists a reliable ultra–high-vacuum condition in the analyser zone of the mass spectrometry instruments, the ions scatter during their acceleration. This scattering causes the energy spread of the ion beam, and it is recognised as a peak tail in the mass spectra.

In this work, the analytical capacity and performance of radiometric and mass spectrometric methods will be compared on diverse environmental samples.

Sahoo, S.K., Kavasi, N., Sorimachi, A., Area, H., Tokonami, S., Mietelski, J.W., Lokas, E., Yoshida, S. 2016. Strontium-90 activity concentration in soil samples from the exclusion zone of the Fukushima Daiichi Nuclear Power Plant. *Scientific Reports.* 6, 23925.
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OPTIMISATION OF GAMMA SPECTROMETRY MEASUREMENTS IN ATMOSPHERE DURING NUCLEAR EMERGENCIES

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Keywords: γ-spectrometry, Minimum Detectable Activities (MDAs), time resolution

During the emergency following a major nuclear accident a prompt and accurate characterization of the radioactive cloud is one of the main task of any radioactivity monitoring system. This task is usually performed by means of γ-spectrometry with high purity germanium detectors (HPGe) on the atmospheric particulate samples gathered by means of high volume pumps. The main parameters describing the performances of a monitoring system are the Minimum Detectable Activities (MDAs) of all the most relevant radionuclides. These parameters depend on a number of factors related to the efficiency of the available germanium detector, the volume of air filtered by the sampling devices and the γ-decay scheme of each radionuclides as well. Besides the MDAs, another very important characteristic of a monitoring system, especially during an evolving emergency, is its capability of giving reliable results at a given and constant pace. It is therefore important to defined the *time resolution* of the monitoring system, i.e., the minimum time needed to produce the data, namely the activity concentrations of the radionuclides in the atmosphere. Generally the time resolution of the system is not decided by the measurement laboratory itself, it's rather an external constraint given by the radiation protection requirements established by the authorities. However, once defined the time resolution, it's up to the labs to optimize the sampling and the measurement procedures in order to achieve the best performances, that are the best MDAs. The optimization of these procedures are discussed in this work. In particular it is demonstrated that, being τ the time resolution of the monitoring system, the lowest MDAs can be achieved with a sampling time given by $(2/3)\cdot\tau$ and a counting time of $(1/3)\cdot\tau$. Finally the MDAs achievable for a standard monitoring system based on a 30% HPGe detector are calculated for all the most important radionuclides, chosen considering a Chernobyl like and Fukushima like radioactive clouds.

Manuale CEVAD, ISPRA, 2010 (Technical Guideline of the Italian Committee for Nuclear Emergencies).
M. Magnoni, Monitoring of the environmental radioactivity in atmosphere by means of gamma spectrometry: MDA optimization during emergencies, Proceedings of the II National Conference on Physical Agentes, Turin, 29-31 October 2003 (in Italian).

MONTE CARLO SIMULATIONS OF THE RADIOLUMINESCENCE PHOTONS INDUCED BY ALPHA PARTICLES IN AIR

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Keywords: Monte Carlo simulations, radioluminescence, optical detection, alpha particles

Within the 19ENV02 RemoteALPHA EMPIR project, a novel detection system is currently being developed to perform the real-time and remote mapping of alpha particles emitting sources by taking advantage of the radioluminescence phenomenon. The emission of radioluminescence photons in air has been formerly studied in the literature, using alpha emitting radioactive sources (Sand et al., 2014), and is based on the ionization of air molecules by alpha particles emitted from the source. The secondary electrons generated through ionization excite the air molecules, which undergo radiative transitions to ground states, thus releasing UV-light photons (radioluminescence), with a range of more than 1 kilometer in air. The long range of the emitted UV-light in air facilitates the remote detection of areas contaminated with alpha particles emitters.

The need for the remote detection of alpha sources arises from the context of a nuclear emergency event, such as the failure of a nuclear installation, a terroristic attack, transportation accidents or any event that may cause a large-scale contamination of the environment with alpha particles emitting radionuclides. Such an event would expose humans to an extreme radiological hazard, considering the high linear energy transfer of alpha particles. In order to investigate this type of event safely and efficiently, the traditional handheld alpha particle detectors, that need to be positioned in the proximity of the radioactive sources, could be replaced by remotely controlled specialized detectors. Thus, the automated detectors could scan the contaminated areas more rapidly, reducing the risks that usually front-line emergency personnel are exposed to.

In this work, Monte Carlo simulations are used to study the characteristics of the radioluminescence photons emitted at the surface of radioactive sources and near accelerated alpha particles, in order to optimize the configuration of the optical systems that are involved in the detection and quantification of alpha-induced radioluminescence.

Sand, J., Ihantola, S., Prajarvi, K., Toivonen, H., Toivonen, J. 2014. Radioluminescence yield of alpha particles in air. *New J. Phys.* 16, 054022.

The project, 19ENV02 RemoteALPHA, has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

DRONE MAPPING RADIOACTIVITY IN EMERGENCY SITUATION

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Keywords: Emergency deployment, drone mapping, real time measurements, real time access to data, mobile *in situ* gamma spectrometry, radiometry.

IRSN is the French public expert in nuclear safety and radiation protection systems. The Institute is placed under the supervision of five ministries (Ecology, Research, Energy, Health and Defense). One of its main missions is to provide technical and operational support to Authorities in case of a radiological emergency. IRSN has a crisis organization that can be activated 24 hours/7 days a week and is able to advise decision-makers and stakeholders to protect population. Thus, the crisis organization is composed of a panel of specialists – such as atmospheric modeling dispersion experts, radiological impact on population and environment experts, environment transfer experts, *in situ* measurement experts – and can deploy its mobile unit to actively take part in human and environmental protection missions. This crisis intervention team can operate in contaminated area to measure radioactivity levels and provide input data to the decision-maker chain. These front-line workers usually use radiation devices, radiation car-borne mapping system, *in situ* gamma spectrometry, deployable probes, and also aerial based systems like drones.

Depending on the engagement scenarios – radioactive material transport accident; orphan source discovery; massive contamination – the role of these airborne systems is to quickly find a source, to identify radionuclides by gamma spectrometry, to provide data to estimate a potential dose for workers/public, or eventually to produce radiation survey map. Hence, IRSN works to improve the accuracy of the measurements by considering the drone flight height, the composition of the source and its size.

The subject of this communication is to present IRSN drone engagement scenarios, how the data processing is carried out, and under which format the results are transmitted to the decision-makers.

COMPARATIVE RE-ANALYSIS EVALUATION OF THE FUKUSHIMA ACCIDENT ATMOSPHERIC RADIOACTIVE EMISSIONS

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Keywords: Fukushima accident, radioactive atmospheric dispersion, comparative re-analysis

On March 11, 2011, the 15-metre tsunami following the Tōhoku earthquake disabled the main and backup power supply of Fukushima Daiichi NPP, causing a complete loss of the cooling systems. Within three days from event, all rectors' core suffered partial meltdown. Controlled radioactive releases (days 4 to 6) where in place. The two main radionuclides dispersed, were hazardous Iodine-131 (half-life of 8 days) and Cesium-137 (half-life of 30 years). Throughout these developments, a series of prognostic scenarios and radiological impact assessments were performed at IFIN-HH, Romania using domestically developed software tools and data inferred from the rather scarce and volatile information, available at the time. Those results were revised recently, using up-to-date decision support systems for nuclear emergency (DSS), global meteorological data, and having the benefit of historical field measurements. Two such DSSs have been engaged in this endeavour: the European Realtime Online Decision Support System for Nuclear Emergency Management (RODOS, version JRodos 2019) – one of the reference nuclear DSSs in Europe providing, among others, a set of modules for the dispersion of nuclides following atmospheric and aquatic releases, dosimetry modules for dose estimation to individuals and communities for all exposure pathways with application of countermeasures, and modules for time estimation of the radiological situation in inhabited and agricultural areas; and CBRNE Platform, developed by IFIN-HH within a research project on anticipative and prognostic evaluation of chemical, biological, radiological, nuclear and explosive events (CBRNE), a tool for effect diagnosis functions, response measures and consecutive recommendation for a large variety of scenarios. We have reproduced the event on both systems, using accident time weather data and updated source terms. Current and initial results were cross-compared and evaluated against available gamma field survey measurements.

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ASSESSING THE RADIATION CONTAMINATION OF LARGE AREAS USING ADVANCED TECHNOLOGIES

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Military, disaster management and in many cases civilian tasks include the survey of a given section of terrain that is likely to be contaminated with radioactive materials. Such a measurement series can form the basis for complete recultivation and decontamination of large areas. This survey can take place after an emergency situation, or before the establishment of any nuclear facility.

This presentation will use concrete surveys to illustrate the efficiency of new measurement technologies and developments. The goal of all these technologies is to carry out radiation reconnaissance tasks as quickly and accurately as possible. Different hot spots were found during aerial, vehicle-based and on-foot radiation reconnaissance. During in-situ measurements, our Bayesian based isotope identifying algorithm was used and the measured data were validated with results from gamma spectroscopy (HpGe detector) in the laboratory. A rapid on-site quantitative analysis was also performed by evaluating the samples taken next to the hot spots.

In addition to the measurement, we had to find the right format in which the data were generated and stored. We had to solve many issues like how the measurement data is associated with relevant additional information (e.g.: time and coordinate stamp), and how the measurement results can be shared with other partner organizations. Another important consideration was the preparation of the team conducting the measurement. The total cost of the survey was significantly reduced by the fact that the measurement was manageable by a small number of relatively low-skilled operators and one expert. We had to establish a proper quality assurance system and meet all relevant standards and strict documentation requirements. The measurement method we have developed is suitable for isotope-specific measurement (or determination) of low-activity mixed radiation sources in contaminated areas with high-background radiation.

DIFFERENCES IN THE ASSESSMENT OF THE NUMBER OF VICTIMS OF THE CHERNOBYL NUCLEAR DISASTER

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Keywords: Chernobyl, stochastic effects, LNT-model

Even 35 years after, the Chernobyl nuclear disaster still is significant in the public discussion about the peaceful use of nuclear energy. However, the debate is frequently dominated by personal experience and emotions. A fact-based discussion about Chernobyl and its aftermaths is not only aggravated by the complexity of the topic but also by contradictory information about long time damages. Especially the number of deaths caused by the accident vary dramatically from 31 [1] to nearly one million[2].

The vast discrepancy between these incompatible numbers carries the risk of diminishing the trust in radiation science and its predictive power. However, public trust in science is vital in times of crisis to enforce necessary measurements that require specific actions by society, as can be seen in current examples like climate change or the Covid-19 pandemic.

This paper aims to process the different estimations of deaths caused by the nuclear accident of Chernobyl and analyze reasons for the large varieties. A special focus is laid on the linguistic and scientific level of the paper in order not to limit the understanding of the subject to the scientific community but make it accessible to the public. An explanation at eye level of the difficulties of predicting deaths from radiation damages shall prevent a loss of trust in radiation science or its independence from various interest groups.

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MODELING AND MEASUREMENT OF AIRBORNE TRITIUM

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Keywords: tritium, atmospheric dispersion modeling, radioactivity, NPP

The aim was to obtain measurement results of airborne tritium in the surroundings of Krško Nuclear Power Plant (NPP), Slovenia, and compare them with existing advanced atmospheric dispersion modeling utilizing the Lagrangian Particle Dispersion Model SPRAY in an association with 3D diagnostic on-line meteorology. The model considers complex situations, especially relevant for the NPP region: strong meteorological inhomogeneities, non-stationary and wind stagnation conditions. The model has been tested and validated in various and complex scenarios, however, it is highly demanding to carry out the comparison of measured and calculated data. Environmental airborne tritium measurements have been used to address this task.

A method for determining the activity concentrations of tritium in the atmosphere that have been developed by JSI and MEIS company was used. Eight sampling campaigns were carried in the vicinity of the Krško NPP in March and April 2018. An in-house developed aerosol pumping system was used to collect airborne tritium. Tritium molecules were trapped in silica gel. Sampling sites were pre-determined using Spray & WRF meteorological forecasts. Typically, five sites were sampled during each sampling campaign. The average sampling time was 25 minutes. The reference sampling was carried out in Ljubljana, 80 km away from the reactor axis, where there is no detectable impact from NPP atmospheric discharges. The activity concentrations of airborne tritium measured at the reference location were subtracted from those measured near the NPP.

For each site, the modelled data were calculated using the modelled dispersion coefficients and emission activities for a given sampling time during a given sampling campaign. Modelled and measured values show good agreement, but there are some anomalies that could challenge further research in this area. The freeze-drying method was used to prepare the samples for the measurements using liquid scintillation counting method.

T10: Regulation

TWENTY YEARS OF INSPECTION INTERVENTIONS IN SLOVENIA

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Keywords: incident, accident, interventions, database, radiation sources, orphan sources, disused sources, illicit trafficking, radioactive, emergency preparedness and response

One of the main tasks of a regulatory body (RB) is to control a response on incidents and accidents. In the EU as elsewhere MSs established appropriate response systems giving particular attention to disused and orphan sources. The international cooperation enhanced, e.g. through "Dijon Conference on Safety of Radioactive Sources and Security of Radioactive Material" in 1998. The first EU legislation was published in 2003 while nowadays Council Directive 2013/59/EURATOM applies.
Lessons learned from incidents and accidents, i.e. not only those related to orphan sources, are taken. Graded approach to emergency preparedness and response is applied.

In Slovenia the response system has been improved in the last twenty years, e.g. registrants and licensees follow rules on reporting incidents and accidents, 24-hour on duty Slovenian Nuclear Safety Administration (SNSA) service exists and radiation monitors are widely used. One of the SNSA tool is the SNSA Database of Interventions (Database), i.e. the database with records of all so-called interventions of the SNSA inspectors from 2002. An intervention in this respect is a situation when an urgent inspection activity, e.g. on-site inspection or even urgent inspector's decision, is required.

The systematic analysis of about 300 interventions which occurred in last twenty years, is presented. About 20% are related to NORM while about 30% are false alarms. Despite the fact that each intervention is unique, several types of interventions might be identified. The Database enables optimisation of radiation protection in the response to one type of interventions using experiences already gained. It also facilitates the identification of:

- initial event leading to an intervention
- trends of a particular type of interventions, e.g. related to scrap metal.

The improvement of the response system which includes several other institutions is continuously taking place to assure enough flexibility to manage new types of interventions.

THE HUNGARIAN RADIATION PROTECTION REGULATORY SYSTEM

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Keywords: radiation protection regulatory system, authority, EU BSS implementation

The current centralized regime for supervising radiation protection aspects of the application of ionizing radiation in Hungary exists since 2016. The main competent authority regarding radiation protection of occupational and public exposure since then is the Hungarian Atomic Energy Authority (HAEA), which has taken over the tasks of several decentralized smaller institute and integrated them into HAEA activity, utilizing synergies of the regulatory tasks (e.g. nuclear safety, physical protection, national registry of nuclear and other radioactive materials). The development of this regime occurred simultaneously with the implementation of EU BSS (Council Directive 2013/59/Euratom laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation). Beside the amendment of the Hungarian Atomic Energy Law (Act CXVI of 1996 on Atomic Energy) new Governmental Decrees were issued to create the legal basis of the new radiation protection regulatory system, which was partly dedicated to fulfil the requirement of implementing the EU BSS. During this work the relevant IAEA documents, standards, guidances, national, international good practices on radiation protection and the outcomes of the Integrated Regulatory Review Service mission – conducted by IAEA - were considered.

The radiation protection regulatory system at HAEA now is based four pillars: registration, licencing, inspection, and enforcement. This structure and the requirements will be detailed in the presentation supplemented with the experiences of five years' operation.

THE ISSUE OF CS-137 IN FIREWOOD AND BIOMASS COMBUSTION: A REVIEW

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Keywords: Cs-137, biomass, firewood, EU BSS

In large parts of Europe, the Chernobyl accident of 1986 caused fallout of Cs-137. In particular, this led to the uptake of Cs-137 in trees or other material used for bioenergy production or as firewood for domestic purposes. This Cs-137 is concentrated in the ashes of the combustion process in such a way that the clearance level of 100 Bq/kg, defined in directive 2013/59/Euratom (EU BSS), may be exceeded.

There is currently no clear consensus in Europe regarding the regulatory approach to this issue: should the import and use of Cs-137 contaminated biomass be considered as a planned exposure situation or rather as an existing exposure situation? If considered as an existing exposure situation, which reference level should be applied?

This presentation will compare the approaches in various European countries, such as Finland, Norway, Sweden, Belgium and the Netherlands. Results of a recent measurement campaign performed in Belgium on firewood imported from Belarus, Ukraine and other countries as well as some samples from biomass combustion show a quite large range of Cs-137 activity concentration in firewood.

A review of dose-assessment studies performed by STUK and from the literature will be presented.

The presentation will also address the general context of biomass energy production: for instance, in the Netherlands, 40 large biomass firing plants (capacity > 10 MW) are operational and some 20 more are already planned. The fly ashes from the biomass combustion may be a valuable resource for the construction industry and the issue of Cs-137 contamination is connected with the requirements of the EU BSS regarding natural radioactivity of building materials. Assessing the impact of Cs-137 contamination and clarifying regulations in the frame of a graded-approach are important elements in this context.

REGULATORY RADIATIONAL PROTECTIONAL OVERSIGHT PROGRAM FOR HUNGARIAN RESEARCH REACTORS

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Keywords: regulatory oversight, research reactor

The Hungarian Atomic Energy Authority (HAEA) is the responsible regulatory body for the radiational protection of the Hungarian research reactors. There are two operational research reactors in Hungary. The licensed power rate of the Training Reactor of the Budapest Technical and Economy University is 100 kWth, and the Budapest Research Reactor is 10 MW. The paper summarize the system of the research reactor related Hungarian radiation protection legislation and the key aspects of its development. Also present the elements of regulatory oversight program for research reactor, describe the application of graded approach principle.

Regulatory oversight consists of 4 main instruments: licensing, inspection, assessment and enforcement. Licensing is the regulatory instrument used prior to the commencement activity: the authority judges before the commencement of the activity whether its implementation will comply with the requirements, and if necessary specifies additional conditions and respective tasks. Inspection typically takes places during the realization of the activity; it reveals the facts and circumstances of the activities and, in addition, it gives opportunity for intervention in the implementation phase. The authority performs the assessment typically after termination of an activity or a process, so the conclusions are drawn subsequent to the completion of the activity or the process, the feedback therefore is an essential part of this regulatory instrument, by which the failures revealed can be avoided next time. Licensing, inspection and assessment are not fully separate instruments: they may and frequently must supplement each other for the appropriate oversight of a certain case. Enforcement means fine for most of us, however in the nuclear field the fine is the ultimate instrument. The authority has a lot of opportunities for the intervention before imposing a fine to enforce the compliance with a legal requirement or regulatory decision.

In addition to the general description the article provide concrete examples from the regulatory oversight activities of the past years in the field.

REASONABLENESS AND TOLERABILITY IN THE SYSTEM OF RADIOLOGICAL PROTECTION: ICRP ON-GOING REFLECTIONS

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Keywords: tolerability, reasonableness, optimization, ethical values

The model of reasonableness and tolerability of radiological risk is a conceptual framework for the implementation of the ICRP principles of optimisation of protection and application of dose limits. Discussions about reasonableness and tolerability have been part of ICRP publications for many years, including the introduction of a model of risk tolerability in Publication 60. This model has been developed for planned exposure situation with a central role for risk indicators. The current issues are to discuss its application for emergency and existing exposure situations and to embark further considerations (notably ethical issues) on the process and the components to be integrated for selecting radiological criteria.

In this perspective, ICRP has set up a dedicated task group (TG114) in 2019, which currently revisits the model of reasonableness and tolerability of radiological risk with the following objectives:

- Investigate the rational for the application of the tolerability of risk as well as the borders with unacceptable level of risks and compare with the approaches adopted for managing other risks.
- Better articulate the link between tolerability and reasonableness in the process of implementation the radiological protection system, with clarification on the criteria to be considered for defining "where we don't want to go above" and which process could be put in place for evaluating "what is reasonable".
- Refine the radiological criteria to be considered and their link with dose limits and reference levels, relying on the radiological detriment as benchmark for tolerability and reasonableness as well as using risk comparison but without limiting to numerical criteria.
- Emphasize the importance of the application of the model for the different exposure situations, including the deliberative process with the stakeholders for the implementation of the optimisation principle, referring to good judgement, fairness, practicability and moderateness.

The presentation will discuss the current developments of the task group and the interactions with international and national organisations, including IRPA.

T11: Radiobiology

EFFECTS OF RADIATION EXPOSURE ON OFFSPRING AND NEXT GENERATIONS: HERITABLE EFFECTS IN NON-HUMAN SPECIES

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Keywords: offspring, heritable effects, non-human species

Experiments on laboratory mice have served as important source of information for estimation of genetic risk. There is now growing information on heritable effects of ionizing radiation in other non-human species too, in particular in plants and invertebrate species (Adam-Guillermin et al., 2019; Horemans et al., 2019). Furthermore, there is now information on wild populations as compared to inbred laboratory strains. The risk of radiation-related heritable effects in wildlife is a major concern for environmental risk assessment in ecosystems chronically exposed to radioactive contamination. In addition, the non-human species related data may be used to assess the taxonomic applicability of radioinduced responses in human. Possible mechanistic contributors to heritable effects in wildlife include genetic and epigenetic effects, changes in energy allocation, and potentially maternal and paternal factors. These effects may induce an increased radiosensitivity or an adaptation in long-term exposed populations, leading to scientific controversies and uncertainties in the risk estimates underlying the construction of the environmental radiation protection system. In the current method adopted to demonstrate the protection of the environment, the biological endpoints of most relevance are those directly relevant to population demography, including mortality, morbidity, reproductive success, and genetic integrity (ICRP, 2008). However heritable effects are not considered.

In this general context, the ICRP decided in 2021 to launch Task Group 121 with the aim of updating the review of the scientific literature on radiation-induced effects on the offspring of individuals exposed to ionizing radiation, for both human and non-human species. The review of heritable effects of ionizing radiation on non-human species will focus on vertebrates and will assess evidence of heritable effects in experimental animal studies and in wildlife.

Adam-Guillermin C., Hertal-Aas T., Oughton D. et al. 2018. Radiosensitivity and transgenerational effects in non-human species. *Ann ICRP*. 47, 327-341.

Horemans, N., Spurgeon D., Lecomte-Pradines C. et al. 2019. Current evidence for a role of epigenetic mechanisms in response to ionizing radiation in an ecotoxicological context. *Environ. Pollut.* 251, 469-483.

ICRP, 2008. Environmental protection: the concept and use of reference animals and plants. ICRP. Publication 108. *Ann. ICRP* 38 (4–6)

THE ADVERSE OUTCOME PATHWAY APPROACH IN RADIATION PROTECTION AND EFFORTS TOWARDS GLOBAL CO-ORDINATION

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Keywords: adverse outcome pathway framework, radiation risk assessment, linear no threshold model, key events, adverse outcome

Over the years, global efforts have been growing to better understand human and ecological health risks from low dose radiation exposure. A better integration of biological mechanism-oriented data to epidemiological data may help to support this using the Adverse Outcome Pathway (AOP) framework. The Organisation for Economic Co-operation and Development (OECD), operating under the Extended Advisory Group for Molecular Screening and Toxicogenomics (EAGMST), has been developing the AOP approach to consolidate published evidence on mechanisms of chemical toxicity in humans and wildlife. The knowledge transcribed in AOPs, provides an organized approach to examine weight of evidence and formulate regulatory decisions. The AOP framework has undergone substantial maturation in the field of hazard characterization of chemicals over the last decade, and has also recently gained attention from the radiation community as a means to advance the mechanistic understanding of human and ecological health effects from exposure to ionizing radiation at low dose and low dose-rates. To fully exploit the value of such approaches for facilitating risk assessment and management in the field of radiation protection, solicitation of experiences and active cooperation between chemical and radiation communities are needed. As a result, the Radiation and Chemical (Rad/Chem) AOP joint topical group was formed on June 1, 2021 as part of the initiative from the Nuclear Energy Agency (NEA) High Level Group on Low Dose Research. The main aims of the AOP joint topical group are to advance the use of AOPs in radiation research and foster broader implementation of AOPs into hazard and risk assessment. With global representation, it serves as a forum to discuss, identify and develop joint initiatives that support research and take on regulatory challenges. The Rad/Chem AOP joint topical group aim to actively liaise with the OECD EAGMST AOP developmental program to collectively advance areas of common interest and, specifically, provide recommendations for harmonization of the AOP framework to accommodate non-chemical stressors, such as radiation. The current presentation will provide an overview of AOPs, and the mission and work of the Topical Group.

DOSE RECONSTRUCTION FOR EPIDEMIOLOGICAL STUDIES AMONG CHERNOBYL CLEANUP WORKERS: REVIEW OF ACCOMPLISHMENTS AND OUTLOOK

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Keywords: Chernobyl, epidemiology, doses, cleanup workers

Analytical epidemiological studies designed to quantify radiation risks set specific demand for dosimetric support. Individual doses to specific organs of interest need to be estimated for all study subjects uniformly, in some situations – post mortem.

There are two practical approaches to the dosimetric support of such studies, specifically, (i) time-and-motion reconstruction of individual doses based on personal interviews and (ii) retrospective validation and adjustment of historical dose records with reconstruction of missing components of dose (i.e., beta eye lens dose).

The first approach was implemented by the RADRUE method that was successfully used for dose reconstruction within several epidemiological studies, notably – study of leukemia and related disorders (1000 subjects – cases and controls, both alive and diseased), study of thyroid cancer (607 subjects), study of *de novo* germline mutations in offspring of exposed parents (298 mother-father-offspring trios). This methodology was tailored to the specific needs of each study to estimate target organ doses (e.g., thyroid gland or gonads) and to consider all significant components of a dose (e.g., external exposure, internal exposure due to inhalation, etc.).

The second approach was implemented within the Ukrainian-American Chernobyl Ocular Study (UACOS, 8607 subjects of the cohort study) where existing dose records of different origins were recalibrated against EPR dosimetry with teeth (gold standard), while beta component of eye lens dose was estimated individually using specially calculated conversion coefficients.

Since the use of the RADRUE methodology largely depends on the subject's memories, its application is naturally limited due to a long (35+ years) time since the accident and respective memory fading. A specialized study was conducted to assess the human factor uncertainties (including memory fading) of the reconstructed doses. Another ongoing activity is the development of a dose reconstruction methodology based on an analysis of the formal characteristics of the cleanup activities rather than on the subject's personal recollections.

The talk will provide the overview of dosimetric support of competed and ongoing epidemiological studies among cleanup workers and discuss further developments in this application area.

MULTIGENERATIONAL EFFECTS OF CO-EXPOSURE TO CHRONIC LOW-DOSE IN-UTERO EXPOSURE TO INTERNALIZED CS-137 AND POST-NATAL HIGH-FAT DIET IN MICE: STUDY PLAN AND COLLABORATION OPPORTUNITIES

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Keywords: low-dose radiation, in-utero, multigenerational effect, co-exposure, metabolic disease, oxidative stress

Potential adverse health effects of in-utero exposure to low-dose ionizing radiation (LDR) are of great concern. While the biological effects of in-utero exposures to high-dose radiation are well defined, Limited data is available for environmentally relevant exposure levels, especially with respect to the risk of non-cancer diseases. Metabolic defects have recently been observed after chronic in-utero exposure to ionizing radiation in mice and may be intensified by co-exposure to other lifestyle stress factors. We therefore hypothesized that a combination an in-utero exposure to LDR and a subsequent postnatal fat-enriched diet can have an additive or synergistic effects on the metabolism and trigger the allostatic load that can lead to diseases of various systems, such as neuronal, reproductive, cardiovascular and others. We are testing this hypothesis in a mouse model study whereby the pregnant C57Bl/6J females will be exposed to various concentrations of Cs-137 in drinking water (absorbed fetus doses of 0, 5, 20 and 100 mGy). Half of the pups in each dose group will be exposed to a fat-enriched diet for 2 and15 months, and the other half will be kept on a standard diet. Metabolomic profiles will be measured in blood and urine at various time points, and in brain and urine at end point, as well as sperm parameters. Additionally, neurobiological studies will be performed. Noteworthy, all tissues will be harvested and bio-banked for subsequent measurements within specific focused studies. Among these focus areas are genomic instability and de novo mutagenesis, epigenetic reprogramming, oxidative stress, mitochondrial function and microbiome. We are open to collaboration within these focus areas and welcome requests, with the hope that our study will help understand complex network of biological responses relevant to health detrimental outcomes triggered by co-exposure to in-utero LDR and a postnatal lifestyle stressor common for modern societies.

ANALYSIS OF RADIATION EFFECTS ON CANCER USING A MATHEMATICAL MODEL

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Keywords: cancer emergence, cancer progression, mathematical model

The effect of radiation on cancer can be divided into: (1) effect on cancer emergence (shortened latency) and, (2) acceleration of cancer progression after its emergence. While the former can be directly observed by periodic cancer screening tests, it is difficult to observe the progression of cancer directly *in vivo*. One of the endpoints related to cancer progression is cancer-related death which includes both effects.

Based on the above concept, we constructed a mathematical model for cancer-related life-shortening. The model links the emergence of cancer to cancer-related death and enables us to analyze the radiation effect on cancer progression quantitatively. By using this model, we analyzed the data obtained from low dose rate gamma-ray irradiation experiments on mice conducted at Institute for Environmental Sciences. In the analysis, we focused on the difference among cancer types, and classified cancers as blood cancers or solid tumors from the pathological viewpoint. We analyzed radiation effects on cancer emergence in each group using cancer emergence data (temporal change of cancer incidence rate). Radiation effect on cancer progression in each group was evaluated by the combined analysis of the cancer mortality data (age at death and cause of death) and cancer emergence data.

The mathematical model is advantageous because it describes phenomena based on their mechanisms. The mechanism-based discussion allows us to apply the same mathematical model to multiple objects such as different animal species if the mechanism is the same. In other words, it is possible to predict radiation effects on humans, by using mathematical models that have been validated through analysis of animal experimental data.

LOW DOSE RESEARCH PROJECTS DATABASE: A NEW TOOL TO FACILITATE GLOBAL COLLABORATION AND EFFECTIVE FUNDING DECISIONS

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Keywords: low-dose radiation, collaboration, funding, radiation protection

Both animal radiobiological and human epidemiological studies of the effects of low-dose radiation are expensive and take many years for the completion and publication of results. Visibility of Low Dose Research (LDR) studies at the stage of planning and execution is usually low for both research community and funding agencies, preventing collaboration and informed effective funding decisions (e.g., to avoid duplication of effort). Recognizing these limitations and needs, an international group of experts have proposed and developed the concept of a LDR database. The LDR database is a searchable collection of relevant on-going and in-planning projects each having 30+ fields providing information on, among other things, principal investigator, funding agency, type of study, type of radiation, dose and dose-rate range used, endpoints, tissues/samples available for sharing. The type of studies is not limited to radiobiology and epidemiology and includes environmental, social, dosimetry and other. One of the fields specifies whether the study deals with the development of Adverse Outcome Pathway (AOP) as objective. One example of how the LDR database can facilitate international collaboration is by sharing biosamples originating from a single LDR project between teams with diverse complementary expertise. This LDR database is developed and implemented by a Topical Group within the High-Level Group on LDR (HLG-LDR) under the patronage of the OECD Nuclear Energy Agency (NEA). The LDR database was launched in early 2022, is open to all for use and to Principal Investigators worldwide for entering their LDR projects via simple registration.

This presentation will 1) provide further detail on the organization of this LDR database, project data collection and entry; 2) describe activities to promote its use by the research community, science funders and policy makers; 3) aim to solicit active participation of relevant project principal investigators around the world.

EFFECTS OF RADIATION EXPOSURE ON OFFSPRING AND NEXT GENERATIONS: CURRENT ISSUES AND POTENTIAL IMPACT FOR RADIOLOGICAL PROTECTION

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Keywords: offspring, heritable effects, in utero exposure

The risk of radiation-related deleterious effects in offspring is a recurring issue for the general public and a major concern for parents exposed to occupational, medical or environmental ionizing radiation. Little is known about the mechanisms underlying radiation-induced genetic diseases, the contribution of epigenetic processes to deleterious effects, and the potential contributory role of lifestyle, physiological factors and maternal and paternal factors. This lack of knowledge leads to uncertainties in the risk estimates underlying the construction of the radiation protection system. These uncertainties are reinforced by a number of divergent epidemiological, laboratory and field studies between humans and non-human species, and on various species of fauna and flora.

In the current system of radiological protection (ICRP 2007), the characterization of health effects on offspring and subsequent generations is based on the International Commission on Radiological Protection Publication 90 (ICRP 2003) for the effects of *in utero* exposure, and on the 2001 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2001) for hereditary effects. Studies on non-human biota were not considered.

The ICRP decided in 2021 to launch Task Group 121 with the aim of updating the review of the scientific literature on radiation-induced effects on the offspring of individuals exposed to ionizing radiation, for both human and non-human species. This includes both preconceptional effects due to parental exposure and postconceptional radiation effects due to exposure of the embryo and fetus. The Task Group will provide guidance on how to take these effects into account in the radiation protection system for humans and non-human biota. The work of Task Group 121 will contribute to the forthcoming revision of the ICRP's recommendations (Clement et al. 2021).

Clement C, Ruehm W, Harrison JD, Applegate KE, Cool D, Larsson CM, et al. 2021. Keeping the ICRP recommendations fit for purpose. *J Radiol Prot.* Epub ahead of print.
ICRP, 2003. Biological Effects after Prenatal Irradiation (Embryo and Fetus). ICRP Publication 90. *Ann. ICRP* 33 (1-2).
ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. *Ann. ICRP* 37(2–4).
UNSCEAR, 2021. Hereditary effects of radiation. UNSCEAR 2001 Report to the General Assembly, with Scientific Annex. New York: United Nations.

PREDICTING TOXICITY AFTER HEAD-AND-NECK CANCER RT: SYNERGIST ROLE OF BIOLOGICAL MARKERS & DOSIMETRY?

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Keywords: radiation toxicity, ATM protein, dosimetry

Purpose: To assess and validate the predictive ability of RADIODTECT© (RDT) (Deneuve et al, 2021) for severe acute/late toxicity (tox) after head&neck cancer (HNC) radiotherapy (RT)

Materials and Methods: 53 consecutive HNC patients (pts) treated with radical/adjuvant RT with/without chemotherapy (CHT) and prospectively evaluated for tox according to CTCAE v4.0 were included in a discovery cohort to test the ability of RDT in predicting acute tox ≥ grade 3 (G3). RDT discrimination power was evaluated through AUC and ROC analysis. 67 consecutive HNC pts, treated with radical/adjuvant RT with/without CHT and prospectively followed for tox scoring in the same way as for the training cohort, were included in the validation cohort. Analysis on the validation population included evaluation of the possible predictive value of the RDT when added to clinical/dosimetric variables (logistic regression models).

Results: 13/53 pts exhibited ≥G3 acute tox in the training cohort with an AUC=0.75. The optimal threshold was estimated at 46 ng/ml. Using this cutoff, 9 and 44 pts were classified as radio-resistant (RR) and radio-sensitive (RS). In the validation cohort, 47/67 pts and 10/67 pts exhibited ≥G3 acute tox and G3 late tox, respectively. An AUC=0.78 was found with a combined biological/dosimetric model including RDT, the minimum dose to the combined parotid glands (cPG) and CHT. Classification of pts as RS/RR was significantly associated with ≥G3 late tox (chi-squared test p-value 0.037). An AUC=0.76 was also found for a combined biological/dosimetric model included RDT and the mean dose to the cPG.

Conclusions: RDT discrimination power is probably influenced by treatment characteristics of clinical cohorts. This underlines the importance of combining RDT with treatment/dosimetric features for predicting tox. Due to our study results, implementing RTD as an easy managing test in common RT clinical practice for HNC patients is advisable.

EFFECTS OF RADIATION EXPOSURE ON OFFSPRING AND NEXT GENERATIONS: GENETIC AND EPIGENETIC EFFECTS

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Keywords: offspring, heritable effects, mutations, epigenetics

The potential for radiation-related deleterious effects in offspring is a recurrent issue for the general public and a major concern for parents exposed to ionising radiation from occupational, medical or environmental sources. There is a lack of knowledge (and subsequent uncertainties in risk estimates) about the fundamental mechanisms underlying potential radiation-induced genetic diseases, the contribution of epigenetic processes to adverse outcomes if any, and the potential contributory role of lifestyle, physiological, and maternal vs paternal factors. Genetic effects from radiation have been observed in a number of species to date, however, observations in humans are nearly nonexistent (Nakamura 2018, Yamada et al. 2021). Recent advances in molecular genetics and epigenetics have provided new tools for the direct investigation of transgenerational effects in the offspring of parents exposed to ionizing radiation (Adewoye et al. 2015, Dubrova et al. 2019, Yager et al. 2021).

The ICRP decided in 2021 to launch Task Group 121 with the aim of updating the review of the scientific literature on radiation-induced effects on the offspring of individuals exposed to ionizing radiation, for both human and non-human species. The work of Task Group 121 will contribute to the forthcoming revision of the ICRP's recommendations (Clement et al. 2021).

Adewoye, AB et al. 2015. The genome-wide effects of ionizing radiation on mutation induction in the mammalian germline. *Nat. Commun.* 6:6684 doi: 10.1038/ncomms7684.
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Dubrova Y. 2019. Mutation Induction in Humans and Mice: Where Are We Now? *Cancers* 2019, 11, 1708; doi:10.3390/cancers11111708
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Yager M et al. 2021. Lack of transgenerational effects of ionizing radiation exposure in cleanup workers and evacuees of the Chernobyl accident. *Science* 10.1126/science.abg2365 (2021).
Yamada M et al. 2021 Congenital Malformations and Perinatal Deaths Among the Children of Atomic Bomb Survivors: A Reappraisal. *Am J Epidemiol.* Volume 190, Issue 11, November 2021, Pages 2323–2333

SIGNIFICANCE OF STEM CELL COMPETITION IN THE DOSE-RATE EFFECTS

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Keywords: low dose-rate radiation, dose-rate effect, stem cell competition

A radiation biological effect of a given dose generally decreases with decreasing radiation dose rate, which is known as a "dose-rate effect". Tissue stem cells could be a target for radiation-induced carcinogenesis. Radiation biological effect may be reduced if damaged stem cells are eliminated by stem cell competition, which leaves an ample possibility for a dose-rate effective factor value larger than unity (ICRP Publ. 131).

Cells expressing Lgr5 are one of the major components of intestinal stem cells. Intestinal organoids are three-dimensional cultured tissue model generated from intestinal stem cells. To evaluate a radiation-induced stem cell competition, we established a quantitative method using mixed-organoid derived from two independent fluorescent protein-expressing Lgr5 stem cells, which one of stem cells were irradiated, for mimicking heterogeneous exposure (Fujimichi et al. 2019). We found that irradiated stem cells exhibited a growth disadvantage in the mixed organoid.

We also constructed a mathematical model to assess stem cell competition under low-dose-rate irradiation condition (Uchinomiya et al. 2020). A stem cell pool, containing a constant number of cells, was assumed, and changed through irradiation and turnover event. The probability of cell division and elimination depended on the properties of cells. Under very low-dose-rate conditions, the accumulation of radiation damage in the stem cell pool was suppressed when the damaged cells were less reproductive than intact cells and tended to be eliminated.

These results suggest that stem cell competition would play an important role in suppression of carcinogenesis under low-dose-rate irradiation condition.

Fujimichi, Y. et al. 2019. An Efficient Intestinal Organoid System of Direct Sorting to Evaluate Stem Cell Competition in Vitro. *Sci Rep.* 9, 20297.
Uchinomiya, K. et al. 2020. A Mathematical Model for Stem Cell Competition to Maintain a Cell Pool Injured by Radiation. *Radiat Res.* 194, 379-389.

RADIATION AND LIFESPAN: REVISITING THE CONCEPT OF RADIATION-INDUCED AGING

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Keywords: radiation-induced aging, cancer incidence, lifespan, mathematical model

The concept of radiation-induced aging was proposed based on the findings in animal experiments that radiation exposures shortened the lifespan. It was later found that the radiation-induced life-shortening was mainly due to neoplasms. In this work, we revisited the concept of radiation-induced aging focusing on the effects of radiation on cancer emergence and on lifespan.

We constructed a mathematical model based on the Armitage-Doll multistage model of carcinogenesis (Armitage and Doll, 1954) to treat the effects of radiation on cancer incidence. The transition rate from one stage to the next is expressed as the sum of the spontaneous (endogenous) term and the radiation-induced term which is proportional to the dose rate. The formula obtained for cancer prevalence shows that radiation dose can be explained in terms of time and provides an interpretation of radiation-induced aging. Radiation-induced aging is frequently categorized as either accelerated aging or premature aging. When we plot the cancer incidence rate as a function of time, the accelerated aging appears as the contraction of the time axis whereas the premature aging appears as the shift of the time axis. Our model shows that the accelerated aging is related to the dose-rate and the premature aging is related to the cumulative dose.

By assuming the effects of radiation on mortality can be described in the similar way to that on cancer incidence, we applied the formula obtained by our model to the lifespan data for mice given single or fractionated exposures over dose ranges from 2 to 9 Gy of gamma radiation (Thomson et al., 1981). It was found that the age-specific mortality rates of the irradiated groups were fitted well by shifting the curve fitting the control group by βD along the time axis, where D denotes the cumulative dose and β denotes the radiation sensitivity. The value of β obtained from the data was 31 day/Gy for single exposure experiments and 25 day/Gy for fractionated exposure ones.

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Thomson, J. F., Williamson, F. S., Grahn, D., and Ainsworth, E. J. 1981. Life shortening in mice exposed to fission neutrons and γ rays: I. single and short-term fractionated exposures. *Radiation Research,* 86, 559-572.

T12: Industry & NPP

RADIATION PROTECTION FOR WELL LOGGING OPERATIONS IN SAUDI ARABIA

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In well logging, sophisticated tools are inserted into a borehole to measure physical and geological properties of rocks surrounding the well. Some of these, known as nuclear logging tools, contain radioactive sources and are used to obtain useful information.

When logging tools containing radioactive sources are inserted into the well, there is a risk that they may get stuck. If this occurs, a recovery operation, known as fishing, is used to attempt retrieval. If fishing fails to recover the radioactive sources, they are abandoned following an established protocol, which is in accordance with international, national and corporate standards, in addition to industry best practices.

This paper provides an overview of radiation protection requirements for well logging operations in Saudi Arabia, to ensure the safety and security of radioactive sources, and the protection of workers and the public without impacting operational productivity.

CONSERVATISM VERSUS SUSTAINABILITY

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Keywords: sustainability, radiation protection

Governments and organizations are increasingly embedding sustainability into their operations. Often environmental sustainability becomes the focus, for example, mitigating climate change or reducing plastic use. Sustainability in its widest sense however covers societal, economic, and environmental factors, sometimes described as ESG (Environmental, Social, and Governance) and focuses on meeting the needs of the present without compromising the ability of future generations to meet their needs.

It is clear then that sustainability, safety and the environment are intertwined. Measures to improve sustainability performance can improve safety and environmental performance, i.e. introducing energy efficient lighting has environmental and economic benefits but often improves visibility, highlighting safety hazards. A sustainable organization protects the environment and the health, safety, and wellbeing of workers and the public. Yet, decisions around safety and the environment can also be unsustainable ones; for example, when radiation protection (RP) professionals build pessimism into shielding calculations, there is an increased use of carbon-intensive resources, such as concrete and steel, and waste production, plus increased decommissioning costs. While this pessimism is a choice taken to protect the workers and the public, the overall environmental and future legacy costs are not always recognized.

The principle of sustainability is not new to RP. ALARA (As Low As Reasonably Achievable) states the need for optimization and consideration of economic and social factors. While BAT (Best Available Techniques) considers reasonable measures when balancing health, safety and environmental impacts with costs (i.e. time, money, effort).

As the world increasingly moves towards sustainability, the RP profession must follow, striking a balance between safety, the environment and sustainability. Working together, the profession can build a better world for future generations.

EUROPEAN NUCLEAR ARENA AFTER THE FUKUSHIMA ACCIDENT

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Keywords: Fukushima accident, radioactive, nuclear power plants, taxonomy, European Union

In the EU NPPs accounted for approximately 26% of total electricity production. As any industry nuclear industry is linked to risk to humans and the environment. In that respect radiation safety plays a crucial role. In 2021 a vivid discussion is taking place regarding investments into nuclear fuel cycle facilities. So-called sustainable investments are addressed in EU taxonomy (EU, 2020) to manage climate changes. Therefore it might be appropriate to systematically analyze the shaping of nuclear arena in Europe after the Fukushima accident. All three major nuclear accidents, i.e. Three Miles Island (1979), Chernobyl (1986) and Fukushima (2011) accidents influenced nuclear area globally, as nuclear industry is a global industry. It seems that influences of the Fukushima accident has been more profound. Namely, it is the very first major nuclear accident initiated by natural events, i.e. earthquake followed by tsunami.

The nuclear arena is under constant development. Two driving forces can be identified. On one hand this is research and on other operational experiences. Such approach is fully in line with basic radiation protection principle, i.e. optimization from Council Directive 96/29/Euratom (EU BSS) where "current state of technical knowledge" shall be used when performing optimization of radiation protection.

Influences of the Fukushima accident on EU regulatory framework, e.g. on EU BSS and Nuclear Safety Directive, are given elsewhere e.g. in (Janžekovič, 2021). Influences are even wider. The article gives a systematic view on NPP policies in recent years in Europe, e.g. considering small modular reactors with limited environmental consequences in case of severe accidents, and on research programs. As fusion reactors seems to be still long term goal open questions related to uncertainties associated with risks to humans and the environment regarding NPPs are outlined as a small contribution to better understanding implementation of justification principle.

EU. 2020. Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment and amending Regulation (EU) 2019/2088. *OJ L* 19, 13-43

Janžekovič, H. 2021. Fukushima Nuclear Accident Impacts on the EU Nuclear Arena, Proc. Int. Conf. Nuclear Energy in Central Europe 2021, Bled, Slovenia, September 6-9, Nuclear Society of Slovenia (accepted to be published).

MONITORING SYSTEM OF THE FUEL-CASETTE-FREE STATE OF THE CONTROL ROD SLEEVES AT THE PAKS NPP

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Keywords: Paks NPP, control rod sleeve, fuel-cassette, monitoring system

During the process of the refueling of the Paks (VVER-440-213 reactor type) NPP one of the most crucial step is the elevation of the control rod sleeves (CRS). The monitoring system is the intellectual property of the Somos Ltd., was invented and implemented more than 20 years ago. It was recalibrated in 2018, because the operation cycle of the reactor was increased from 12 to 15 months (A. Marusa. et al., 2021).

The objective of the monitoring system is to indicate any discrepancies during the lifting process, especially a possible adhesion of the fuel cassettes or the control rods to the CRS and even to determine the presumable positions of the adhesions. Such an emergency situation beside the serious consequences of a nuclear event could also result in an unintended exposure of the workers.

During the refuelling of the unit 1. at Paks NPP at 6th May 2021 the monitoring system indicated an adhesion of the fuel rods to the CRS. In this publication would like to give overview about the operation of the monitoring system of the fuel cassette, about completed tasks relating to recalibration of the measuring system and about the adhesion event, the measurement methods, and the result on the unit 1. at Paks NPP.

A.Marusa. et al. 2021. Recalibration of the monitoring system of the fuel-casette-free state of the control rod sleeves (A védőcsőblokk emelését monitorozó dozimetriai mérőrendszer újra kalibrálása) Sugárvédelem. XIV./1. 65–79.

RADIATION PROTECTION AT ULTRASHORT-PULSED LASERS IN MATERIALS PROCESSING

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Keywords: ultrashort-pulsed laser, radiation protection, laser-induced X-rays

Ultrashort-pulsed lasers with pulse durations in the sub-picosecond range are increasingly used in materials processing. Such short pulses with a high intensity allow accurate material removal without heating up the surrounding material. They are used, for example, for cutting Gorilla Glass for cell phone displays or for drilling injection nozzles for lower-emission engines.

In these processes, single laser pulses with very high intensities are fired at a workpiece, generating a plasma for material removal. The high-energy plasma electrons accelerated by laser-plasma interactions can emit X-rays with photon energies of more than 5 keV when the laser intensity exceeds 10^{13} W/cm^2 (Legall et al., 2021; Behrens et al., 2021). Due to this undesired emission of X-rays, ultrashort pulse laser machines are subject to the German Radiation Protection Act (StrlSchG). Several regulations and concepts for ensuring the radiation protection at these machines are under development.

In this contribution, the generation of X-rays and the radiation protection issue will be addressed, and first measurement results will be presented. As the emitted X-rays are pulsed and of very low photon energy, generated in a complex and unstable process, the radiation exposure measurements are challenging.

Legall, H., Bonse, J., Krüger, J. 2021. Review of x-ray exposure and safety issues arising from ultrashort pulse laser material processing. *J. Radiol. Prot.* 41, R28–R42.
Behrens, R., Pullner, B., Reginatto, M. 2021. Measurements at laser materials processing machines: spectrum deconvolution including uncertainties and model selection. *J. Sens. Sens. Syst.* 10, 13-18.

IMPLEMENTATION OF THE NOVEL SOURCE TERM MONITORING FACTORS AT CANDU PLANT FOR OUTAGE RADIATION FIELD REDUCTION

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Keywords: radiation fields, source term, CANDU

The outage radiation fields of a reactor unit exhibit various trends with operating time. The source term, responsible for these gamma fields, is mainly determined by the types of construction materials of the reactor unit, the Primary Heat Transport (PHT) system design and operational parameters. It may also be influenced by reactor unit service conditions, purification system performance, and various abnormal conditions during operation and/or outages. All of these parameters can impact the source term and the resulting trends in surface radionuclide activities measured during outages. As a result, the observed outage radiation fields may deviate from the theoretically predicted trends. Therefore, in order to effectively manage the radiation field reduction, novel source term monitoring factors for the key radionuclide contributors were introduced. By analyzing these factors, the effectiveness of various source term reduction strategies can be estimated with a goal of decreasing the unit's occupational dose targets.

UPDATING A RADIATION PROTECTION PROGRAMME FOR A CHANGE IN BUSINESS ACTIVITY AND FINGERPRINT

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Keywords: waste, fingerprint, uranium, metals recycling, business development

Urenco Nuclear Stewardship operate as a tenant on the Capenhurst Nuclear Licensed Site in the United Kingdom. The activities that Urenco Nuclear Stewardship undertake have historically been storage of uranic materials and decommissioning of remaining parts of the Uranium Diffusion Plant. Utilising their extensive decommissioning and Waste Management experience, Urenco Nuclear Stewardship have operated as the Waste Management provider to all companies on the Nuclear Licensed Site since 2019. The radiological hazards have been from uranium and have been consistent, stable and well understood by everyone.

From 2021 Urenco Nuclear Stewardship started operating under the Low Level Waste Repository Ltd (LLWR) Metallic Treatment Framework and started taking receipt of wastes with different radiological properties than had ever been experienced on site in the past. Instead of Uranium, these would contain fission and activation products, tritium and other actinides. These wastes are to be treated in the Waste Management Facility (WMF) to optimize the amount of waste that is able to be recycled and minimize the volume of LLW.

The Radiation Protection regime at Urenco Nuclear Stewardship required a complete update to ensure it was fit-for-purpose. This work included:

- Regulatory reviews and updates to licensing and permitting arrangements.
- Development of Waste Acceptance Criteria (WAC).
- Prior risk assessments.
- Introduction of new physical control measures.
- Review and update of company instructions, risk assessments, method statements, local rules and signage.
- Instrument selection and calibration.
- Dosimetry arrangements.
- Training and Radiation Protection culture updates.

Throughout this process the Radiation Protection team have worked closely with the Business Development, Commercial, Waste and Operational teams to ensure that new requirements and changes are understood by all parties early in the project process.

T13: Perspectives from ethics, social sciences and humanities

COMMUNICATING RADIATION RISK: THE ROLE OF PUBLIC ENGAGEMENT IN REACHING ALARA

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Keywords: ALARA, radiation risk, communication, public engagement

The ALARA principle, keeping the likelihood of incurring exposure, the number of people exposed and the magnitude of their individual doses 'as low as reasonably achievable, taking into account economic and societal factors', is at the core of radiation protection.

Historically the stakeholders involved in the application of the ALARA process have primarily been assumed to be internal to an organisation, with the exception of regulatory 'buy in'. However, could there be instances when the public should be a key stakeholder?

The proposed talk will explore the area of perceived risk with reference to a particular case study [1] in which the dredging of non-hazardous sediment in the United Kingdom near a now decommissioned nuclear power station raised substantial public concern about radiological exposure. This turned what was a straightforward construction activity into a complex public engagement and reassurance task, at a significant cost disproportionate to the level of radiological risk.

This case study will be used to highlight the key lessons learnt and the importance of public engagement as part of the ALARA process. The talk will additionally highlight the ongoing work and guidance produced by the Society for Radiological Protection in the UK on the development of Guidance for Practitioners to support the Communication of Radiation Risk [2][3].

[1] Bryant, P. A. 2021. Communicating radiation risk: the role of public engagement in reaching ALARA. *J. Radiol. Prot.* 41, S1
[2] Society for Radiological Protection. 2021. Guide to communicating radiation risk in support of action before, during and after a radiation emergency.
[3] Bryant, P. A., Yoshida, H., Butlin, M., Wood, M. D., Raines, K., Bannon, A., Hunak, S., 2020. SRP workshop on ‘communication of radiation risk in the modern world’ *J. Radiol. Prot.* 40 319

ETHICS IN RADIOLOGICAL PROTECTION IN MEDICINE – ICRP TG 109

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Keywords: ethics in medical radiation exposures

The ethical basis of the System of Radiological Protection (RP) is presented in ICRP Publ.138[1], which describes the historical development and identification of four core values (beneficence/non maleficence, prudence, justice and dignity) and three procedural values (accountability, transparency and inclusiveness). Medical practice has a long history addressing ethical considerations, formalised under the field of biomedical ethics. TG109 'Ethics in RP for Medical Diagnosis and Treatment' aims to advise medical professionals, patients, families, care takers, the public and authorities about the ethical aspects of radiological protection of patients receiving ionizing radiation as part of their medical treatment. The TG draft Report introduces scenarios of examples in both diagnosis and treatment involving radiation, proposes a method to analyse each scenario from an ethical point of view on the basis of compliance/non-compliance, with the key ethical values in a wide range of situations (e.g., pregnancy, elderly, paediatric, end of life)[2]. The scenarios are presented to provide an opportunity for reflection and balance, applying the values to answer ethical questions. Scenarios are discussed, with attention to specific patient circumstances and how evaluating their ethical values can help in the decision-making process. The need to extend the set of values identified in ICRP Publ.138, with those existing in medical ethics, is discussed in the draft Report, considering the values of precaution, solidarity, autonomy, honesty, and empathy. The importance to include content on ethics in an effective and balanced RP education and training program, that enables patient centered decision-making can lead to the greatest possible benefit for the patient at the lowest possible risk, is recognised together with continuing the ethical education of health professionals who deal with the medical use of radiation throughout their careers. Although ethics cannot provide conclusive solutions in all specific cases, its thoughtful consideration can undoubtedly help to facilitate discussions among those acting to promote the wellbeing of our patients and their families.

[1] Ethical foundations of the system of radiological protection. ICRP Publ. 138, *Ann.* 47(1) 2018

[2] F.Bochud, M.C.Cantone, K.Applegate, M.Coffey, J.Damilakis, M. del Rosario Perez, F.Fahey, M.Jesudasan, C.Kurihara-Saio, B.Le Guen, J.Malone, M.Murphy, L.Reid, F.Zolzer. Ethical aspects in the use of radiation in medicine: update from ICRP Task Group 109. *ICRP Ann.* 49(1) 2020

LEARNING FROM DAILY WORK PROCESSES PROMOTES SAFE WORKING

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Keywords: Safety II, incident investigation, Work as done, Work as imagined

Why is information from daily work practice valuable to include in investigations of undesirable radiation events or incidents? Today, most industries face increasing complexity and dynamics. So there is a chance that only looking back in the system to where 'it went wrong' people will overlook things. Why working with ionizing radiation usually goes well in our daily work processes is often not a point of attention. A more representative and realistic starting point for research is therefore to pay attention to everyday practice. Not only because this provides insight into the coherence, interaction and variability of the work processes involved, but it will also place the undesirable event in context and perspective. This presentation is about learning and improving from this different point of view in relation to the daily practice of radiation protection.

A new perspective on working safely will be introduced, from the central thesis that 'safety should not be approached from failure, but rather from things that go well'. Hollnagel (2014) states that undesirable events and accidents arise from the same process as where things always go well in 98% of the cases. What can we learn from these cases? Concepts of Safety I and Safety II in relation to Work as done and Work as imagined will be discussed from the perspective of learning. An example of using the method FRAM (Hollnagel, 2019) in a Dutch company will be taken up in the discussion.

Dekker, S. 2014. The field guide to understanding 'human error'. United Kingdom: Ashgate.
Hollnagel, E. 2014. Safety-I and Safety-II: The past and future of safety management. Farnham, United Kingdom: Ashgate.
Hollnagel, E. 2019. Course FRAM at ANVS 28-29 January 2019.
Schreurs, E. 2020. Presentation Incident in reactor protection system. ANVS.

T14: Other radiation protection

OUTPUTS OF A HORIZON STYLE EXERCISE TO ADVANCE THE USE OF ADVERSE OUTCOME PATHWAY IN RADIATION PROTECTION

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Keywords: adverse outcome pathway framework, radiation risk assessment, horizon style exercise, key events, adverse outcome

The Adverse Outcome Pathway (AOP) framework is a means to integrate radiobiological and epidemiological data across different levels of biological organization for an adverse outcome of interest relevant to regulatory decision-making. Although predominantly used in chemical hazard identification, it is gaining interest among the radiation community to advance research and support regulation. The AOP approach is envisioned to strengthen the weight of evidence, enhance the understanding of radiation-induced effects at low doses and low dose rates and decrease the uncertainty in radiation risk assessment. However, to integrate its use effectively within the field of radiation, uptake from the research community, policy makers, regulators, and other stakeholders (e.g., industry) will be needed. To explore the diversity of opinions and ideas on incorporating the AOP framework in research and regulation, an international horizon-style exercise was initiated through the Nuclear Energy Agency's High-Level Group on Low Dose Research (HLG-LDR) Radiation/Chemical (Rad/Chem) AOP joint topical group. This exercise has identified the most important open-ended questions regarding the use of the AOP framework in radiation research and regulation. The first phase of the horizon-style exercise gathered 227 questions of interest to the global radiation community. A dedicated steering committee has sorted these collected questions and identified 25 priority questions where the AOP framework can support as well as the existing challenges to its implementation in regulatory decision-making. These 25 top priority questions were included in an international survey for dissemination globally. This presentation will discuss the results of this international survey, and highlight priority questions specific to institutional interests. The outcome of the international survey will guide future initiatives of the Rad/Chem AOP joint topical group, inform focused workshop topics, and ultimately facilitate the integration of the AOP framework into radiation risk assessment and radiation protection.

THE FITNESS TO WORK AT RISK OF IONIZING RADIATIONS: CRITERIA AND ASSESSMENT PROCESS IN EMPLOYEES WITH AN ONCOLOGICAL DISEASE

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Keywords: fitness to work, cancer, radiation protection

The ageing of working populations has many epidemiological consequences, including an increased incidence of neoplastic diseases among several categories of workers. Thus, it is more frequent than in the past that the Approved Physician (i.e. the clinician licensed to carry out the health surveillance of workers exposed to ionizing radiation, "Autorizzato" according to Italian legislation definition) has to judge working fitness in employees suffering from cancer (clinically cured) and at the same time are exposed to ionizing sources. The assessment of the fitness to work certificate in employees both affected by neoplasia always represents a clinical issue, as well as human and social. According both to AIRM (Italian Association of Medical Radioprotection) guidelines and to results of previous studies, several elements have to be considered to carefully analyze a specific case in order to evaluate the assessment of fitness in workers affected by neoplastic disease. Four different areas have been taken into considerations, and their features are presented in the following.

1. Characteristics of the neoplastic disease: time since the neoplasia has elapsed from clinical onset; neoplasia target organ; histological type, degree of differentiation and staging; oncological prognostic judgment; rank of the neoplasm within the radioinducibility scale; evaluation of the causal probability (PC).

2. Health condition of the worker: presence of any coexisting diseases not directly related to cancer; evidence of any previous chemo or radiation treatment; worker psychological condition; evaluation of worker qualification, his contract position and career, and also the worker's will.

3. Work activities and tasks carried out by the worker: radiation protection classification; type of potential exposure: partial external irradiation, global external irradiation, possible internal contamination; use of individual protection devices to avoid the exposure.

4. Legislation and indications from the guidelines.

Our aim is to describe clinical evaluation and assessment of fitness.

AIRM (Italian Association of Medical Radioprotection). 2013. Health surveillance for workers exposed to ionizing radiations. IPSOA. Assago (MI), Italy: Wolters Kluwer.

IAEA. 2004. Occupational radiation protection in the mining and processing of raw materials. Safety Standards Series. Specific Safety Guides No.RS-G-1.6.

Taino G et al. 2014. Judgment of fitness for work in employees with a history of malignant neoplastic disease and exposed to ionizing radiations: Evaluation criteria and their application in a case-series study. *Med. Lav.* 105(6): 445–72 (Italian).

RADIATION PROTECTION CHALLENGES IN THE LARGE HADRON COLLIDER UPGRADE

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Keywords: FLUKA, Monte Carlo simulation, LHC, radioactive waste

In 2022 the Large Hadron Collider (LHC) will enter its third and final period of physics, called Run 3. In 2025-2027, known as Long Shutdown 3 (LS3), the LHC will be upgraded to the High-Luminosity Large Hadron Collider (HL-LHC) which will allow for a number of collisions 5 times greater than the current rate and to develop a plan of experimental physics until 2040.

In this context, a series of radiation protection challenges will need to be addressed. The LHC upgrade operations require for a number of activities to be carried out in highly radioactive environments. Among these, the decommissioning of nearly 800 m of magnetic elements, collimators, passive absorbers, cables, vacuum and cryogenic components (LHC Point 1 and 5). In addition, both beam dumps (LHC Point 6) will be removed and replaced with new elements that can withstand the increased HL-LHC beam intensity. These two elements are among the most radioactive in the whole LHC, with dose rates in contact of a few mSv/h even after more than 3 years cool down.

To ensure high radiation protection and safety standards, operational radiation protection is supported by a series of tools, such as Monte Carlo codes, which allows to study and properly plan complex interventions. The CERN Radiation Protection Group (HSE-RP) makes extensive use of the FLUKA code, being an active member of the FLUKA CERN collaboration in the development, maintaining and benchmark of the code.

This work aims to provide an overview of the interventions related to the LHC upgrade during LS3 and the main radiation protection challenges in terms of optimization and reduction of dose to personnel (ALARA) as well as the decommissioning of highly activated components (inner triplet, TAN shielding, dumps).

SUPPORTING THE RADIATION PROTECTION PROFESSIONAL IN PROMOTING RADIATION PROTECTION CULTURE IN THE NETHERLANDS

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Keywords: culture, guideline, IRPA, associate societies

This abstract is written on behalf of the Dutch Society for Radiation Protection (NVS).

In 2014, IRPA published guiding principles to promote safety culture in Radiation Protection (RP). After all, integrating radiation protection into an organization's culture leads to the most effective way to achieve radiation protection goals. The Dutch Society for Radiation Protection (NVS) plays a key role in supporting RP experts. Traditionally, the focus of the RP expert has been on a technical and organizational (procedures/guidelines) level. The more 'soft' elements that are needed to shape a cultural program are not always obvious. Nevertheless, IRPA believes that the RP expert could play an important role in increasing the safety culture such that employee involvement and motivation can grow to a more professional level.

The IRPA guiding principles depict ten activities that an associate society, such as the NVS, can undertake to support its members in developing a RP culture in their organization. Therefore in 2017 the board of the NVS introduced a new committee for RP culture. The board's assignment to the new committee was to advise on the ten activities mentioned in the guiding principles and propose an action plan.

This presentation will give an overview of the actions taken by this committee and presents information on the introduction of 9 behavioral elements of a general RP culture, based on the IRPA guiding principles supplemented with general views on safety culture.

Based on the 9 elements, several workshops were given to RP experts. These workshops are practical and contain, besides some theory, room for discussion, role playing and games. Two games have been developed especially for the RP expert to use in their own organization to bring discussion to RP culture and will be available for all members of NVS.

Furthermore, an overview will be given of the actions that will be taken in the near future.

THE PROTECTION AGAINST IONIZING RADIATION VS. THE PROTECTION AGAINST COVID-19: SOME USEFUL PARALLELS

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Keywords: radiation protection, protection measures, protection equipment, protection against the COVID-19 pandemic

The world is currently in the grip of the global COVID-19 pandemic. As of October 2021, there have been worldwide over 240 million cases. Despite unprecedented interventions to quell the pandemic, the number of COVID-19 cases continues to rise. There are striking parallels between the COVID-19 pandemic protection and the radiation protection. Both areas share invisibility that can be frightening, both rely on the adoption of some procedures directed towards the prevention or minimizing spreading the infection or radioactive contamination into the environment. There is a wealth of data and extensive experience from the protection against CBRN (Chemical, Biological, Radiological and Nuclear) threats. One of the key principles of radiological protection is to keep doses As Low As Reasonably Achievable (ALARA). This is achieved by various combinations and variations of three basic parameters: time of exposure, distance from the source of radiation, shielding to reduce the radiation. Knowledge acquired during several past decades in the protection against CBRN and especially against ionizing radiation, can be very helpful in fighting and taking efficient measures against COVID-19. In the ongoing COVID-19 pandemic, the probability of an individual being infected is dependent on the viral load that an individual is exposed to in public spaces over a period of time. All prevention and control measures are based on preventing any such exposure to the virus, that can be achieved through limiting space for movement of the virus, using barriers and increasing distance to vulnerable surfaces, and limiting the duration of exposure. The paper discuses the similarities of protection against these two agents and analyzes application of know-how from one field to another.

Mukherji, A. et al. Time, distance, shielding and ALARA; drawing similarities between measures for radiation protection and coronavirus disease pandemic response**.** *Indian J Cancer*, April-June 2020; 57(2):221-223.

Sabol, J., Nejedlý, J.: Specific aspects of CBRN protection usable for COVID-19 pandemic protection. Proc. Intern. Conference CrisCon 2021, TBU University, Uherské Hradiště (Czech Republic), pp. 239-258. ISBN 978-80-7678-028-6.

TRANSDISCIPLINARITY IN RADIOLOGICAL PROTECTION RESEARCH AND PRACTICE: WAY FORWARD AND PRACTICAL CONSIDERATIONS

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Keywords: Transdisciplinarity, radiological protection research, joint problem solving, participation

Radiological risk governance is confronted with scientific and societal uncertainties, politicisation and societal polarisation, discrepancies between technical experts' and citizens' perceptions and understandings of risks, and/or the need to balance social, environmental, technical and economic aspects into decision-making. This complexity calls for transdisciplinary approaches to radiological protection research and practice, as these are deemed to generate socially robust knowledge, taking due account of societal values, needs and expectations. Transdisciplinarity differs from multidisciplinary approaches, as it transgresses boundaries between academic disciplines. It also goes beyond interdisciplinarity, as it not only seeks to integrate knowledge from various disciplines, but also to involve knowledge users and "recipients", including "non-scientific" actors (e.g. citizens) in joint problem solving. Another key feature of transdisciplinarity is self-reflexivity on the justification and implication of research and its applications.

The need for transdisciplinarity in radiological protection research and practice has been emphasized in the public declaration after the RICOMET 2016 International Conference, and recognized in the Joint Roadmap for radiological protection research in Europe. However, some questions remain, including how should such reflective approaches be developed and what processes are conducive to the integration of insights from different knowledge systems, specifically from multiple disciplines and multiple actors in research and practice? This contribution reflects on practical aspects relevant to further embedding transdisciplinarity in radiological protection research and practice. We base our reflection on lessons learned from national and international projects and networks; an international workshop showcasing challenges and opportunities for transdisciplinarity in radiological protection co-organized by the RadoNorm project and the Belgian Radiation Protection Association in the framework of the RICOMET 2021 conference; and an initiative with Early Career Researchers aimed at stimulating their attention to other disciplines and to the wider social, ethical, and environmental issues relevant to their research. All these initiatives suggest venues for new and alternative forms of learning, knowledge production and problem solving that integrate actors from and beyond the scientific community in order to address complex problems in radiological protection.

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THE IMPORTANCE OF MEENAS IN THE EUROPEAN RADIATION PROTECTION RESEARCH AND INNOVATION SCENE

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The six European radiation protection platforms embody the diversity and multidisciplinarity of the European radiation protection research community. Together we highly value the integration and expression of a common vision to ensure that radiation protection research and innovation maximally respond to the societal needs for radiation protection of human and environment. Therefore, MEENAS, the Consortium of European Radiation Protection Research Platforms, MELODI, EURADOS, EURAMED, NERIS, ALLIANCE and SHARE, was officially established by an MoU on 12 March 2020.

By uniting the forces of the individual platforms, we intend to operate as a strong shared-voiced vehicle towards third parties, such as the European Commission, and to enforce the position of radiation protection research in Europe and beyond.

We will present the functioning of MEENAS, its foreseen tasks and future perspectives in shaping European radiation protection R&I. In this context, we will inform how the extended MEENAS group prepared a robust radiation protection co-funded partnership vision document towards the establishment of a partnership for radiation protection research. The final document was transmitted to the European Commission on 8 January 2021 following a number of iterations with the EC, programme owners and managers and platform members.

This vision document and the CONCERT joint roadmap form the basis of our radiation protection R&D community response to the HORIZON-EURATOM-2021-NRT-01-09 call. The involvement of MEENAS in the proposal writing will be explained and our engagement in the future project will be described.

MEENAS expert role as representative for European Radiation Protection R&I is recognised: we are invited to attend the High-Level European Nuclear Roundtable with Commissioner Mariya Gabriel where MEENAS will be able to present the stakes of European Radiation Protection R&I. We will communicate the highlights of that meeting and the role of MEENAS within the HLENR.

Poster presentations

T01: NIR Non-ionising radiation

SOME CONSIDERATIONS ON THE CHALLENGES RELATED TO THE USE OF THE NEW ICNIRP RESTRICTIONS FOR HUMAN EXPOSURE TO RADIOFREQUENCY FIELDS

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Keywords: electromagnetic fields, radiofrequency, exposure limits, regulations

The ICNIRP 2020 guidelines for limiting exposure to radiofrequency fields brought many changes to previous guidelines from 1998, starting with a more rigorous definition of substantiated effects taken into account for setting exposure limits. The new approach also included a new kind of threshold level above which radiofrequency exposure causes health effects: operational threshold. Another essential change consists in taking into account the brief local heating of tissue and setting exposure limits and reference levels for rapid temperature rise. Moreover, new physical quantities were included in the guidelines to express the new type of exposure limits and reference levels.

Although more rigorous in comparison with previous guidelines, provisions of the new guidelines might confuse the reader by novelty, and the amount of changes is another challenge for practitioners. For example, provision of four tables for reference levels meant to cover four different exposure situations might be somehow confusing for simple practitioners as good knowledge on exposure evaluation is needed to correctly apply them. Other examples of challenges for the personnel involved in measuring electromagnetic fields levels are: changes of some physical quantities to be determined, modified exposure metrics, as well as more complex formulas for the evaluation of simultaneous exposure to fields of different frequencies.

The amount and the complexity of changes, as well as the novelty related to concepts, quantities and specific provisions led to more rigorous and precise guidelines, but more complex and more difficult to assimilate and use in practice. Therefore, qualified advice for compliance with reference levels is needed, as well as adequate measurement methods, procedures and equipment. Further advice on the entire process of exposure assessment will be required to facilitate the implementation of the new ICNIRP guidelines in practice when they are adopted as national regulations.

INVESTIGATION OF UV-INDUCED ΓH2AX PHOSPHORYLATION ON HUMAN KERATINOCYTE AND FIBROBLAST CELLS *IN VITRO*

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Keywords: UV radiation, γH2AX, DNA damage, pan-nuclear phosphorylation, dosimetry

Ultraviolet (UV) radiation is divided in the literature into 3 ranges, UVA (320-400 nm), UVB (280-320 nm) and UVC (100-280 nm). The UVC range is completely filtered by the ozone layer, therefore it can only be found at artificial sources. Certain ranges of UV radiation have been used for a long time to treat various types of skin diseases. Treatments of psoriasis, vitiligo and atopic dermatitis are used for both UVB and UVA radiations. The low dose UVA radiation is used for treatment of morphea (Totonchy and Chiu 2014). The UVC radiation has been successfully used to cure non-healing wounds, infected with multi-resistant bacteria (Gupta et al. 2013). In addition, UVC radiation is a well-known disinfection agent in industry and healthcare. Several areas, UV radiation is increasingly being used, which is known to be carcinogenic. The UV radiation has been classified as Group 1. carcinogen by the WHO's cancer agency, IARC (International Agency for Research on Cancer). It would be important to know the molecular biological processes that occur in different skin cells when exposed to UV radiation. The γH2AX assay is a method that is able to detect DNA double-strand breaks with immunofluorescent procedure. After ionizing radiation, the Ser-139 of H2AX histone is phosphorylated – then called γH2AX –, which is labelled with an anti-γH2AX fluorescent antibody to mark the double-stranded DNA damage as a focus. UV radiation causes a completely different phenomenon, known as pan-nuclear phosphorylation, which is still poorly understood. The aim of this study is to construct an adjustable wavelength UV irradiation system (254 nm, 305-311 nm, 350-368 nm) in which cells can be irradiated in sterile circumstances with determined doses and wavelength of UV radiation, in order to better understand the phenomenon of pan-nuclear phosphorylation on human keratinocyte and fibroblast cells in vitro.

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Totonchy, M. B. and M. W. Chiu (2014). "UV-based therapy." *Dermatol Clin* 32(3): 399-413, ix-x.

INVESTIGATION OF THE INTERMEDIATE FREQUENCY MAGNETIC FIELD INDUCED ADAPTIVE RESPONSE ON HUMAN FIBROBLASTS *IN VITRO*

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Keywords: adaptive response, intermediate frequency, fibroblasts, comet assay, micronucleus, ɣH2AX

Intermediate frequency (IF) magnetic field (MF) ranges from 300 Hz to 10 MHz. Nowadays many consumers and industrial equipment - such as household devices, hybrid and electric vehicles, airport control gates - produce IF MFs varying widely ranges of frequency and strength. Because this topic is underrepresented and its exposure is increased in everyday life, a general concern about its possible health effects has become constant. We investigated IF exposure alone and in combination with ionizing radiation, through the adaptive response phenomenon have any effect on humans. Normal human dermal fibroblasts were exposed to 22 kHz or 250 kHz magnetic field for 24 hours or exposed to IF MF for 24 hours and 4 hours later challenged with 2.5 Gy ionizing radiation. Intermediate frequency exposure system consisted of a solenoid coil, a function-generator, and an RF power amplifier. The entire coil system was placed in a CO_2 incubator. The temperature of the exposure was controlled by water flow and maintained at 37 °C. The cells in Petri dishes were placed in the coil, which was operated at resonant mode at 22 kHz or 250 kHz with 100 μT magnetic flux density. Ionizing irradiation with 2.5 Gy for adaptive response protocol and 4 Gy for positive control carried out by X-RAD 225/Xli X-ray source. After the exposures genotoxicity assessments were carried out by classical methods. Single-strand DNA breaks and oxidative stress were measured by FPG-enzyme modified Alkaline Comet Assay, double-strand DNA breaks by ɣH2AX Assay and chromosome aberration by Micronucleus Assay. Our results showed that the 22 kHz IF MF exposure had no significant genotoxic effect. Furthermore, we did not detect the adaptive response phenomena, i.e. the 22 kHz IF MF had not got protective effect on ionizing radiation. Further results of the 250 kHz IF MF exposure are in progress and will be presented in the conference. This study was carried out as part of the FiGe project, funded by ANSES.

MAGNETIC FIELDS EXPOSURE IN ELECTRIC VEHICLES: A REAL-LIFE STUDY CASE

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Keywords: ELF, EMF exposure assessment, Electric Vehicles, fast DC charging

Electric Vehicles (EVs) are spreading out in all European Countries as well as charging infrastructures, both in Alternating Current (AC) and fast Direct Current (DC). EVs occupants are exposed to low frequency magnetic fields generated by the currents flowing from the high-voltage batteries to the electric motor and generated by inverters and other electrical components. The magnetic field exposure in EVs may generate concern in population and it may limit the EVs expansion [1].

The aim of this work is to investigate the magnetic fields exposure during everyday uses of different EVs. The measurements are made during different conditions of travelling such as urban and motorways, and during AC and fast DC charging. Broadband and narrowband measurements are conducted in several position inside the car: driver, front passenger and backseats. Following Trentadue et al. [3] measurements are performed around fast DC stations and, following Yang et al. [2], inside the EV, during travelling and charging processes.

Due to the complex broadband spectrum, the ICNIRP weighted peak approach is performed to assess the human exposure of magnetic fields. Results are compared to the general public ICNIRP reference levels.

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[2] Yang L, Lu M, Lin J, Li C, Zhang C, Lai Z, Wu T. Long-Term Monitoring of Extremely Low Frequency Magnetic Fields in Electric Vehicles. Int J Environ Res Public Health. 2019 Oct 7;16(19):3765. doi: 10.3390/ijerph16193765. PMID: 31591344; PMCID: PMC6801816.

[3] Trentadue, G., Pinto, R., Salvetti, M., Zanni, M., Pliakostathis, K., Scholz, H., & Martini, G. (2020). Assessment of Low-Frequency Magnetic Fields Emitted by DC Fast Charging Columns. Bioelectromagnetics, 41(4), 308-317

RADIOFREQUENCY EXPOSURE MEASUREMENTS OF 2G-5G MOBILE SYSTEMS DURING YOUNGSTER's OUTDOOR ENTERTAINMENT

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Keywords: personal dosimetry, band-selective, 2G-5G, base-station, microenvironment

The radiofrequency (RF) exposure is continuously increasing in the public area. However, most users of 2G-5G mobile communication systems are youngsters, little is known about personal RF exposure of their life-like situations. Thus, our personal dosimetry study aimed to assess exposure of 2G-5G mobile communication systems in a real situation where the user-habits of young adults are most dominant. A measurement situation was chosen where people occur crowded thus the nearest neighbourhood effect can also be obtained. A summer outdoor music festival intended for undergraduates provided an adequate opportunity to collect realistic electric field strength data.

Two young volunteers received personal exposimeters (ExpoM RF) during two days of a music festival. They wore them close to their body (in their backpack) moving freely at the festival staying close to each other. They were allowed to use their own mobile phones without restriction. They visited various venues – e.g. themed tents, resting areas, concerts with crowded people, vicinity to base stations. Their activities were marked in the exposure diaries and subsequently compared with collected data of the exposimeters (field strength (V/m) and GPS data). Band-selective exposure sorted along 2G-4G uplinks and downlinks and 5G 3.5 GHz band were calculated. Field strength data subsets were classified on the basis of mass (crowded /low attendance events) as well as topics (e.g. concert /food /resting area). Data of each subset were randomly reduced to equal amount and compared.

While the majority of RF exposure was recorded from 2G-4G systems, the 5G data were negligible. From this result we concluded that the use of the 5G system was not yet typical. In the case of other frequency bands it was found that data separated along selection criteria differ. This reflects the importance of the behaviour and the microenvironmental RF exposure of the users.

OCCUPATIONAL HAZARDS RELATED TO ENERGY AND INFORMATION TRANSFER NEAR RADIOFREQUENCY READERS

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Keywords: environmental engineering, occupational exposure, public health, RadioFrequency IDentification (RFID), Internet of Things (IoT), Electronic Article Surveillance (EAS)

Radiofrequency (RF) readers emit electromagnetic field (EMF) of various frequencies (usually: 13; 450; 900; 2450 MHz - depending on the technology) to read information (RadioFrequency IDentification - RFID) or not (Electronic Article Surveillance - EAS), and to transfer energy (operating with passive tags) or information only (operating with active tags), and may also be incorporated into Internet of Things (IoT) systems (Zradziński et al., 2019, 2020, 2021).

The level of occupational hazards near RF reader depend significantly on the EMF frequency, dimensions of reader, emitted power (dependent on a reading range required in application and a sensitivity of used tags), type of used tags (passive/active), type of tasks performed near to readers and environment there (handheld/fixed readers). The use of active implantable medical devices (AIMD) may cause also specific hazards near RF readers.

Numerical calculations of the specific energy absorption rate (SAR), quantifying thermal effect-related hazards, were performed. The obtained results showed that at 900 MHz only handheld RF readers emitting <1W and fixed readers emitting <5W may be considered as environmentally insignificant EMF sources.

Zradziński, P., et al. 2019. Electromagnetic Energy Absorption in a Head Approaching a Radiofrequency Identification (RFID) Reader Operating at 13.56 MHz in Users of Hearing Implants Versus Non-Users. *Sensors.* 19, 3724.
Zradziński P., et al. 2020. Environmental safety aspects of using UHF RFID systems in hospitals. *Inżynier i Fizyk Medyczny*. 2(9), 133-140.
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T02: Education and training

HEADS OF PROFESSION NETWORK

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Keywords: Heads of Profession, Network, Society for Radiological Protection, UK

The UK's Society for Radiological Protection, Heads of Profession Network is a new group that provides a forum for discussion and sharing of experience focussing on topics such as recruitment, retention, training and career development of radiation protection personnel. This is an opportunity for SRP organisations to gain awareness from others, potentially introducing efficiencies and looking at best practice. The group is unique as it is a cross industry group with participants representing healthcare, nuclear, non-nuclear and regulators with the shared focus of the development and promotion of UK radiation protection careers. The group has been running for three years; communicate through a forum page and Microsoft Teams channel with meetings twice a year. The initiative has increased from 5 to over 25 institutions. Covid-19 caused the cessation of further face-to-face meetings, but the Network forum space was considered a vital communication channel to assist those who needed support and guidance through the difficult lock-down months. Recognized as a Network within the Society for Radiation Protection, the Heads of Profession continue to inform and debate with the aim of increasing the profiles and development of radiation protection careers through all UK industries.

8TH INTERNATIONAL CONFERENCE ON EDUCATION AND TRAINING IN RADIOLOGICAL PROTECTION (ETRAP): GRONINGEN NL, 26 – 30 JUNE 2023

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Keywords: Education & Training, Conference

It is widely recognized that education and training are essential pillars for applying ionizing radiation safely. Since 1999, a series of seven conferences on Education and Training in Radiological Protection has been organized in Europe. With the focus on benchmarking current practices and experiences on one hand, and on a harmonized approach towards education and training in Europe on the other, this series has proven to be very successful (see etrap.net/previous-editions). The 8th ETRAP conference will be hosted by the Groningen Academy for Radiation Protection / University of Groningen, in close collaboration with SCK-CEN. The conference will be held in the week from 26-30 June 2023 in the beautiful city of Groningen in The Netherlands, most likely preceded or combined with a workshop of the European foundation for Training & Education in Radiation Protection (EUTERP). In this contribution we will update the congress participants on the details and program of the ETRAP conference and EUTERP workshop.

CHANGING FACE TO FACE TO ONLINE RADIATION PROTECTION TRAINING: EXPERIENCES OF TRAINERS AND TRAINEES

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Keywords: education, training, online training

The SCK CEN Academy for Nuclear Science and Technology functions as the umbrella structure coordinating the education and training activities of the Belgian Nuclear Research Centre (SCK CEN).

One of the main activities of the SCK CEN Academy is to provide customized training to professionals working in nuclear industry, healthcare, research or governmental institutions. These courses address all topics of SCK CEN's R&D portfolio. In the specific field of radiation protection themes such as dosimetry, radiobiology and –ecology, nuclear and radiological emergency management, ALARA and safety culture, decommissioning and radioactive waste management are addressed, as well as topics related to social sciences and humanities and ethical aspects. During most of these courses, theoretical lectures are complemented by exercises and hands-on sessions in the specialized laboratories of SCK CEN. These courses and practical sessions are usually given in a face-to-face format.

This drastically changed in the last two years due to the COVID-19 pandemic where we were forced to switch course delivery from face-to-face to an online format. This change in approach required flexibility from both trainee and trainer, as well as from the training organization. Did it also affect the effectiveness of the training?

This poster highlights the results of the analysis of trainees' and trainers' feedback. Feedback was gathered from different training courses in radiation protection provided in face-to-face and online format. The analysis of this feedback allows training providers to make better-informed decisions on the best-suited training format depending on the content, target audience and the duration of the learning activity. It also provides input to optimize the support for the trainers and trainees adapted to the delivery format of the training course.

THE IMPACT OF COVID-19 ON RADIATION PROTECTION EXAM RESULTS

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Keywords: education, examination, exam results, COVID-19

The Covid-19 pandemic has had an enormous impact on society. This also affected the education and training in the field of radiation protection. Courses were cancelled, exams postponed, physical lectures changed into online lectures and practicals had to be adjusted to comply with social-distancing rules. Members of radiation safety courses, as well as their teachers, had to find new ways of learning the required knowledge, skills and attitudes.

But what was the effect of this necessary adaptation on the exam results? To investigate this we looked at the exam results of a number of courses which were given before and during the COVID pandemic. To get statistically significant results courses were selected which were given multiple times and/or with large numbers of participants. Also the tested learning outcomes must be unchanged during the survey period.

The selected courses and periods were:

- Radiation safety for medical specialists, May 2018 – October 2021
- Radiation safety for dental cone beam CT, February 2014 – December 2021
- Radiation Protection Officer for dispersible radioactive substances, June 2018 – July 2021

In total the results of 700 individual exams were used as data, of which 2/3 was pre-COVID and 1/3 was during the COVID pandemic.

Surprisingly, the exam results were identical in both periods: 83% of the candidates passed their exam! This was no doubt caused by extra effort made by the course members, especially in the first months of the pandemic. But also during the pandemic more and more new online teaching methods were developed and used:

- Pre-recorded video lectures
- Interactive response lectures with quizzes to promote questions from course members
- Exercises interlaced with quizzes as formative assessment
- Virtual practicals and exercises

The newly developed online methods are proven successful and definitely will be used post-COVID, next to physical lectures!

INTERACTIVE DIGITAL LEARNING TOOLS FOR RADIATION PROTECTION TRAINING

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Keywords: radiation protection training, online, interactive, learning tools

The Covid-19 restrictions had a huge disrupting effect on education and training. But the necessity to change from physical courses to online courses also gave an enormous boost in the development of online learning tools. Together with the Radboud Health Academy we have developed various fun and effective learning tools. In the poster presentation we hope to inspire other teachers to develop their own learning tools.

The decontamination strategy is the simplest tool, a picture game in which the steps to remove a contamination are randomised. You can drag and drop the pictures in the correct order, which is a good primer for performing this task in real life.

The Escapelab is much more complicated, especially for the developer! In this adventure game an alarm urges you to leave an isotope laboratory fast and safely. A menu with options is shown and selecting an option starts a short video. An actor illustrates your choice and a voice over provides feedback. A bad choice gives you a retry, a good choice gives you new options. This results in a large amount of possible scenarios, but only in a few scenarios you will leave the lab safely.

A 360 degrees virtual reality video is used for training medical specialists who use fluoroscopy. Using your smartphone in a special viewer you stand at the table as member of the team. A fluoroscopy procedure starts, but around you strange things are happening … You have to spot the good, the bad and the ugly, which then is discussed with other participants and a trainer. This trains ALARA-awareness, but also shows the different roles in the team and organization.

The online fluoroscopy practical teaches you how to interact with the X-ray operator. For this a video-stream of the fluoroscopy room with the X-ray operator and the generated X-ray images are merged in one single livestream. The operator can see and hear you and together you adjust the C-arm to get the right images, without unnecessary radiation for the patient and operator.

MPSR: A UNIQUE MASTER´S COURSE ON "RADIATION PROTECTION AND SAFETY" IN PORTUGAL. LESSONS LEARNT AND RECOMMENDATIONS FOR THE FUTURE

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Keywords: Portuguese Master´s degree course on Radiation Protection and Safety, higher education, University of Lisbon, IST

Higher education and training in Radiological Protection and Safety, encompasses the development and preservation of competences, knowledge and skills, providing lifelong learning opportunities and ensuring the transition of KSCs to future generations of experts. Appropriate E&T of professionals has long been identified by ICRP, IRPA, the European Union, IAEA, the OECD/NEA and other international organizations and institutions as instrumental for implementing an adequate radiation safety culture in workplaces.

Having this in mind, Instituto Superior Técnico (IST) of the University of Lisbon offers since 2016, a Bologna Master's degree Course in Radiation Protection and Safety (MPSR), unique and first of its kind in Portugal, currently in its fourth edition. This master course consists of 4 semesters, corresponding to 120 ECTS and includes 12 compulsory curricular units (6 ECTS each) plus 11 options and a final master dissertation (30 ECTS). In this work, an overall analysis, conclusions, lessons learnt and recommendations of the obtained results and accumulated experience of this Master´s Course will be delivered. The assessment provided is informed by feedback collected from students, by lecturer's analysis, employability and internationalization, among other parameters and indicators.

TRAINING AND TUTORING FOR THE EXPERTS OF NUCLEAR REGULATORY AUTHORITIES OF COUNTRIES OUTSIDE THE EU

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Keywords: training and tutoring, nuclear safety, radiation protection, Nuclear Regulatory Authorities, European Commission

Safe utilization of nuclear energy requires competent, independent, and adequately financed National Nuclear Regulatory Authorities (NRAs) and Technical Support Organizations (TSOs). Because of the high demands on technical competence, the continuous availability of new information (development of new reactor types, new safety mechanisms or new assessment methodologies), the recruitment of new staff, there is always a need for general, in-depth and specific training for the experts of NRAs and TSOs to build and maintain their necessary knowledge and skills. The European Union (EU) supports the achievement of the above in countries outside the EU through the Instrument for Nuclear Safety Cooperation (INSC) and initiated several actions to provide training for countries in need of technical assistance.

Training & Tutoring initiative to support competence building worldwide is part of the INSC's efforts towards making the EU a global reference in matters of nuclear safety and radiation protection, emergency preparedness and regulatory framework.

Phase 5 of the European Commission's INSC project has been launched in January 2022 and implemented by a Consortium led by EK (Hungary), having members of NucAdvisor (France), N.IN.E. S.r.l. (Italy), VUJE, a. s. (Slovakia), Uni-Energy Ltd. (Hungary) and ENEN (Belgium). Throughout the nearly three years of the project, several courses – both in the form of trainings and several weeks tutoring – and assistance will be provided for the experts of non-European countries' NRA(s) and TSO(s) to strengthen their capabilities with regard to their tasks and responsibilities related to radiation protection and nuclear safety. Developing such expertise is more than a matter of education, as it involves not only the transfer of technical knowledge, experiences, and best practices, but also helps promote the nuclear safety culture. In addition to details of the programme, initial results and lessons learnt will be presented.

EDUCATION AND TRAINING PROGRAM OF THE PROJECT RADONORM: TOWARDS EFFECTIVE RADIATION PROTECTION BASED ON IMPROVED SCIENTIFIC EVIDENCE AND SOCIAL CONSIDERATIONS - FOCUS ON RADON AND NORM

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Keywords: education and training, early career researchers, radiological protection, radon, NORM

The RadoNorm project kicked off in September 2020 (www.radonorm.eu). It aims at improving protection against harm arising from exposure to radon and NORM. Education and training (E&T) activities form an integral part of the project. The E&T program is based on hiring and supervising PhD students and early career researchers (ECR) in the course of their projects. It includes financial support for courses that are organised in an open-call manner and travel grants. In this way, the future researchers receive profound education in the field of radiation protection research and pave the road for maintaining and expanding relevant competence in Europe.

During the first year of the project 18 PhD students and 2 postdocs were recruited. Four further PhDs and 12 postdocs will be recruited soon. The COVID-19 pandemics lead to lower than initially planned number of courses and exchange visits/travel grants. Nevertheless, two on-line seminars were organized where each ECR presented her/his project. Five exchange visits/travel grants were funded and five courses were organized. The courses, in chronological order, were:

- Naturally occurring radionuclides in work and the natural environment – establishing the problem definition, finding sources and exposure assessment, 12 – 26 April 2021, GIG, on-line, Poland.
- The art of public opinion survey analysis: surveying the public on radon and NORM. 26 – 30 April 2021, SCK-CEN and Antwerpen University, on-line, Belgium.
- Interdisciplinary radiation research on radon – InterRad, 14 - 25 June 2021, BfS, on-line, Munich, Germany.
- NORM impact assessment toolkit: from microorganisms to human cells. 30 August - 10 September, 2021, Aveiro University and Porto University, Portugal.
- Cellular and genotoxic effects of high and low LET ionizing radiation – introduction to radiation biology. 8 – 19 November 2021, Stockholm University, Sweden.

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 900009.

T03: Medical applications

DIGITAL RADIOGRAPHY REJECT ANALYSIS AT A SPANISH UNIVERSITY HOSPITAL

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Keywords: digital radiography, reject analysis, reject rate, x-rays, quality assurance

The introduction of digital radiography has improved image acquisition. Conversely, it has prompted an increase in the number of examinations requested (ICRP, 2004). Besides, rejection of images is still a matter of concern, since the radiation burden of patients is unnecessarily increased (Jones, 2015). Reject analysis is part of the quality assurance program in radiology and helps identify potential errors or lack of training.

Data were retrospectively collected from nine digital X-ray rooms during a five-month period in 2021 at the University and Polytechnic Hospital La Fe, including emergency and radiology departments, with rooms dedicated to paediatric and hospitalised patients and to scheduled examinations. An application was developed in Microsoft Excel (v.2010) with Visual Basic to enable categorisation of data by age, sex, examination and rejection cause.

An overall reject rate of 3.8% for pediatric units and 4.7% for adults was found, with the emergency department having a reject rate of 4.1%; scheduled examinations 5.0% and examinations of hospitalised patients 6.4%. The highest reject rate was found for abdomen AP in adults (11-18%) and thorax lateral in paediatric patients (12%). The main rejection cause was “moved patient” (45-65% of overall rejected examinations), with the highest proportion in paediatric examinations. Exposure errors accounted for 4-11%. Most frequently performed examinations corresponded to limbs (25-61%) and thoracic spine (11-32%).

Exposure errors contribute to a minor part of rejected images, with patient movement being the main cause, especially in paediatric examinations. Paediatric patients tend to be less collaborative, especially at younger ages, hence the higher proportion of rejected images due to patient movement in paediatric-dedicated rooms. Although overall reject rates lie within the recommendations by AAPM TG 151 (Jones, 2015), corrective actions should be considered by targeting major rejection causes.

ICRP, 2004. Managing Patient Dose in Digital Radiology. ICRP Publication 93. *Ann. ICRP*. 34 (1).
Jones, A. K. et al., 2015. Ongoing quality control in digital radiography: Report of AAPM Imaging Physics Committee Task Group 151. *Med. Phys.* 42(11), 6658-6670.

LOCAL DIAGNOSTIC REFERENCE LEVELS FOR DIAGNOSTIC AND INTERVENTIONAL RADIOLOGY AT A SPANISH UNIVERSITY HOSPITAL

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Keywords: diagnostic reference levels, diagnostic radiology, interventional radiology

In the radiation protection of patients, the application of dose limits or constraints is not recommended; emphasis is made on the justification and optimisation of medical exposures (ICRP, 2007). Diagnostic Reference Levels (DRL) are a key tool for the optimisation of radiation exposure of patients in diagnostic and interventional procedures (ICRP, 2017). The Council Directive 2013/59/Euratom states the need of establishing and using DRLs for diagnostic and, if possible, interventional radiology.

A retrospective study was conducted at the University and Polytechnic Hospital La Fe (HUiP La Fe) to obtain local DRLs for relevant radiology procedures. Two CT units, a radiofluoroscopy room, nine digital radiography rooms and three interventional radiology suites were evaluated. Data were collected during a six-month period. DRLs were obtained as the 75th percentile of the DRL quantity, being the dose-length product for CT and the air kerma-area product for the rest. Paediatric procedures were classified according to weight or age, depending on the data and prioritising the former (ICRP, 2017), and the DRL quantity was fitted to a function of weight or age when few data were available (EC, 2018).

In interventional suites, a value of 284 Gy·cm^2 was obtained for hepatic chemoembolisation and 58 Gy·cm^2 for cerebral angiography; in CT rooms, 704 mGy·cm for coronariography and 820 mGy·cm for skull CT; in radiography, 580 mGy·cm^2 for chest PA and 3060 mGy·cm^2 for abdomen AP. Other procedures were also evaluated.

An evaluation of local DRLs for interventional and diagnostic radiology procedures was performed at HUiP La Fe. Comparison of local values with published DRLs in interventional radiology was limited due to variations in patient characteristics, procedure complexity or equipment performance (ICRP, 2017). In diagnostic radiology, discrepancy of obtained values with regional/national DRLs for certain procedures suggests the revision of image quality and radiation exposure.

ICRP, 2007. Radiological Protection in Medicine. ICRP Publication 105. *Ann. ICRP*. 37 (6).
ICRP, 2017. Diagnostic reference levels in medical imaging. ICRP Publication 135. *Ann. ICRP*. 46(1).
EC, 2021. European Study on Clinical Diagnostic Reference Levels for X-ray Medical Imaging (EUCLID). Radiation Protection No. 195. Publications Office of the European Union.
EC, 2018. European Guidelines on Diagnostic Reference Levels for Paediatric Imaging. Radiation Protection No. 185. Publications Office of the European Union.

DEVELOPMENT OF PHANTOM FOR CURRENT MODULATION QUALITY ASSURANCE TEST ON COMPUTED TOMOGRAPHY

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Keywords: automatic tube current modulation, quality assurance, computed tomography, phantom

Automatic tube current modulation (ATCM) in computed tomography (CT) is a powerful tool for enhancement the image quality reducing the dose delivery to patient during scan. According International Commission on Radiation Protection, the dose reduction can achieve 40% using ATCM (ICRP, 2017). The ACTM consists of adjusting the current according to size, shape and X ray attenuation of patient anatomic area. The quality assurance (QA) programs establish the test criteria but not specify the phantom. The phantom to perform the ATCM test should allow assessing how the CT system adapts the tube current as a function of object size with either discrete or continuous changes in attenuation using a pre-fixed parameters. The AAPM TG233 remarks that various sets of phantoms can be used for test. The discrete adaptation test utilizes a phantom of different fixed sizes (at least two) in the longitudinal direction. The continuous adaptation test uses a phantom with continuous changes in water-equivalent diameter in the longitudinal direction (AAPM, 2019). Considering the different recommendations of QA programs (Brazilian and international documents), we developed a dedicated phantom for ATCM test. The phantom was built in high-density polyethylene in cylindric shape with 3 different diameters (300, 280 and 250mm). To verify the applicability of this phantom we tested it on a CT scan using ATCM in 2 different CT scans (Toshiba and Philips). The results demonstrated the spatial concordance between a discontinuous change in phantom size and the corresponding change in the tube current, indicating that CT system was able to adapt current when an abrupt change in attenuation occurred.

AAPM (AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE) 2019. Performance Evaluation of Computed Tomography Systems. AAPM Report nº 233.
ICRP (INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION) 2017. Diagnostic reference levels in medical imaging. ICRP Publication 135.

RADIOSURGERY DOSIMETRY USING OSL FILM MADE WITH $CASO_4$:EU – A FEASIBILITY STUDY

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Keywords: optically stimulated luminescence, calcium sulfate doped with europium, 2D dosimetry, solid-state detectors

Recent studies demonstrated that optically stimulated luminescence (OSL) systems allow the evaluation of doses for 2D mapping in a relatively fast and simple way and results show sub-millimeter resolution (Ahmed et al., 2017; Jahn et al., 2013). The two most advanced-stage studies with satisfactory application in 2D dose mapping are based on commercial prototype detectors (Al_2O_3:C and BeO). Some OSL materials have been evaluated in research laboratories for use in 1D and 2D dose distribution assessments and there is no common sense on the best OSL material for each application (Yukihara and Kron, 2020). This work presents, for the first time, an optically stimulated luminescence (OSL) film made with $CaSO_4$:Eu particles embedded in a silicone elastomer matrix. The OSL film was produced using a low-cost and relatively simple methodology. This film is reusable and the signal can be satisfactorily bleached using blue LEDs. The main dosimetric properties were evaluated using TL/OSL Risoe reader with blue stimulation and Hoya U-340 filter. Investigation shows repeatability within 5% when measuring with the same film sample. Regarding the OSL film homogeneity, nearly 15% sensitivity change was observed within the 5 x 5 cm^2 produced film. Additionally, the dose response curve shows linearity from 5 to 25 Gy. Further studies are necessary to understand and minimize the influence of OSL signal fading, which seems as high as 70% in the first week and then is stable. Nevertheless, a 3 x 3 cm^2 OSL film was successfully used to map dose distribution in radiosurgery (6 MeV photon beam). This work demonstrates the feasibility of 2D dosimetry using low-cost and reusable OSL films based on $CaSO_4$:Eu.

Ahmed, M. F.; Shrestha, N.; Ahmad, S.; Schnell, E.; Akselrod, M. S.; Yukihara, E. G. 2017. Demonstration of 2D dosimetry using Al2O3 optically stimulated luminescence films for therapeutic megavoltage x-ray and ion beams. *Radiation Measurements*, 106, 315–320.
Jahn, A.; Sommer, M.; Ullrich, W.; Wickert, M.; Henniger, J. 2013. The BeOmax system - Dosimetry using OSL of BeO for several applications. *Radiation Measurements*, 56, 324–327.
Yukihara, E.G.; Kron, T. 2020. Applications of Optically Stimulated Luminescence in Medical Dosimetry. *Radiation Protection Dosimetry*, 192, 122-138.

DOSIMETRY USING A RADIOCHROMIC FILM AND A MAMMOGRAPHY PHANTOM

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Keywords: radiochromic film, mammography dosimetry, dose distribution, dose in depth direction

Mammography is one of the most effective diagnostic methods for the early detection of breast cancer; however, it poses the risk of radiation exposure. To date, mammography dosimetry has been performed according to the mean glandular dose (Dance and Sechopoulos, 2016); however, the actual exposure in the breast has not been assessed. Herein, dose distributions and depth doses were measured using both radiochromic films and mammographic phantoms, and intra-mammary dose assessment was conducted in three dimensions.

Gafchromic EBT3 (EBT3) for radiotherapy was used as the radiochromic film, while the Modular DBT Phantom, which is a uniform composition of the breast and glandular-tissue-mimicking materials, was used as the mammographic phantom. The phantom comprises one 20-mm-thick semicircular cylinder and two 10-mm-thick cylinders of the same shape. The cylinders were piled up to form a 40-mm-thick breast. EBT3 was then placed on the surface and at depths of 20, 30, and 40 mm of the phantom. X-rays were subsequently delivered using a mammography device (Mammomat, 3000, Siemens). The exposure parameters were 30 kV, 100 mAs, and Mo/Mo.

The absorbed dose distribution at the surface was markedly higher on the chest-wall side and lower on the nipple side, with a difference of approximately 2 mGy. The effect of the higher absorbed dose distribution on the chest-wall side became less pronounced as depth increased. The absorbed doses in the deep direction exponentially decreased in the order of 12.08, 1.93, 0.89, and 0.44 mGy at the surface, 20-mm depth, 30-mm depth, and 40-mm depth, respectively.

Since EBT3 could be placed inside the phantom, the absorbed dose inside the breast could be evaluated in three dimensions. Results suggest that a more comprehensive dosimetry can be performed if the phantom considers the distribution of the glandular tissue rather than the uniform composition of the phantom used herein.

Dance, D.R., Sechopoulos, I. 2016. Dosimetry in x-ray-based breast imaging. *Phys. Med. Biol.* 61(19), R271-R304.

AN OCT SCANNER FOR 3D ASSESMENT OF CLINICAL LINAC DOSE FIELDS AND DEVELOPMENTS OF SPECIFIC POLYMER GELS

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Keywords: gel dosimetry, optical CT, polymer gel, 3D dosimetry

The accurate measurement of the dose distribution delivered by a linear accelerator of radiotherapy treatments is of utmost importance of the quality control system.

One of the emerging techniques to obtain three-dimensional (3D) information about the dose field is the use of polymer gel phantoms, that alters its optical attribute proportionally to the received dose. The dose information can be read out from the exposed polymer gel by means of optical computed tomography (OCT).

Prototype of an OCT scanner was developed to offer instrumentation for researchers who are involved in developments of polymer gel variations to this application area.

The reader scans cylindrical volume of polymer gel with size of 12 cm x 12 cm x 15 cm.

It is equipped with an image reconstruction software using filtered back projection.

The performance is validated by comparative analysis between the treatment plan of a clinical LINAC and the reconstructed images for a set of basic dose fields.

IMPACT OF X-RAY MACHINE REPLACEMENT ON THE RADIATION PROTECTION AT INTERVENTIONAL RADIOLOGICAL WORKPLACES

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Keywords: radiation protection, medical physics, interventional radiology, fluoroscopy

Introduction

With regard to radiation protection, special attention should be given to interventional radiology workplaces, where patients and staff can receive considerable exposure from ionising radiation. Several studies have been conducted with the conclusion that there is a chance that the dose limits may be exceeded when using X-ray fluoroscopy during extensive catheter interventions. Therefore, the staff must carefully examine every parameter that could affect the radiation protection at these workplaces. The purpose of this study was to investigate the impact of x-ray machine replacement on the exposure of the staff.

Materials and methods

This study presents a laboratory for peripheral vascular examination and intervention. A 18 years old angiography unit was replaced with a new one, and the acceptance test was performed. Beside the analysis of its results, legally verified thermoluminescent dosimeters (Panasonic UD802AT, TLDs) were used to measure radiation exposure of the staff, along with dosimeters (MCP-N), which are also suitable for measuring $H_p(10)$, as well as the equivalent dose to the eye lenses, skin and limbs.

Results

The assessment of the results shows that the radiation field produced by the new X-ray machine is even higher. Measurements show relatively high entrance skin dose using the standard settings. Moreover, the readings from the TLDs showed increased exposure of the staff especially in the physician's position.

Conclusion

It can be concluded that when operating angiographic equipment, special attention must be given to choose the appropriate settings. The exposure of the staff is influenced by several factors, such as machine settings, the patient anatomy, and its utilisation. Regular radiation protection measurements and adjustments have to be made, to avoid overexposure of the patient and personnel. If an equipment is "new" it does not necessary mean that it has a lower radiation output.

PATIENT DOSE REDUCTION WITH THE IMPLEMENTATION OF LOW DOSE PROTOCOLS IN COMPUTED TOMOGRAPHY

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Keywords: computed tomography, patient dose, DLP, CTDIw

Computed Tomography (CT) is an image technique that is constantly evolving. The new technologies in its design allow to reduce the radiation dose to the patient without a detriment in the quality of diagnostic image. This concern has led to the proliferation of clinical protocols called "low dose". They are used in indications for which we know that a slight loss in the quality of the image does not compromise the patient's diagnostic. In parallel to this, in recent years, applications for the registration and management of patient doses have become very powerful tools.

The aim of this work is to review the dose reduction of some of these so-called "low dose" protocols and their correct indications. Standard chest, abdomen and head protocols and their "low dose" counterparts have been studied. To this end, DolQA, the official dose registration and management program of the Community of Madrid (Spain), has been used. The dose-length product (DLP) corresponding to large samples of studies carried out with standard protocols and with "low dose" protocols have been compared.

The data used in the study came from two CT scanners model Siemens Somatom Sensation 64 from Puerta de Hierro-Majadahonda Hospital. In all cases, the DLPs provided by the CT scan have been corrected by a factor obtained from the annual quality control test carried out by the medical physicist. In this control, the CT dose index (CTDIw) is measured with phantoms and compared with those provided by the CT scan. With these factors, DLPs obtained from DolQA are corrected.

Dose reductions provided by low-dose protocols range from 43% for kidney stones to 67% for the chest. In all cases they are therefore very significant decreases.

Finally, a group of radiologists have evaluated the quality of the images of both protocols, analyzing whether it is reduced in such a way that the images lose diagnostic quality or, on the contrary, they continue to serve their function.

Radiation doses and associated risks for CT head exposures

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Keywords: medical exposure, effective doses, risks associated

Background
Medical exposure to ionization radiation for diagnostic of population represents the most important source of artificial exposure and it can be modified in a way to maximize the benefits from using the radiation while the risks can be minimized. Radiation doses are annually monitored and the purpose of doing so is that all examinations can be justified when they are used to confirm a clinical diagnosis, while the practitioner can use an optimized procedure to obtain the best information, assuring a reasonable dose.

Methods
It was used radiological investigation, done on 5 different age groups, which are representative for the usage of CT investigation and the region of interest is the head, from 5 different counties from S–W part of Romania. It was calculated the effective dose and the equivalence of that dose with the natural background and it was also estimated the associated risks (cancer) of that procedure.

Results
The head procedure is situated on the first place from all CT investigations, representing a 33%. Effective dose values were between the interval 0.46-1.38 mSv ($p<0.001$). These values were compared with the national levels recorded from the entire country. The most investigated age groups were above 45 years. The risk associated to this type of investigation is greater for the persons below 40 years and is higher for women than men because women are more radiosensitive than men.

Conclusions
The study revealed that about 60% from the total number of this type of investigation are unjustified. It is necessary to implement a QA procedure which can be the most sensitive point in the patient radiological protection. Education for radiological protection of the patient, for medical exposure, can ensure in the future a more active implication of the specialists which can make qualified means of information to both the physician which prescribes this type of investigation and also for the patient.

INVESTIGATION OF SCATTER RADIATION FIELD AND ACTIVE SURVEY DOSIMETER PARAMETERS APPLYING STANDARD PROTOCOL FOR CHEST RADIOGRAPHY

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Keywords: radiation monitoring, scatter radiation field, active survey dosimeter, chest x-ray, temporal resolution, angular dependence

Area monitoring performed with active survey dosimeters should have appropriate accuracy to measure radiation fields generated by medical x-ray tube when using clinical protocols. The aim of this study was to investigate distance dependence of scatter radiation field of standard phantom and to investigate temporal resolution and angular dependence of active survey dosimeter when applying standard protocol for chest radiography. Experiments were carried out by using digital radiographic system Siemens Ysio and active survey dosimeter Atomtex AT1121. During the experiments the scatter radiation field of standard PMMA phantom was measured at 121 kV at different angles, distances and x-ray tube exposure times.

Average exposure time set by the automatic exposure control (AEC) of the radiographic system in chest examinations stays under 20 ms. Temporal dependence of the survey dosimeter was measured at exposure times in between 5-200 ms. At exposures under 32 ms relative standard deviation was up to 28%. The best repeatability of the experiment was at exposure times 100-200 ms and it is recommended to conduct area survey without AEC with such fixed exposure times. Exposure times set by AEC in chest examinations are too short for accurate measurement of scatter radiation dose rates by Atomtex AT1121 active survey dosimeter.

Angular dependence of the dosimeter to scatter radiation from the phantom was measured in extent of 90° and it was compared to the manufacturer's specification for angular dependence. The difference of scatter radiation dose rate compared for 0° and 90° directions of the dosimeter was 9%, the same difference by the manufacturer was approximately 15%.

Scatter radiation intensity decreases approximately three times between the distances 50 cm and 100 cm. Measurements performed in the distance under 50 cm show that the scatter radiation intensity decreases even slower, at distances longer than 100 cm the decrease is by inverse square law.

T04: Measurement and standardisation

AUTOMATIC CLASSIFICATION OF TLD GLOW CURVE ANOMALIES USING MACHINE LEARNING TOOLS

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Keywords: TLD, glow curves classification, machine learning

A method for the automatic classification of thermoluminescent dosimeter (TLD) glow curve (GC) anomalies was developed. This automatic classification can improve the estimation process of ionizing radiation dose by enhancing its repeatability accuracy. Moreover, it can help external dosimetry laboratories to forecast some malfunctions of their TLD readers. This method implicitly enables the classification of GCs into either a 'good' GC or into five different kinds of anomalies:

- 'lttl' – GC having a high thermoluminescent (TL) signal in the low temperature region.
- 'httl' – GC having a high TL signal in the high temperature region.
- 'wide' – wide GC compared to 'good'.
- 'spikes' – GC characterized by random high TL signal at some of its channels.
- 'other' – any other anomaly that can not be captured by the above four described anomalies.

The machine learning classifier applied for this purpose is support vector machines (SVM). The SVM algorithm categorizes TLD GCs into either a 'good' GC or into these above five types of TLD GC anomalies. When applied on an uncategorized GC, SVM associates it with a classification probability for each of the six categories. Results show an accuracy rate of 87.5% for the correct categorization of GCs to either of the six classes by computing the accuracy of the confusion matrix. Explicitly the classifier's accuracy per class is 93.2% for 'good', 71.5% for 'lttl', 59.5% for 'httl', 83.1% for 'wide', 26.6% for 'spikes' and 59.5% for 'other'.

Gal A, Hanan D. 2019. Computerized categorization of TLD glow curve anomalies using multi-class classification support vector machines. *Radiation Measurements.* 125, 1-6.

INTERCOMPARISON STUDY OF SENSITIVITIES FROM COMMERCIAL OSL READERS AND A NEW DEVELOPED OSL READER

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Keywords: optically stimulated luminescence (OSL), dosimetry, OSL reader, radiation measurements

The optically stimulated luminescence (OSL) technique has several applications for radiation measurements, including dating and personal dosimetry (Yukihara and McKeever, 2011). Although several studies in the literature presented dosimetric materials used with the OSL technique, the number of OSL commercially available readers is limited. In this study, we compared the sensitivities of a newly designed OSL system with two commercial systems, performing OSL readouts of Al_2O_3:C (Luxel, Landauer Inc) irradiated with doses from 10 mGy up to 10 Gy. The developed reader is our first prototype with all the modules have preferably open-source software. We used a cluster of eight blue LEDs (2W each and approximately 450 nm) for the optical stimulation in the modes continuous wave (CW-OSL) and pulsed (detection between the optical stimulation). The detection window used a band-pass filter allowing detection of OSL signal with a wavelength shorter than 360 nm. The luminous emission from the material was detected by a photodetector module P25USB (Sens-Tech, United Kingdom) with a photomultiplier tube with a quantum efficiency peak at UV band (200 – 400 nm). We compared the readouts with the commercial readers: Risǿ TL/OSL reader (DTU Nutech, Denmark) and MicroStar (Landauer Inc), respecting the different characteristics of each reader, that present different wavelengths for optical stimuli (blue and green, respectively) in CW-OSL mode. With the results obtained, we concluded that the developed reader can be applied for OSL readouts of detectors expose to high doses (up to a few Gy).

Yukihara, E. G., McKeever, S. W. 2011. Optically Stimulated Luminescence – Fundamentals and Applications. Wiley.

CLEARANCE MEASUREMENTS AT PSI

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Keywords: clearance, dismantling

The Paul Scherrer Institute (PSI) consists of a wide range of different facilities such as accelerator facilities, nuclear facilities and radioactive waste treatment. At PSI a proton accelerator, a spallation source, two electron accelerators and a proton accelerator for medical treatments are operated. Additionally the facility Hotlab and the Centre for Radiopharmaceutical Sciences are situated at PSI where on the one hand highly activated samples are investigated and on the other hand where short-lived radionuclides for medical research and patient application are produced. Furthermore, four former nuclear installations are dismantled: Three former nuclear research reactors and one incineration plant for radioactive waste material.

This diversity of these facilities is quite challenging for clearance measurements of potentially activated or contaminated material for the release from regulatory control.

In this contribution, examples and challenges for clearance measurements at PSI will be presented.

ANALYSIS OF ATTENUATION FACTORS FOR THERAPEUTICAL RADIOISOTOPES IN INDONESIA : PREPARATION OF IMAGE QUANTIFICATION FOR RADIONUCLIDE THERAPY DOSIMETRY

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Keywords: attenuation factors, therapeutic radioisotopes, image quantification, radionuclide therapy

There is a rapid development of locally produced radioisotopes and radiopharmaceuticals in Indonesia, such as ^{153}Sm, ^{131}I, and ^{177}Lu. In addition, radionuclide therapy dosimetry in Indonesia has been reported as a rising concern, following the success of participation of Indonesia in the IAEA Coordinated Research Project E23005. This study investigates the impact of the amount of activity on attenuation factors for image quantification, as a part of personalized dosimetry in radionuclide therapy. The investigation of attenuation factors was done by using locally produced radioisotopes such as ^{153}Sm, ^{131}I, and ^{177}Lu , starting from low (±2 mCi), medium (±25 mCi), and high activities (± 50 mCi). All radioisotopes were placed in a 1 ml syringe and assumed as point sources. The syringe was placed on the detectors in a gamma camera Mediso AnyScan S, and PMAA slab phantoms were used. The low and medium energy collimator was applied for ^{153}Sm, and ^{177}Lu - ^{131}I studies. The result shows that for ^{153}Sm and ^{177}Lu, the level of activity does not affect the attenuation factors, with the result, respectively: 0.12±0.008 and 0,11± 0.003 cm^{-1}. However, for ^{131}I, between low and high activity, the attenuation factors produced were very different, about 0.07± 0.037 cm^{-1}. Hence, for ^{131}I acquisition, an improved protocol need to be applied. To conclude, when ^{153}Sm and ^{177}Lu have been administered in the clinical study, the attenuation factors can be used either in pre-therapy dosimetry which uses low-level activity, or post-therapy dosimetry which uses high-level activity. For ^{131}I, the attenuation factor in high-level activity, the imaging acquisition protocol needs some intervention and improvement to achieve better accuracy of image quantification.

Ramonaheng K, van Staden JA, du Raan H. The effect of calibration factors and recovery coefficients on 177Lu SPECT activity quantification accuracy: a Monte Carlo study. *EJNMMI Phys;* (2021) 8:27.
Ramírez-nava G, Santos-cuevas C, Chairez-oria I, et al. Assessment of 99m Tc-Octreotide through a hybrid quantification method. AIP Conference Proceedings 2348, 050014 (2021)

MEASUREMENTS OF BACKSCATTER FACTORS OF PHANTOMS FOR THE CORRECT EVALUATION OF UNCERTAINTY CONTRIBUTIONS IN OCCUPATIONAL DOSIMETRY

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Efforts are being made to identify any uncertainty contributions in practical personal dosimetry for the purpose of conservative risk assessment in radiation protection. Calibrations of dosemeters for assessment of personal dose equivalent – and in future also for personal dose – are performed using the ISO slab phantom as a surrogate for the human trunk. However, the geometric mismatch of the calibration phantom with the person carrying the dosemeter in practical use leads to intrinsic uncertainty due to different backscatter and is usually not taken into account.

In this paper, reliable techniques for measuring backscatter factors of an ISO slab phantom and an anthropomorphic Alderson Rando phantom metrologically correct for the determination of this uncertainty contribution are presented and discussed. Backscatter factors of both phantoms were determined using a shadow-free diagnostic ionization chamber for standardized X-ray spectra in the most interesting energy range of 20 keV to 120 keV. Since the exact dosemeter carrying position on the body is not prescribed, relative backscatter factors for various detector positions on the Alderson Rando were measured and therewith another uncertainty contribution was estimated.

ESTABLISHMENT OF RADIATION QUALITIES FOR USE IN MEDICAL DIAGNOSTIC ACCORDING TO THE IEC 61267:2005 STANDARD IN THE SECONDARY STANDARD DOSIMETRY LABORATORY OF THE CENTRO NACIONAL DE DOSIMETRÍA

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Keywords: medical diagnostic, standard, radiation quality

The SSDL of the Centro Nacional de Dosimetría (CND) has recently modified its calibration services, incorporating new series of radiation qualities to calibrate the equipment used in medical diagnostic. This work describes how the reference qualities of these beams have been implemented. The following beam qualities have been established based on IEC 61267:2005:

- Radiation qualities in radiation beams emerging from the X-RAY source assembly: RQR-2, RQR-3, RQR-4, RQR-5, RQR-6, RQR-7, RQR-8, RQR-9 and RQR-10.
- Radiation qualities based on copper added filter. CT applications: RQT-8, RQT-9 and RQT-10.

To establish the qualities, the attenuation curve was measured using different aluminium attenuators (purity> 99.9%). A cylindrical chamber connected to an electrometer was used. Initially, the measurement was carried out without any additional filtration. For each quality, the corresponding voltage was selected (from 40 to 150 kV). The additional filtration necessary to achieve the desired qualities was then determined, following the method recommended in IEC 61267 and IAEA TRS No. 457.

Finally, the additional filtration determined previously for each quality was set up and the value of the first and second half value layers HVL1 and HVL2 and the coefficient of homogeneity were determined.

The HVLs and their uncertainties were determined by fitting the attenuation curve using internal curve fitting software.

The additional filtrations necessary to establish the RQR and RQT qualities have been determined. For the RQR qualities, the HVL1 and the corresponding coefficient of homogeneity are within the criteria accepted by IEC 61267 of 3% and ± 0.03, respectively.

For the RQT qualities, an additional filtration equal to that obtained for the RQR qualities of the same tube potential has been used, and the copper filter indicated in the IEC standard has been added.

In conclusion, our laboratory can provide calibration services with beam qualities based on the IEC 61267 standard.

RECENT DEVELOPMENTS IN THE INTERNATIONAL IEC AND EUROPEAN EN STANDARDS FOR RADIATION PROTECTION INSTRUMENTATION

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Keywords: standards, IEC, EN, radiation, protection, instrumentation

The presentation discusses the recently published IEC (International Electrotechnical Commission) standards on radiation protection instrumentation as well as their transposition as European EN standards. The following topics and standards are covered.

Dosemeters and contamination meters:
- IEC 61563 Ed. 2 (2019) Equipment for measuring specific activity of gamma-emitting radionuclides in foodstuffs.
- IEC 63050 (2019) Dosemeters for pulsed fields of ionizing radiation.
- IEC 62387 Ed. 2 (2020) Dosimetry systems with integrating passive detectors for individual, workplace and environmental monitoring of photon and beta radiation.
- IEC 61322 Ed. 2 (2020) Installed dose equivalent rate meters, warning assemblies and monitors for neutrons of energy from thermal to 20 MeV.

lllicit trafficking control instrumentation:
- IEC 63121 (2020) Vehicle-mounted mobile systems for the detection of illicit trafficking of radioactive materials.
- IEC 62484 Ed. 2 (2020) Spectroscopy-based portal monitors used for the detection and identification of illicit trafficking of radioactive material.

Security inspection systems using active interrogation with radiation:
- IEC 62963 (2020) X-ray computed tomography (CT) inspection systems of bottled/ canned liquids.
- IEC 63085 (2021) System of spectral identification of liquids in transparent and semi-transparent containers (Raman systems).

Environmental requirements:
- IEC 62706 Ed. 2 (2019) Recommended climatic, electromagnetic and mechanical performance requirements and methods of tests.

New developments started recently are also presented.

ISO 17025 ACCREDITATION OF LSC MEASUREMENTS IN THE LMBA

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Keywords: ISO 17025, accreditation, implementation, quality assurance, quality control, LSC

The laboratory of low activity measurements (LMBA), from the University of the Basque Country UPV/EHU, through its almost 40 years, has carried out a great deal of radioactivity analysis. From its beginning, the LMBA has made a big effort to perform its analytical procedures according to ISO 17025 requirements [1]. Therefore, it has had to implement a quality management system (QMS).

In accordance with the QMS of the laboratory, analytical procedures to be accredited by ENAC, the Spanish National Accreditation Body, should be well documented, internally and externally validated using reference materials and participating in interlaboratory comparisons and controlled.

Thus, this work describes the accreditation process of analytical procedures that require liquid scintillation counting (LSC), for which only a few labs worldwide are accredited: ^{3}H, ^{14}C, ^{55}Fe, ^{63}Ni and ^{99}Tc in any kind of sample and ^{222}Rn and ^{226}Ra in water.

Regarding documentation development, technical operations usually based on standards or reference documents are recorded on both electronic and physical formats.

Internal and external validations of the above-mentioned procedures are feasible in aqueous samples, but critical in solid samples. Hence, the LMBA had to develop fit for purpose strategies, which entail reference materials preparation and measurement by LSC. Then, accuracy, precision, reproducibility and linearity of the entire samples are analysed and detection limits and uncertainties of the methods established, when validation parameters are in the acceptance range.

Concerning the control of the aforementioned procedures, we check the conditions of a spectrometer 1220 QUANTULUS™, from Perkin Elmer, daily (^{3}H efficiency) and quarterly (noise and ^{3}H and ^{14}C efficiencies and backgrounds) and the quality of the methods by calibrations, blanks and chemical yields.

[1] ISO 17025, 2017. General requirements for the competence of testing and calibration laboratories. Geneva, Switzerland.

DIFFICULTIES IN USING THE PRESENT SYSTEM OF THE QUANTIFICATION OF RADIATION EXPOSURE

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Keywords: radiation protection, quantities, units, inconsistences, problems

The present radiation protection system relies on too many quantities, most of which cannot be directly measured. This is causing some difficulties in presenting the radiation risk, particularly in the risk communication to members of the public when, especially in the case of radiation or nuclear emergencies, where the information should be disclosed in a simple, clear and understandable manner. Moreover, even those working with radiation sources are sometimes confused in distinguishing between such quantities as dose equivalent, equivalent dose, ambient dose equivalent, directional dose equivalent, effective dose etc. Since most quantities introduced in radiation protection are related to the assessment of stochastic biological effects, there is no coherent system of radiation quantities reflecting deterministic effects (tissue reactions) where incorrectly, quantities based on the dose equivalent are often applied. It seems that there is an urgent need to express the overall harm caused by high radiation exposures in a coherent manner, similar to the evaluation of the impact of low-level exposures where the effective dose is used universally. Some attempts in introducing the RBE-dose with the unit of Eq-Gy for this purpose may be extended to cover the whole body exposure where some selected organs should also be considered. The author believes that the current system of radiation protection is too complicated for routine applications where a simplified system should be elaborated based on a limited number of measurable quantities. The current system may continue to be used mainly at universities and research institutes, but for practice, the present system should be simplified.

EFFECT OF RAINING AND TEMPERATURE ON BACKGROUND SIGNAL OF RADIATION PORTAL MONITOR

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Keywords: radiation portal monitor, background signal, raining, temperature

For homeland security, a radiation portal monitor (RPM) has been widely used for detecting illegal radioactive materials at seaports, airports, nuclear facilities, and gates of highly-secured buildings. In general, commercial RPMs are based on a large plastic scintillator detector (i.e., PVT-polyvinyl toluene) and associated electronics. In order to detect radioactive materials passing through the RPM, the alarm criterion should be set based on the background level which depends on the operating location due to composition difference in soil and rocks and the weather (raining and temperature). It is well known that the background signal level of the RPM increases with rain and the PVT signal depends on the temperature due to scintillation light yield variation. In this study, the background signal level of the commercial RPM (model: 4525-3800, Ludlum), which is installed and operated at Incheon Port in Korea, was analyzed by using the 1-year database which records the background signal of the RPM in every one minute. We also used the database of raining and temperature provided by the Korea Meteorological Administration. In terms of temperature, the background signal level was varied within ~5% with the temperature range of -10°C to 35°C. In the case of raining, the variation of the background signal level was examined in terms of the amount of rainfall and the rainfall rate. The results showed that a consistent tendency was hardly found between the background change and the rainfall rate; however, the averaged increase in the background signal level up to 20% as a function of the amount of rainfall was found. The dependency of the background signal level in terms of the temperature and the amount of rainfall could be used to realistically estimate the background level contributing to the optimization of the alarm criterion of the RPM.

VERIFICATION OF THE SAMPLING PROCEDURE FOR WASTE AND INDUSTRIAL MATERIAL

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Keywords: ISO17025, sampling, waste, industrial material, gamma-ray spectrometry

In accordance with ISO/IEC 17025:2017 - *General requirements for the competence of testing and calibration laboratories*, the laboratory needs to verify its ability to properly perform methods before introducing them, by ensuring it can achieve the required performance (article 7.2.1.5). Also, if a laboratory carries out a sampling of a material, it needs to have a sampling plan and method established (article 7.3.1).

In laboratories dealing with radionuclide content testing, the sampling does not affect the testing results directly, but the sampling procedure has to ensure that the taken and later measured sample adequately represents the tested material.

In order to verify the sampling procedure for the needs of radiological tests, a sampling of red mud (13 samples) and bauxite ore (6 samples) was conducted in the aluminum factory "Alumina ltd", Zvornik, Bosnia and Herzegovina in June 2021. In accordance with the established sampling procedure, GPS coordinate and ambient dose rate were recorded for each sample. Samples were prepared in accordance with IAEA, TRS 295 (1989), placed into identical PVC cylindrical boxes and measured by HPGe gamma spectrometer. Spectra of bauxite and red mud were recorded in 10 consecutive measurements for 21000 s and 6000 s, respectively, in order to achieve good statistic. For the purpose of sampling procedure verification, the counting rates per unit mass in the recorded spectra were compared.

For each measurements series, the total counts in the spectrum as well as individual energies mean value and standard deviations were calculated. After the measurements were completed, the average of the each individual series mean values and the associated/corresponding standard deviation were calculated. The measurement result of each individual series is considered satisfactory if, taking into account the calculated standard deviation, it is within +/- two standard deviations of the average of the mean values.

The obtained results verified the sampling procedure, i.e. it was shown that the applied sampling procedure ensures the representativeness of the bulk material.

T05: Radioecology

DETERMINATION OF CS-137 AND SR-90 IN WOOD AND WOOD ASH PURCHASED IN AUSTRIA

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Keywords: Cs-137, Sr-90, wood fuels, wood ash, dose

The aim of this study was to evaluate the radiological risk to the public due to the use of wood ash as a fertilizer in gardens as well as the necessity for regulations on imported wood in Austria. As various regulations on wood exist within the EU, some member states are considering harmonisation.

The Chernobyl fallout contaminated Europe with Cs-134, Cs-137, Sr-89 and Sr-90. Thirty years later Cs-137 and Sr-90 can still be detected in the vegetation and wild animals. The wood fuels analysed in this study were logs, chips, briquettes and pellets. The measurements of 64 different wood fuels indicated no necessity for special regulations on wood imported to Austria.

The accumulation of radionuclides in the ash depends on the type of wood fuel that was burned. Wood pellets have the lowest ash content amounting to less than 1% of the initial mass. Wood pellet boilers are on the rise in Austria and their users benefit from government grants. The Austrian citizens are used to fertilizing their gardens with wood ash, but the accumulation of Cs-137 and Sr-90 in ash resulting from pellets is higher compared to traditional wood ash.

Sr-90 was analysed for 10 of the 22 wood ash samples. It was shown that determining a nuclide vector for Cs-137 and Sr-90 depends on many different factors. The origin of the wood is the most important factor alongside the type and the part of the tree. It was impossible to determine the exact origin, type and part of the trees for all the wood fuel samples purchased in Austria. The highest measured activity concentration of Cs-137 was 867±68 Bq/kg in a wood pellet ash sample. The highest one for Sr-90 was 1200±180 Bq/kg in a wood briquette ash sample.

We carried out a dose assessment for a member of the public using the highest concentrations of Cs-137 and Sr-90 measured in this study. The resulting calculated dose was 0,193±0,028 mSv per year. The main part of the dose arises from the ingestion of locally produced foods fertilized with pellet ash.

ENVIRONMENTAL MONITORING OF THE KRŠKO NPP SURROUNDINGS

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Keywords: environmental monitoring, radionuclides, passive dosimetry

Monitoring of human activity and natural radiation oscillation is part of the protection of the human health and the environment. The nuclear power plant (NPP) Krško (PWR type) is located close to densely populated areas with over one million inhabitants, which includes the of Zagreb. Under normal operating conditions nuclear power plant release small quantities of radiation (radioactive isotopes) into the environment. Therefore, radiological environmental monitoring programs at NPPs are required in accordance with the regulations. Objectives of program include: identification, measurement and evaluation of existing radionuclides in the environs of the facility fluctuations in radioactivity levels and the evaluation of the measurements to determine the impact of operations on the local radiation environment. Furthermore collection of data to refine transport models and verification that radioactive material containment systems are functioning to minimize environmental releases ensures levels that are as low as reasonably achievable (ALARA). Implicit in these objectives are the requirements to trend and assess radiation exposure rates and radioactivity concentrations in the environment that may contribute to radiation exposures to the public. Therefore, the main aim of this work is to demonstrate results of monitoring on the impact of NPP Krško on environment and public. For this purpose, the following environmental pathways and sample analyses are investigated: liquid discharge from NPP, bottom sediment, fish, river water, drinking or potable water, ground water, and direct radiation using passive solid state dosimeters. Results of long term measurements of ^{3}H, ^{90}Sr, gamma emitting radionuclides and ambient dose equivalent ($H^*(10)$) will be presented. On the base of these results the contribution by each pathway to the individual and cumulative dose will be assessed.

SEDIMENTATION EVALUATION IN LAKES LOCATED IN DIFFERENT ALTITUDES USING RADIONUCLIDES

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Keywords: Caucasus lakes, radionuclides, sedimentation, runoff

The sediment inflow features into bottom sediments of North Caucasus six lakes in over the past 100 years have been studied using artificial ^{137}Cs and natural (^{210}Pb, ^{226}Ra) radionuclides. The lakes are located in contrasting geographic conditions at different hypsometric positions and have different origins. The sedimentation dynamics changes significantly in small lakes of the Western and Central Caucasus located in different altitudinal zones.

The watersheds of the studied lakes of the high-mountainous and mid-mountainous belt of the Caucasus are practically not subject to anthropogenic impact, therefore, the rates of sedimentation in them and their changes over time are controlled exclusively by natural factors. It has been established on the example of the study of Lake Donguz-Orun and its delta that the rate of accumulation of bottom sediments increased by about 1.5 times in the period from 1986-2014. compared to the period 1963-1986. Mainly due to climate warming and, especially since the mid-1990s, of glacier melt and the rate of denudation in the watershed, which is currently comparable to the rate of denudation in the Alps proglacial zone. Catchment area and bottom sediments the of Lake Garabashi, located in a high-mountain zone, made it possible to trace the stages of sedimentation rates changes from the moment the slope glacier melted to the complete development of the lake catchment area by herbaceous vegetation. It has been established that they varied from 0.55 mm/year during the active melting of the glacier to almost zero values in the last 50-70 years. Sedimentation rates in the studied lakes of the mid-mountain belt (Khorlakel, Bolshoye Khmelevskoye, Khuko) are very low, and 40-50% of bottom sediments consist of organic matter of lacustrine origin. The obtained dates indicate that the sedimentation regime decreased over the past 2.8-3.5 thousand years, despite the climatic fluctuations of this period. The main limiting factor preventing the runoff formation from lake catchment areas is the high projective cover of the soil surface with herbaceous vegetation. At the same time, air temperature changes over the past millennia have affected only the productivity of aquatic vegetation and, accordingly, the ratio of bottom sediments organic and mineral matter. The current sedimentation rates in the low-mountain lake Sukhoi Liman depends on the combined natural and anthropogenic factors, namely, the precipitation specifics, sparse projective soil cover and increased recreational load.

RADIOACTIVITY IN HUNGARIAN DRINKING WATERS

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Keywords: drinking water, indicative dose, total alpha activity, uranium

In accordance with the 2013/51/Euratom directive, radioactivity in Hungarian drinking waters has been intensively studied since 2016. Approximately 8000 water samples have been analyzed. Activity concentrations of radon and tritium have been determined and the indicative dose (characterizing the radiation exposure via water consumption) was estimated. Results of the analyses by accredited testing laboratories have been uploaded into the National Drinking Water Quality Database.

In the tested samples, activity concentrations of radon and tritium have been (with a few exceptions) below the parametric value (100 Bq/L).

To estimate the indicative dose, several measurement techniques can be used. As a primary approach, waterworks generally have been chosen measurements of total alpha and total beta activity concentrations. In the tested samples, total beta activity concentrations have been below the screening level (1 Bq/L). However, in 6.7% of the samples the total alpha activity concentrations have been over the (quite strictly set) screening level (0.1 Bq/L).

In cases of some non-complying water samples, activity concentrations of some individual alpha emitting radionuclides have been determined by nuclide-selective methods. Activity concentrations of U-238, U-234 and Po-210 have been determined by alpha spectrometry after radiochemical separations; while activity concentrations of Ra-226, Ra-228 and Pb-210 have been determined by gamma-spectrometry after evaporating large volume samples. The indicative dose values calculated on the bases of individual activity concentrations of these radionuclides have been below the parametric level (0.1 mSv in a year). The results suggest that radiological parameters in Hungarian drinking waters do not pose a risk to consumers' health.

U concentrations of water samples from areas of elevated alpha activity concentration have been measured by ICP-MS. A slight correlation has been found between total alpha activity concentration and U concentration.

RADIOLOGICAL RISK ASSESSMENT FOR A RADIOACTIVE EFFLUENTS BUFFER TANK DECOMMISSIONING

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Keywords: buffer tank, reactor decommissioning, risk assessment

The VVR-S nuclear research reactor from "Horia Hulubei" National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania was operated between 1957 and 1997. The main purpose of reactor was the radioisotope production in the thermal column for medical and industrial purposes and research activities. The reactor was decommissioned between 2010 and 2020, using the strategy of immediate dismantling of the contaminated and activated components and structures. The reactor was provided with a system for collecting of the radioactive leakages resulted from hot cells and primary circuit emptying. The main component of this system was the 30 m^3 underground buffer tank for liquids intermediate storage, buried in soil at a depth of 5.5 – 6.5 m, located in the immediate reactor vicinity. The radioactive liquids were transferred from the reactor to the buffer tank and further to the Radioactive Wastes Treatment Plant by the underground stainless-steel pipes system. As part of the decommissioning process, the dismantling of the buffer was performed in 2018 using an ALARA methodology. The evaluation of the radiological risks for the workers involved in the buffer tank dismantling and environmental radiological effects of this operation was performed with RESRAD-ONSITE Code, using in-situ dose measurements and activity concentrations of soil and water samples.

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ACTIVITY LEVELS OF NATURAL AND ARTIFICIAL RADIONUCLIDES FROM SOIL IN A VVR-S NUCLEAR RESEARCH REACTOR DECOMMISSIONING AREA

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Keywords: soil contamination, environmental, reactor, decommissioning

The paper presents a comparative analysis of the activity levels for natural and artificial radionuclides from soil around the VVR-S Nuclear Research Reactor from "Horia Hulubei" National Institute for R&D in Physics and Nuclear Engineering, Romania. The analysis was performed both at the end of reactor operation (2005) and reactor decommissioning (2020). The purpose is to demonstrate that are met the free release criteria under Regulatory Body regime of reactor at the end of decommissioning. Soil pollution sources were: stack for gaseous effluents evacuation into the atmosphere, accidentally discharging liquid effluents or uncontrolled landfill of waste. Gamma spectrometry indirect measurements of soil sampled from 10 cm and 30 cm depth were performed to obtain information's about soil contamination caused by recent radioactive airborne dust, respective from past unknown "accidents" as well as natural background. Natural radionuclides from uranium and thorium family and artificial radionuclides were detected. From ^{226}Ra and ^{232}Th activity correlation graphs resulted that the values are lognormal distributed; samples are grouped without a correlation tendency expressed by a positive regression line. ^{226}Ra and 232Th concentrations were less than 100 Bq/kg in 2020, by comparison with 2005, when for ^{226}Ra some values were higher than the background. In 2020 the mean value of ^{226}Ra (37 Bq/kg) is comparable to that of 2005 (40 Bq/kg) and corresponds to equilibrium with 3.3 ppm Unat., soil background characteristic value. For ^{232}Th, mean values were 38 Bq/kg (2020) and 35 Bq/kg (20005), and corresponds to equilibrium with a content of 8.75 ppm Th_{nat}. At the end of reactor decommissioning, the activity levels of ^{226}Ra and ^{232}Th, do not exceed the exclusion level of 1000 Bq/kg provided by National Safety Requirements, in force. The ^{137}Cs exclusion level of 100 Bq/kg was not exceeded. It can be stated that the decommissioning activity did not generate soil contamination.

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T06: Personal dosimetry

DOSIMETRY TECHNIQUES FOR THE COMPLEX MIXED IONIZING RADIATION FIELDS

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Studies concerning reasearch on dosimetry systems for personnel and environment are relevant for the accurate evaluation risks and the establishment of all radiological safety measures at Extreme Light Infrastructure Nuclear Physics facility .The ionizing radiation fields produced in the experimental areas of the ELI-NP hosts experiments with high-power lasers, that can generate on two front ends very short pulses of 10 PW power each and a brilliant variable energy gamma beam system that has unique spectral characteristics. Optically Stimulated Luminescence has become the technique of choice for many areas of radiation dosimetry. The technique is finding widespread application in a variety of radiation dosimetry fields, including personal monitoring, environmental monitoring, space radiation dosimetry and many more. At ELI-NP the basic choice for personnel and environmental dosimetry is a combination of passive and active dosimeters. This paper gives a generalized description of the dosimetry equipment and all the measurements that we use for characterising the ionizing radiation fields for personnel and also for the environment.

INVESTIGATION OF RADIATION DOSE AROUND C-ARM FLUOROSCOPY AND ITS RELATED INCIDENT CANCER RISK ON OPERATING ROOM STAFF

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Keywords: C-arm imaging, fluoroscopy, cancer risk, dosimetry

Introduction

A surge of interest in the use of C-arm imaging during surgical procedures lead to an increase in the exposure of operating room (OR) staff to X-ray radiation. This study aimed to evaluate the ambient dose equivalent around the C-arm device during spinal surgeries and determined the optimum locations for the surgeon and staff to be safe of radiation exposure as low as possible. Furthermore, the cancer risk incidence would be estimated using excess relative risk (ERR) function of biologic effects of ionizing radiation (BEIR) VII report for the OR staff.

Material and Methods

The lateral projection of the C-arm setup during spinal surgery was considered in the current study. To estimate the received dose by OR staff at a different position, ambient dose equivalent rate was measured using an electronic dosimeter in 30º steps all around for 1, and 1.6-meter heights and 1, and 2-meter distances away from the scatterer. By applying the workload, the annual ambient dose and maximum permissible operation were determined for our hospital. The worst condition of received dose in the current study was used to estimate the ERR for various organs at the attained ages of 35, 40, 50 years old.

Results

The maximum ambient dose equivalent rate was seen at 330º and 30º and were about 600 μSv/hr at one-meter height and away from the scatterer. By considering the exposure time, the maximum permissible workload for an OR staff is about 2.5×106 operations. The ERR for the prostate, ovary, breast, lung, thyroid, and colon were estimated based on the obtained dose values in our study.

Conclusion

Based on our results, 30º next to the image intensifier is the optimum position for the surgeon, the backside of the tube and image intensifier is the optimum for OR staff, while the 30º next to the tube is the worst position, because of backscatter radiation. The incidence of lung cancer in the female is more probable than the other site as well as male radiation workers.

DEEP TL: PROGRESS OF A MACHINE LEARNING AIDED PERSONAL DOSE MONITORING SYSTEM

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Keywords: individual monitoring, thermoluminescence dosimetry, artificial neural networks

In routine personal dosimetry, the aim is to estimate the radiation dose for one month. Dosemeters using thermoluminescence (TL) detectors, which are among the most used for passive dosemeters, can provide further information such as the time of irradiation or the number of irradiation fractions within the monitoring interval.

We are developing multivariate glow curve analysis techniques, which allow information extraction beyond the irradiation dose estimation. Usually, a complex deconvolution process of the TL signal is required. However, a first idealized proof-of-concept study using a convolutional neural network (CNN) on raw glow curves shows that an accurate irradiation date prediction is possible without glow curve deconvolution (Mentzel, 2021). The data set used in that study considered only the variation of the irradiation date for the same irradiation dose and is therefore limited in generalization towards real world applicability. That study showed that a deconvolution of the glow curves is not necessary to provide further information about the irradiation scenario.

In our new study, we present results using a data set that is comparable to a real-world application with varying dose and storing conditions. Several thousand glow curves are measured to ensure a good generalization of the CNN. In addition to the irradiation dose, more accurate information on the time of irradiation or the number of irradiation fractions can be obtained, which introduces additional values to the use of passive dosimeters and improves thereby an existing radiation protection concept. The TL dosemeters used in this study are TL-DOS dosemeters developed by the personal dose monitoring service at the Materialprüfungsamt Nordrhein-Westfalen in corporation with the Department of Physics at TU Dortmund University.

Mentzel, F. et. al. 2021. No more glowing in the dark: How deep learning improves exposure date estimation in thermoluminescence dosimetry. *Journal of Radiological Protection.* Accepted Manusctipt

EVALUATION OF FACTORS ASSOCIATED WITH THE EFFECTIVENESS OF RADIATION PROTECTION GLASSES

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Keywords: eye lens dose, radiation protection glasses, occupational exposure, lead equivalence, area of the lens, ERCP

Purpose: In interventional radiology (IR), the physician's eye lenses are frequently exposed to radiation, hence radiation protection glasses are useful. However, if the lens of the radiation protection glasses is too large, it burdens the surgeon due to its high weight, and if it is too small, the dose value of the dosimeter for the lens may be overestimated. This study aimed to examine the effects of the differences in lead equivalence and lens area between radiation protection glasses on lens exposure management.

Methods: The endoscopic retrograde cholangiopancreatography procedure was modeled using an over-couch X-ray TV system, which is considered to subject the physician's eye lenses to high radiation doses. The simulated patient underwent 10 minutes of X-ray fluoroscopy, and the lens dose of the simulated surgeon wearing radiation protection glasses was measured via lens dosimeters. A whole-body phantom for computed tomography (CT) imaging was used for the simulated patient; a head CT phantom was used for the simulated surgeon. Lens dosimeters were attached to the corner of the eye and to the eyeball. Ten types of radiation protective glasses with different lead equivalence, frames, and lens shapes were selected for measurement. Correlation analysis of the measured lens equivalent dose with lead equivalence and lens area was performed.

Results: The lens equivalent doses of the dosimeters attached to the corner of the eye showed 0.21-1.38 mSv, which were negatively correlated with the area of the lens. The equivalent lens doses of the dosimeters attached to the eyeballs ranged from 0.22 to 0.47 mSv, and showed a strong negative correlation with lead equivalence.

Conclusion: Lens dosimeters, when worn at the corner of the eye, may overestimate the lens equivalent dose as a function of the lens sizes of radiation protection glasses. Moreover, the effect of lead equivalence on lens exposure was larger than that of the area of the lens.

THE MOST EXPOSED FLIGHT CREWS IN FRANCE OVER THE PERIOD 2015-2019

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Keywords: workers, personal dosimetry, occupational exposure, cosmic radiation

Cosmic radiation is one of the natural sources of ionizing radiation. Airline flight crews (FCs) are therefore exposed during flights. Each classified FC benefits from individual dosimetric monitoring implemented by the employer. In France, this is carried out using SievertPN (https://www.sievert-system.org/), which makes it possible to calculate the dose from the flight parameters and the presence data of the personnel on board provided by the airline companies. A study of the dosimetry results of the 100 most exposed FCs over the 2015-2019 period was carried out.

Between 2015 and 2019, an increase in the average individual dose of these FC is observed (4.0 mSv in 2015 *versus* 5.2 mSv in 2019), in connection with a slight increase in annual time spent in flight (740h in 2015 *versus* 753h in 2019).

The number of FCs having received a dose greater than 5 mSv remains low overall, but it increases each year (4 in 2016 *versus* 96 in 2019).

Regarding FCs who received a dose greater than 5 mSv, most of them are technical flight crew (TFCs): number of TFCs over the period 2016-2019 = 109 *versus* 60 for commercial flight crew (CFCs), but the number of CFCs tends to increase year by year.

Among TFCs who received a dose greater than 5 mSv, 78% are airline pilots and 15% are aircraft commanders. Among CFCs who received a dose greater than 5 mSv, 52% of them are stewards, 41% are flight attendants and 7% are cabin managers. These most exposed FCs make long-haul flights from Europe to America and Asia.

In application of the ALARA principle, appropriate flight planning (rotation with shorter flights, less dosing routes) could allow a reduction in the exposure dose. Apart from the flight conditions (number of hours, destination, type of aircraft), another parameter to be taken in consideration is the influence of the solar cycle on the dose received.

COMPARISON BETWEEN RADIOEMBOLIZATIONS WITH YTTRIUM-90 AND HOLMIUM-166 CONCERNING RADIATION PROTECTION OF HEALTH PROFESSIONALS

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Keywords: radioembolization, microspheres

Hepatic radioembolization treatments use microspheres marked with a radioisotope, which has traditionally been yttrium-90 (Y-90), supplied by two companies: Sirtex Medical Group and TheraSphere™. Subsequently, Quirem Medical B. V. introduced holmium-166 (Ho-166) microspheres, pointing out their advantages over the Y-90: for Ho-166, the images for planning and post-treatment dosimetry are obtained with a gamma emission of 81 keV, while the planning of Y-90 treatment is done from images of simulation with Tc-99m macroaggregated albumin (MAA) and dosimetry after treatment with images of the Y-90 bremsstrahlung, much less accurate. In addition, Ho-166 is a paramagnetic material and volumetric distributions with nuclear magnetic resonance can be obtained.

However, the characteristics of Ho-166 microspheres are not as advantageous with respect to radiation protection. On the one hand, the prescribed activities can be up to four times higher than a similar treatment with Y-90. On the other hand, Ho-166 has gamma emissions of very high energies, being the peak of 1,379 MeV the one that most contributes to the dose rate in the environment of the source and, therefore, to the dose received by the professionals who apply the treatment. This peak is very difficult to shield and, as it is not mentioned in the commercial product information, it is usually not taken into account when planning procedures. In addition, the response of some detectors may not be linear in this energy range.

In this work, the radiological risks of the different professionals have been compared by calculating the body dose rate, in the fingers and in the lens for each type of microspheres, and applying it to the standard activity values, dilution volume, source distance, shielding and exposure time at each stage of preparation and treatment. The process has revealed the complexity of radiation protection planning with the use of Ho-166, not described in the information provided by the supplier company.

DEPOSITION OF RADON PROGENY IN LARYNGEAL AND PHARYNGEAL REGIONS OF RESPIRATORY TRACT

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Keywords: radon progeny, Computational Fluid Dynamics, aerosol deposition, cancer

Inhalation of a high concentration of radon progeny may result in significant radiation doses in the respiratory tract which can result in cancer. Directly after the radon decay, the progeny in ambient air: 1. forms clusters due to reactions with the air humidity and atmospheric trace gases (unattached progeny) or 2. attaches to the surface of aerosol particles spread in the ambient air (attached progeny). According to the data reported in the literature, the activity median diameter of the particle size distribution of unattached progeny is smaller than 4 nm, while the median diameter of the particle size distribution of attached progeny varies between 100 and 400 nm (Mohamed et al., 2014).

A large cohort study (Kreuzer et al., 2014) focusing on mortality of cancer affecting various airway areas evaluated the increase of mortality of all cancers connected to the radon progeny exposure as Excess Relative Risk (ERR) related to Working Level Months (WLM). A small increase in mortality of all cancers of the extra-thoracic (ET) airway was found while ERR per 100 WLM was a bit higher for pharyngeal cancer (0.077, $p = 0.2$, $n = 74$) than for laryngeal cancer (0.017, $p > 0.5$, $n = 94$). Even though the difference between larynx and pharynx cancer mortality is not large, it is a stimulus for verification whether the difference is connected with different amounts of radon progeny depositing in the two sites.

This study uses the Computational Fluid Dynamics (CFD) for clarification of the difference between radon progeny dose which reaches the larynx and pharynx region during the exposure. ET airways geometry used for CFD simulations was created from CT scans of human airways (Lizal et al., 2020). The inspiration flowrate of 50 l/min corresponding to (light physical exercise) is used.

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REVIEW OF MEASUREMENT METHODS AND CALIBRATION PROCEDURES USED IN PERSONAL NEUTRON DOSIMETRY

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Keywords: neutron radiation, personal neutron dosimetry, passive dosemeters, active dosemeters

Implementation of detection of neutrons for personal dosimetry purposes is a serious challenge, as there is no internationally uniform practice and no general method that can be reliably applied to all measurement conditions. Measurements are therefore particularly difficult in mixed or pulsed radiation fields, e.g., around a nuclear reactor or particle accelerators used in research or medical applications. In this paper different dosimetry methods were reviewed to be used in personal neutron dosimetry.

Aim of the work is to enhance the neutron dosimetry programme in Hungary to ensure radiation protection of workers exposed to neutron radiation due to usage of radiation sources and application of nuclear technologies.

Domestic and international requirements, guidelines and technical documents were reviewed, furthermore the characteristics of the most widespread passive and active personal neutron dosimetry systems (using e.g., albedo thermoluminescent detectors (TLDs), solid-state nuclear track detectors (SSNTDs), and electronic personal dosimeters (EPDs)) were examined. Advantages and disadvantages of methods and systems in different applications were determined on the basis of several criteria.

Based on our research results, we found that to be able to measure complex radiation fields (wide energy range, variant directional distribution, time-dependent radiation field), a compound system of passive detectors (TL albedo and SSNTDs) and active EPDs, supplemented by methods (Bonner spheres and simulation tools) for characterizing the mixed gamma and neutron radiation fields are the appropriate solution.

EXTREMITY DOSIMETRY FOR EXPOSED WORKERS IN POSITRON EMISSION TOMOGRAPHY IN BOSNIA AND HERZEGOVINA

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Keywords: nuclear medicine, PET-CT, equivalent dose, finger ring

Occupational exposure in Bosnia and Herzegovina is regulated by the national Regulation on radiation protection for occupational and public exposure. All radiation workers are required to be monitored using whole body passive thermoluminescent dosemeters and, in case of non-uniform external exposures, by dosimeters that would indicate dose to the most affected body ports. Exposed workers are almost exclusively employed in the medical field, and some of them work in nuclear medicine departments where they handle unsealed radioactive sources. Introduction of the positron emission tomography – computed tomography (PET-CT) in two largest clinical centers in the country was expected to cause the increase of equivalent doses to hands received by staff handling the positron emitting radionuclides. Hence, routine monitoring of finger doses became a necessity. The purpose of this study was to evaluate the available data on monitoring with ring dosemeters during PET-CT procedure in two hospitals in Bosnia and Herzegovina and compare them with other practices in the nuclear medicine department, as well as with the results of monitoring in other countries. In general, results confirm that equivalent doses to hands are well below the limit of 500 mSv in a year. Finger dosemeters have been proven to be an invaluable asset in the incidental situations that sometimes occur in nuclear medicine departments. Different number of patients and differences in injection methodologies are identified as a possible source of differences between doses in two hospitals. Overall, routine evaluation of doses to hands provides a sound basis for possible optimization processes, as well as confirmation of good practices.

RADIATION SAFETY OF SENTINEL NODE BIOPSY PROCEDURE - INSTITUTIONAL EXPERIENCE

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Keywords: radiation protection, sentinel lymph node biopsy, radiation dose equivalent, thermoluminescent dosimetry

Axilary nodal staging in breast cancer surgery is done via sentinel node biopsy procedure, involving radioactive ^{99}Tc.The staff involved in the procedure are surgeon (injects the isotope into the breast tissue) and nurse at the operating theatre,while other staff involved and potentially exposed to ionizing radiation are anesthesiologist, anesthetist, pathologist).This study had aim to evaluate radiation risk and improve measures of radiation protection.

The measurements of following quantities were done:Hp(10) personal dose equivalent to whole body and Hp(0.07) to extremities for staff as well as ambiental dose for operating theatre and during injection.The Hp(10) was evaluated through termoluminescent dosimeters (surgeons, nurses) and electronic dosimeters (anesthesiologists, anesthetists) while Hp(0.07) was evaluated by ring dosimeter worn by surgeons and pathologist.Ambiental dose was measured at the operating theatre at different spots before surgery was actually started, as well as at the workplace of pathologist.The study involved two surgeons, two anesthesiologists, three anesthetists and one pathologist during the two months period.

The patient was administered 18.5MBq of antimone sulphide (one day protocol).The doses received by all staff,were far below limits set by law (<0.8mSv/month).Monthly dose to surgeon's hands is measured at 0.24mSv,and exhibits good radiation protection practice, according to ICRP 106.The yearly dose to skin of surgeon's hands is estimated at 16 mSv/100 patients/year,while pathologist's was less than 1mSv/100 patients.The exposure of anesthesiologist and anesthetists equals to natural background of the workplace.Dose rate at the operating theatre,at the beginning of procedure was 3 μSv/h (at 20cm).The patient is measured on discharge from operating theatre at natural background level.

Sentinel node procedures are proven to be low radiation level procedures and persons involved in the procedures are exposed to low levels of radiation.

PERFORMANCE ASSESSMENT AND IMPROVEMENT OF FLUORESCENT NUCLEAR TRACK DETECTORS AS NEUTRON DOSIMETERS

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Keywords: neutron dosimetry, FNTD, PADC, Track Detector

Neutron dosimetry based on Fluorescent Nuclear Track Detectors (FNTDs), a relatively recent radiation detection technology, can overcome some of the limitations affecting other neutron dosemeters, such as the sensitivity to a narrow portion of the neutron spectrum or the post-irradiation chemical treatment, thus potentially improving the dose assessment.

This piece of research summarises the main findings and results on the FNTD technology gathered during a PhD work, illustrating the FNTDs performance on fast neutron dosimetry and the comparison of such performance with the one of more established and widely used poly allyl diglycol carbonate detectors (PADC).

The studies carried-out were additionally devoted to identifying and proposing improvements in the current FNTD dosimeters evaluation technique and explore innovative assessments that can further enhance the accuracy of fast neutron dose estimations. The studies were supported by data obtained with Monte Carlo simulations and by experimental irradiations, which were used to conceive and verify the newly developed analyses.

A new image analysis of the FNTDs readouts was proposed, allowing, on the one hand, a more precise characterisation of the track-spots and, on the other hand, demonstrating the trajectory reconstruction of recoil protons that interacted with the detectors.

The image processing results were used to develop a more effective technique to reject the spurious track-spots generated by concomitant photon-induced delta electrons in neutron exposures, and to formulate and corroborate a novel analysis method, based on the collective evaluation of the reconstructed recoil proton trajectories, to infer the angles of exposures and the mean energy of a neutron field, providing the information to correct for angular and energy dependence of the dosimeter, thereby improving the dose estimation.

ROMANIAN NATIONAL METROLOGICAL TRACEABILITY CHAIN ASSOCIATED WITH EYE LENS DOSIMETRY BY HIGH-PRECISION DOSIMETRY PHANTOMS AND MONTE CARLO TECHNIQUE

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Keywords: dosimetry, eye lens, metrology, traceability chain, 3D printer, Monte Carlo

In this work, an innovative method has been proposed to obtain the Romanian national metrological traceability chain associated with eye lens dosimetry. This metrological method is based on using modern 3D printing techniques to create high-precision human head phantoms and supporting the experimental results by the Monte Carlo calculations. At a national level in Romania, "Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)" is in charge of performing all the ionizing radiation-related metrology activities.

In the first phase of this project, a human head phantom was created by a 3D printer. Five standard dosimeters (BeOSL) were attached to the forehead, both eyes, and both temples of the head phantom. Then, it was exposed to a standard ionizing radiation field (Co-60 radionuclide, certified source) from 1.5 meters distance in three sets of experiments for 115, 230, and 345 minutes, respectively. The horizontal axis of the source was aligned with the forehead dosimeter. After each exposure, the Hp(0.07) and Hp(10) quantities absorbed by each of those 5 dosimeters were determined and registered. The same experimental setup including source, collimators, phantom, and dosimeters was modeled by MCNP6.2 code and the 3 experiments were simulated. This was repeated both experimentally and computationally, while the horizontal axis of the source was aligned with the dosimeter attached to the right temple of the head phantom. The experimental and computational absorbed dose values by each dosimeter were compared and the observed discrepancies were interpreted.

In the second phase of this project, the determination of the uniformity of the ionizing radiation field was carried out, meaning that a special pair of glasses with passive detectors was worn by the head phantom. After gradually reading the dose values along to the radiosensitive parts of the glasses, the uniformity of the radiation field was determined. This field uniformity was double-checked as well by using the Monte Carlo method (MCNP6.2 code). The final step of the experiment is providing traceable, reliable, and precise calibration factors (with the associated uncertainties) for the commercially available dosimeters used.

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T07: NORM & Radon

ANALYSIS OF INDOOR RADON CONCENTRATION IN KINDERGARTENS OF TWO BULGARIAN DISTRICT

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Keywords: indoor radon, kindergartens, basement, track detectors, reconstruction

The study presents the analysis of the results for indoor radon concentration in the state kindergartens of two Bulgarian districts (Razgrad and Silistra). The influence of presence of the basement and reconstruction of building on the radon concentration variations were investigated.

Material and Method: Measurements of indoor radon concentrations were performed with passive method (CR-39 track detectors) for the period from February to May 2015. The study was conducted in 411 children's rooms situated in 157 state kindergartens of two districts located in north Bulgaria. The analysis of the variation and influents of factors on the radon concentration was done within the national project supported by the Bulgarian National Science Fund, in the framework of Grant No КП-06-Н23/1/07.12.2018. The study was performed on the evaluation of answers from special developed Questionnaire.

Results: The variations of the measured radon concentrations in the children's premises were from 10 to 1087 Bq/m^3. The arithmetic means of radon concentration of Silisra district was 139 Bq/m^3, while in Razgrad was higher 152 Bq/m^3. Radon concentration in 10% of kindergarten premises are higher than the national reference level of 300 Bq/m^3. The applied statistical test confirms a significant difference between the groups with basement and without basement (MW, $p<0.0001$). Our results demonstrated higher value of arithmetic mean in renovated premises in both districts.

Conclusion: For both districts the presence of a basement in the building significantly reduced the concentration of radon while carrying out the reconstruction increases this concentration in the rooms. Those analyses confirm the needs the measurement the indoor radon concentration before implementation of building reconstruction or repairs. It is especially important before applying energy efficiency measures, in order to avoid the children radon exposure.

THE EUROPEAN NORM ASSOCIATION (ENA) - PROMOTING RADIATION PROTECTION IN THE FIELD OF NORM IN EUROPE

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Keywords: NORM, stakeholder involvement, professional association

The European NORM Association (ENA) was founded in 2017, merging previously informal European networks. It has the statute of an International Non-profit Organization established under Belgian law.

The objective of ENA is to promote and advance radiation protection in the context of exposure to NORM. It operates as a European platform and forum for discussion, dissemination and exchange of information, training, and education and by supporting scientific knowledge and new directions of research related to NORM issues. A key activity of ENA is to share practical solutions. To this end, ENA gathers radiation protection practitioners, regulators, scientists, and industry representatives in order to support the management of NORM in compliance with European standards and according to best practice.

Since its foundations, ENA has organized three workshops where topical issues on NORM have been discussed. It has established close working relationships and links with IAEA, HERCA, IRPA and other international initiatives – getting a recognition at international level. ENA has set up working groups on NORM in the industry, in the environment, in building materials, and as recently as in 2021, a working group on decommissioning of NORM facilities. A series of webinars have been organized to present case-studies on NORM decommissioning and discuss associated challenges and practical solutions.

INDOOR RADON DISTRIBUTION IN RESIDENTIAL AND PUBLIC BUILDING FROM SOME MAJOR URBAN AGGLOMERATIONS OF ROMANIA

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Keywords: indoor radon, public buildings, houses

Radon and its decay products are the most important sources of natural radiation for the human exposure. As the second cause of lung cancer (after smoking), radon is received indoors, in houses and other buildings by the majority of the population exposed. (ICRP, 1993). In the past decades, systematic radon surveys in dwellings were carried out all over the world (UNSCEAR 2000). Almost half of the radioactive dose is due to radon gas.

The radon requirements in the new Euratom Basic Safety Standards Directive include the establishment of a national reference level for indoor radon concentration in workplaces and public buildings ≤ 300 Bq/m3. Although research on indoor radon concentrations in dwellings is actively conducted in Romania, systematic surveys in public buildings are still lacking.

The objective of this present study was to study aims to determine the distribution of indoor radon in public buildings from major urban agglomeration from Romania, in comparison with the radon concentration levels in dwellings from the same region, and to analyze the main factors affecting indoor radon levels.

A comprehensive radon survey has been carried out in public buildings located in urban agglomeration from Romania. The results in these high occupancy public buildings were compared with the indoor radon levels obtained for dwellings in the frame of SMART_ RAD_EN project as well as in other projects implemented in the last decade.

Together with the detectors a questionnaire was completed in each surveyed building in order to collect relevant information about factors relating to measurement site as characterization of house, building materials, occupancy hours, indoor air quality etc. The preliminary results clearly show the need to implement mitigation actions in affected public buildings in the frame of the national radon program. In workplaces where radon concentrations continue to exceed the national reference level cost-effective actions must be taken to optimize the exposure.

The research is supported by the project ID P_37_229, Contract No. 22/01.09.2016, with the title „Smart Systems for Public Safety through Control and Mitigation of Residential Radon linked with Energy Efficiency Optimization of Buildings in Romanian Major Urban Agglomerations SMART-RAD-EN" of the POC Program.

RADON IN COVASNA AND HARGHITA COUNTIES (ROMANIA): FROM EPICURIAN TO ALL-PERVASIVE PERSPECTIVE

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Keywords: Radon, mofettes, indoor measurements, effective dose

Radon represents the most important contribution of population exposure to natural ionizing radiation. Radon contributes to over than 50% of the natural radiation dose received by the population. In radon risk areas this contribution can be as high as 90–95%, leading to an exposure to natural radiation 5–10 times higher than normal. Measurements of this study were performed using CR-39 alpha-track detectors.

In the Harghita post-volcanic range (Eastern Carpathians) there are many occurrences of dry CO_2 emanations, called mofettes. These emanations contain mainly CO_2 but also important quantities of radon, thoron and other gases. Mofettes are used for curative purposes of several illnesses, in most cases without medical supervising. We proposed to measure the radon activity concentration levels and to determine the effective dose for some frequented mofettes.

While the radon in mofettes might be considered an epicurean scientific question, the indoor radon is an all-pervasive topic also in the studied area. The problem of radon was assumed in Romania at national level by responsible authorities through the National Radon Action Plan and an adequate legislation, in line with the framework of the Council Directive 2013/59 (Euratom, 2014) laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation. Measurements of soil, water and indoor radon concentrations were performed in Covasna and Harghita counties, and the annual effective dose for the whole body was calculated.

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Incze R., Papp B., Burghele B.D., Cosma C. şi Gyila S. 2016. Follow - up measurements to estimate the exposure to patients in the mofettes from Covasna County (Romania). *Romanian Journal of Physics*, Vol. 61, Nr. 7-8, 1320-1329.

INDOOR RADON CONCENTRATION IN STATE SCHOOLS OF FOUR BULGARIAN DISTRICTS

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Keywords: indoor radon, schools, track detectors, classrooms, Bulgaria

The new EC Directive 2013/59/EURATOM demand an adequate level of protection for people again the radon exposure in building with public access. Based on this circumstance, the systematic study of indoor radon in the school buildings, where children spend most of their time began in 2019. Public schools in four districts of Bulgaria were surveyed from November/December 2019 to May/June 2020. The total number of investigated schools were 230, where 2427 rooms on the underground, ground and first floors were measured with passive track detectors of the RADOSYS system. Regional health inspectorates by districts are responsible for the deployment and collection of detectors, according the tasks of National Radon action plan, while detector processing is performed in the National Center for Radiobiology and Radiation Protection. For distribution of detectors, an information meeting with the school management was organized. The detectors were spread and information on radon and health effects and how to place the detectors was given on the meeting. The total loss of the detectors is only 3%, which shows that the way of distributing the detectors is successful. The evaluation of the results of indoor radon concentration in state school buildings was made under the National Science Fund of Bulgaria, in the framework of grant No КП-06-Н23/1/07.12.2018. The assessed arithmetic and geometric means with standard deviations were 153 ± 154 Bq/m^3 and 114 Bq/m^3 (GSD=2.08) respectively, which are the higher than those from the National Radon Survey. The radon concentration in 9.4% of premises was above reference level of 300 Bq/m^3. The indoor radon concentrations in the four districts were significantly different, which prove the it's spatial variation. Most school buildings were built before 1990 and renovated or will without taking in account the radon. Therefore, it is very important to pay attention to schools buildings, in order to control and reduce the children's exposure.

A DIFFICULT WAY TOWARDS A RATIONAL AND HARMONIZED INTERNATIONAL REGULATION OF INDOOR RADON

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Keywords: indoor radon, regulation, reference level, measurements, temporal uncertainty

The national threshold reference levels (RL) are set to limit indoor radon annual concentrations. However, a reliable comparison of the estimated annual average indoor radon concentration from short- or long-term measurement results with the RL remains an unsolved problem because the radon concentration in buildings is subject to significant temporal variations (daily, weekly, and seasonal). It is well-known that the shorter the duration of a measurement, the more complicated is it to assess compliance of a building with radon safety criteria. This has remained a serious challenge, and significantly complicates making an informed and reliable decision as to whether mitigation measures are needed.

The main trends of modern indoor radon regulation in Europe are quite adequately expressed by the international (albeit not mandatory) standard ISO 11665-8. However, this standard ignores the short-term tests (2-7 days in practice), which are the main tests in the US, and instead requires conducting long-term tests only, the result of which should not exceed the RL. Without any justification, the indoor radon long-term tests are recommended to be carried out for “at least two months”, which also looks uncertain when standardizing measurements. In fact, if the duration of the test is less than 1 year, then one cannot ignore the temporal uncertainty of indoor radon behavior, which is often much larger than the instrumental uncertainty, including in the case of long-term tests (Tsapalov and Kovler, 2021). However, traditionally, national regulators continue focusing on instrumental uncertainty only. This paper reports interim results of the storming discussions within the ISO 11665-8 Focus Group, which is in charge of the revision of this standard.

Tsapalov, A., Kovler, K., 2021. Studying temporal variations of indoor radon as a vital step towards rational and harmonized international regulation. Environmental Challenges. V. 4, 100204 https://doi.org/10.1016/j.envc.2021.100204.

RADON SURVEY AND EXPOSURE ASSESSMENT IN REPUBLIC OF MOLDOVA

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Keywords: radon national survey; risk assessment; dwellings; Republic of Moldova

The exposure of the population to natural radioactive sources is primarily due to radon (^{222}Rn), constituting over 50% of the total exposure. International studies point out that for exposure to radon with a concentration of 200 Bq/m^3, the estimated risk is 2.98-6.55% for smokers and 0.19-0.42% for non-smokers, under the conditions of a multiplicative relationship for the common effect of radon and smoking. The paper presents the results of National radon survey, made in the conditions of the Republic of Moldova. Radon concentrations were monitored in the air of different types of dwellings (n=2500) using long-term alpha detectors of the RADTRAK2 type with an exposure period of 90 days. The monitoring established the variability of the indicator depending on the geographical area, abiotic conditions, the type of house and the type of floor and walls. Based on the descriptive statistics analysis of the results (valid number n = 2435), it was established that the arithmetic mean of the index was 252.8 Bq/m^3, and the standard deviation of the mean—215.9 Bq/m^3. The study demonstrated an increase in radon concentrations in the air in homes in the Southern part of the country (330.3 Bq/m^3), followed by the Center area (253.8 Bq/m^3) and Northern area (237.9 Bq/m^3). The study of the variability of radon concentration in the air of dwellings placed in different geographical districts revealed increased values in the Causeni district and the lowest ones in the Chisinau municipality. The research shows that the average concentration of radon in dwellings was higher in rural areas compared to urban ones. Through the cluster analysis, the interactions within the relationships „radon × oncological maladies" were established. The overlapping of maps of the incidence of bronchopulmonary cancer and radon concentrations has shown partial interaction between these two factors, which indicates that the onset of bronchopulmonary cancer under the action of radon is a cumulative effect, determined by long-term chronic exposure and also influenced by other factors such as smoking, exogenous factors, etc. Mapping radon concentrations in the air of homes across the country will be useful for legislators and construction specialists to select land for the construction of buildings, resulting in a diminished radon hazard.

PROGRESS OF TRACERADON – EMPIR 19ENV01 PROJECT

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Keywords: radon, metrology, radiation protection, climate observation

The overall aim of the EMPIR project 19ENV01 traceRadon[1] is the development of metrological capacity (reference monitors, transfer standards, and robust methodology) to measure low levels of radon in the environment, which can be used to determine emission reduction strategies of greenhouse gas (GHG) and improve radiation protection of the general public. The project will provide the necessary measurement infrastructure and use the data to apply the Radon Tracer Method (RTM). It is relevant for GHG emission estimates that support national reporting under the Paris Agreement on climate change.

The project has 4 technical work packages: WP1 - traceable measurements of outdoor radon activity concentrations, WP2 - radon flux measurements, WP3 - validation of radon flux models and inventories using radon flux and terrestrial data, WP4 - radon and radon flux in maps for radiation protection issues.

The following metrological activities for realization and dissemination are carried out: development of radon activity standards, calibration of low-level atmospheric radon concentration monitors, development of reference infrastructure for radon flux from soil, calibration of continuous radon flux monitors in the field, and validation of radon flux models and inventories.

CHALLENGES ASSOCIATED WITH DISPOSAL OF EXHAUST AIR FILTERS AT PSI

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Keywords: clearance, filters, NORM, disposal

The Paul Scherrer Institute (PSI) consists of a wide range of activities in different facilities such as accelerator facilities, nuclear facilities and radioactive waste treatment. The exhaust air of these buildings has to be filtered before it is discharged to the environment. Besides potentially activated or contaminated air, some naturally occurring radioactive materials (NORM) can be found on these filters. The latter are responsible for dose rates above 0.1 μSv/h and activities concentrations above the clearance limits for NORM (LLN).

According to the Swiss Radiation Protection Ordinance these filters can be released from the site with the approval of the Federal Office of Public Health (FOPH), if the disposal via the usual channels would be impossible or would involve disproportionate effort and, as a result of appropriate measures, the effective dose to members of the public arising from emission remains below 0.3 mSv per calendar year.

The faced problems and possible solutions for the disposal of these filters are discussed.

AMBIENT GAMMA LEVEL, SEASONAL AND SPATIAL DISTRIBUTION OF NORM IN BEACH PLACER DEPOSITS

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Keywords: seasonal variation, natural radioactivity, mineral deposits

Radioactive heavy mineral assemblages along the beach placers are influenced by a series of factors like host rock weathering, deposition, and climate conditions prevailing in the area (Paschoa, 2000). The level of natural radiation exclusively depends on the minerals' assemblage and transportation trends. This study establishes a complete scenario of natural radionuclides enrichment in beach placers due to the transportation trends, seasonal and oceanographic processes. The study area is sandwiched between the Arabian Sea and the Western Ghats group of rocks. 41 rivers are flowing westwards from the Western Ghats terrain (Krishnan et al., 2001) to maintain the supply of heavy minerals to the shoreface. They are later sorted hydrodynamically based on their physical properties, largely specific gravity by waves and seasonal rains.

The ambient gamma radiation level was carried out along the coastlines using a sensitive scintillometer. The dose rates in the air were recorded 1 m above the ground level, and about twenty-five readings were recorded in each location. The beach sampling was carried out spatially; at the waterline and 20m and 40m away from the waterline during pre-monsoon and post-monsoon seasons. All the samples were carefully processed following IAEA standard procedure. The sealed samples were taken for radiometric analysis. A High-resolution gamma spectrometry HPGe detector was employed to determine the activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th.

The results showed that the overall dose rate in air varied from 157-26,087 nGy h^{-1} and higher during post-monsoon. This is due to the maximum wave activity during the monsoon and the action of constructive waves building up post-monsoon. The Multivariate statistical Cluster analysis (CA) showed a significant difference in the spatial and seasonal gamma levels. The seasonal variations are very much pronounced in overall radioactivity. The higher activity of ^{232}Th and ^{226}Ra in Karunagapalli and Chavara was observed post-monsoon. This indicates the higher deposition rate of beach placers during monsoon. It must be noted that the region showed high activity for ^{232}Th, varying from 45-51.2 kBq kg^{-1}, and for ^{226}Ra varying from 21-78.7 kBq kg^{-1}, respectively. The activity of ^{40}K was found to be very low, BDL to 481 Bq kg^{-1}. The higher 232Th and 226Ra concentration are found in finer size fractions due to the selective enrichment of the radioactive minerals.

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Krishnan S, Viswanathan G, and Balachandran K, 2001, Heavy mineral sand deposits of Kerala, *Exploration Research for Atomic Minerals*, Vol.13, pp.111-146.

Outdoor radon measurements by means of SSNDT and active monitoring

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Keywords: radon, metrology, radiation protection, climate observation

Outdoor (atmospheric) radon activity concentrations need to be measured as accurate as possible for radiation protection as well as for climate applications. Particularly radon concentrations below 100 $Bq \cdot m^{-3}$ calibration and measurement capabilities, which are very important for the retrieval of radon prone areas and for atmospheric process modelling, still need a robust metrological traceability chain to ensure their quality. For this purpose, the traceRadon project works towards this goal, which will help EU member states to comply with the Council Directive 2013/59/Euratom.

One of the widely-used techniques to quantify radon concentrations is using solid state nuclear track detectors (SSNTD) method. The SSNTD work is based on the principle that ionising particles are creating microscopic defects (tracks) in the detection material that can be revealed by etching treatment with chemicals. In this study the aim is to observe the integral radon exposure at an Atmospheric Monitoring Network Station (AMNS) while comparing data obtained with the integral value of active monitoring device, because in operational services, the sensitivity and accuracy of the readings are key factors, which must be properly estimated to provide correct exposure from radon. The results in the development of this activity as well as the application of a new approach in the data analysis by means of intercomparison will be presented. Knowledge of such joint efforts can offer a solid background in providing more accurate and traceable results for both types of measurement methods. This is even more challenging due to the outdoor environment.

The results presented in this work are developed in the framework of the 19ENV01 traceRadon "Implementation of radon metrology for the analysis of the atmospheric budget of greenhouse gases and radiation protection in the environment" *project. This project, 19ENV01, has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme. 19ENV01 traceRadon denotes the EMPIR Joint Network Project reference.*

INVENTORY OF NORM INDUSTRIAL SECTORS IN ITALY: PRELIMINARY RESULTS

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Keywords: NORM, radiological characterization, inventory

Starting from the list of NORM industrial sectors considered in the Italian transposition of the 2013/59/Euratom Directive (EU_BSS), a research project is ongoing with the aim to develop technical and scientific tools to support regulators and stakeholders in the new regulation implementation. These tools will be useful to draft guidelines addressed to the stakeholders involved at different levels.

One of activities of the project focused on the update of the inventory of NORM involving industries in Italy carried out in 2014. Indeed, the transposition of EU BSS and global economic challenges required a review of the previous inventory, done in 2014. The scheme of inventory takes into account the inputs received by the IRPA TG Group and the discussion in the framework of RadoNorm project. The collection covers all industrials sectors identified by the Italian regulation and for each sector collects information about the following topics:

- type and amount of NORM involving sites in Italy and distribution on regional basis;
- description of the production processes;
- data relating to the radiological content of NOR raw materials and residues;
- identification of the most significant exposure scenarios for workers and the members of the public.

In order to facilitate the usability of the inventory results, the collected information is also summarized in technical data sheets, organized in three modules:

- the first module deals with information about the occupational exposure (most significant scenarios, type of exposure, dominant natural radionuclides, range of effective doses, etc.);
- the second one deals with information on radiological content of raw materials and residues;
- the third one reports information relevant to the public exposure (effluents, main route of exposure, dominant natural radionuclides, etc.).

In the present work main outcomes will be discussed.

RADON LEVELS DISTRIBUTION IN UNIVERSITY'S BUILDINGS LOCATED IN AN ITALIAN KARST REGION

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Keywords: indoor radon, karst area, spatial distribution, temporal distribution

Recently, an indoor radon survey in 54 buildings belonging to the UniSalento University (South East Italy) was carried out. The monitored buildings differ by type, construction period, materials, etc., and are located in a karst area. The survey considered about 1000 rooms at different floors: mainly, rooms located at ground floor (67%), first floor (12%) and below ground (12%).

In each room, the annual average radon activity concentration was measured by SSNTD passive dosimeters for two consecutive semesters (spring/summer and autumn/winter).

Data analysis investigated the radon spatial distribution among buildings and inside each building at different floors: in particular, the spatial variability within buildings was investigated in terms of both variation between floors and among rooms at the same floor.

Main results highlighted that radon levels at ground floor and at first floor within a building are very similar. Moreover, the analysis of radon data in both semesters (temporal distribution) are very similar. The results show a low temporal variability and a low spatial variability with median values of CVs less than 30%.

To better investigate indoor radon behavior in this sample of buildings, radon data were analysed considering the age of construction, the type of foundation, the intended use of room, building materials etc.

Main results put in evidence that the karstic characteristics of soil and building materials affect radon levels within buildings.

In the present work main outcomes will be discussed.

EXPERIENCES WITH ACCREDITATION FOR RADON MEASUREMENT LABORATORIES

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Keywords: radon, accreditation, authorization, measurement, calibration, 2013/59/EURATOM

With the adaption of the Council Directive 2013/59/EURATOM into Austrian national law, new challenges arose for businesses, homeowners, authorities and measurement services. In addition to measurement of underground workplaces and workplaces in waterworks, the new law defines regions of the country in which a high risk of radon exposure is to be expected. In these regions, all employers are required to hire an accredited and authorized monitoring laboratory to determine radon activity concentration in indoor air. These authorized laboratories are charged with recording the measured value in the national radon database and – if the reference value of 300 Bq/m³ is exceeded for a certain workplace even after remediation efforts were undertaken – calculate the annual effective dose for each affected worker.

In this paper a comprehensive overview of our experiences with the process of gaining accreditation as a radon-monitoring service and authorization by the Federal Ministry for Climate Action as a dose monitoring body is given. It describes in detail the issues that had to be tackled in order to become an accredited radon-monitoring laboratory using active and passive radon measurement equipment.

The main challenges to overcome were related to measurement uncertainty, metrologically traceable calibration of the track-etch detector system, as well as information not covered by ISO 11665-1, ISO 11665-4 and ISO 11665-5, availability of proficiency tests, etc.

This paper aims to be a guideline for laboratories seeking accreditation in the field of determination of radon activity concentration.

T08: Radioactive waste management and geological disposal

DETERMINATION OF NUCLIDE CONCENTRATION IN WASTE MATERIALS IN THE INSIDER PROJECT

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Keywords: waste management, Monte Carlo simulation, gamma spectrometry

The aim of the H-2020 INSIDER project was to improve the nuclear site characterization for waste minimisation in decommissioning and dismantling operation under constrained environment.

Two sites were assigned for the in-situ measurements:

1. Biological shield of the BR-3 reactor in Belgium,
2. Two fluid waste tanks in JRC Ispra.

The complexity of the task is comprised in the 3D character of the measured object, which was done by combination of the evaluation of gamma spectra taken by HPGe detectors with Monte Carlo modeling. The crucial point of the modeling was to divide the bulk of the material to properly chosen cells. In the case of BR-3 the concrete wall was divided by concentric cylinders coaxial by the detector crystal and planes parallel by the wall. Volume elements were added until the contribution of the new element became negligible in both directions. The depth profile of the nuclides of interest were given by local scientists. The question was how deep the limit concentration lies in the material.

At the Ispra site a prefabricated rectangular collimator had to be used. The bulk of the fluid was divided by horizontal and vertical planes. The concentrations were considered to be locally homogeneous, the question was the concentration ratio $^{137}Cs/^{60}Co$ at different heights.

Unit concentration of nuclides at the maximum of the depth profile was presumed at the BR-3 and so was at the measuring height in Ispra. In both cases the modeling of the bulk of the source, the collimator and the detector crystal gives the expectable count rate in the case of unit activity concentration using a correction factor received by comparison of the measurement of a calibration source with the modeling of the point source with the same collimator and detector crystal.

Measuring with the real setup gives the count numbers and comparing it with the model result gives the nuclide concentrations.

https://insider-h2020.eu/

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SIMβ-AD PROJECT: METHODOLOGY TO ASSESS β-ONLY RADIONUCLIDES ACTIVATION INTO CYCLOTRON MATERIALS

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Keywords: activation, cyclotron, radioactive waste management, accelerators, Monte-Carlo code, neutron detection

Rising concerns appeared for some years to eliminate radioactive waste produced by French particle accelerators facilities to dedicated disposal because of their difficulties to assess activity of β-only radionuclides. The Simβ-AD Project has been launched in 2020 to validate a methodology to assess activity inside the materials of cyclotron facilities. Numerical simulations made with Monte-Carlo codes to assess the neutron and photon spectra will be compared with experimental data obtained with active and passive detectors. The aim is to determine correlation factors between β-only radionuclide and γ-emitting radionuclide inside radioactive waste of various materials.

Several topics will be studied: optimizing the use of activation foils to choose the best materials regarding physics and environmental performances; providing efficient and easy-to-use active neutron detectors in mixed and high-flux particle fields; defining the accuracy needed for geometrical and physical modelling with Monte-Carlo codes; identifying the advantages of different Monte-Carlo and deterministic codes to determine neutrons and photons fluence spectra and to assess activity inside radioactive waste.

The project is led by two laboratories sharing their expertise in numerical simulations (Horodynski and Wurth 2017), neutron detection (Arbor, Higueret et al. 2017) and radioactive waste management (Pauwels, Horodynski et al. 2013). At this time, three facilities, chose for their specificities will provide beam time for the project: CEMHTI (Orléans, France), CYRCé (Strasbourg, France) and CYCERON (Caen, France). First experiments were made, and results will be presented.

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ASSESSING THE EFFECT OF NATURAL ZEOLITE ADDITIVES ON THE IMMOBILIZATION OF BORIC ACID RADIOACTIVE WASTE BY CEMENT

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Keywords: immobilization, cementitious waste-form, leaching test, chemical stability, zeolite

Zeolites are minerals made of hydrated alumino-silicates of alkaline/alkaline earth metals. Their key characteristic is a molecular cage structure which is important for ion-exchange interactions. Many zeolites are pozzolanic, and therefore react with lime to produce a cementitious material, similar to the final product of cement- hydration. In this study, we aim to optimize the retention capabilities of cementitious waste-forms by applying zeolite additives to different types of cement. Zeolite-rich rhyolitic tuff samples extracted from Tokaj Mountains in north-eastern Hungary (clinoptilolite and mordenite) are possible candidates for our research. Literature indicates that using some types of zeolites may decrease the leaching of important elements (Ca, Si, S, Al, Na, and B) from a mixture of quicklime and fly ash due to the increase in ion-exchange sites of cementitious matrices. However, a high ratio of zeolite can decrease the physical stability due to the increase of matrix porosity. Hence, finding the suitable zeolite type and optimum zeolite/cement ratio for radioactive waste is of special importance. Different types of zeolite-modified waste-forms will be prepared, subjected to the American standard leaching test and then extracted liquid samples will be analyzed using ICP-MS, ICP-OES, and the treated solid samples by XRD and SEM-EDX techniques to compare the chemical and physical stabilities of different types of zeolite-modified waste-forms.

IMMOBILIZATION OF NOVEL RADIOACTIVE WASTE OF B-10 ENRICHED BORIC ACID WITH OPC AND SAC CEMENTITIOUS MATERIALS

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Keywords: novel neutron absorber, boron molecular geometry, leaching test, cementitious matrix, chemical stability, long-term durability

Boric acid enriched in ^{10}B (EBA) is a novel neutron absorber that is being substituted for natural boric acid (NBA) by some advanced nuclear power plants (NPPs), and therefore the volume of radioactive waste containing EBA is increasing continually. Though there are many studies about the abilities of EBA compared to NBA during NPPs operation, there is no published data about the immobilization of the EBA radwaste. Nevertheless, some of the boron's unique properties such as the high relative mass difference of the boron's stable isotopes ($^{10}B/^{11}B$), the pH dependency of the different borate geometries (trigonal and tetrahedral forms) also, the tendency of the two boron's stable isotopes to each of those geometries, may cause different geochemical behavior of NBA and EBA in cementitious final waste forms.

In this study, the leaching behaviors of the structural elements of cementitious matrices (Ca, Si, S, Al) and B and Na were indexed to compare the chemical stabilities and durabilities of OPC (ordinary Portland cement), SAC (sulfoaluminate cement), and OPC-SAC cementitious waste forms. Solidified waste forms with three levels of boron concentration and two levels of enrichment (NBA and EBA) were prepared. The leaching test introduced in ASTM C1308-08 standard, SEM-EDX and XRD (for geochemical assessments), ICP-OES and ICP-MS techniques (for elemental and isotopic measurements) were applied.

The results showed the phase compositions of the final waste forms were significantly different with changing the boron concentration and enrichment in each set of the cement types. Also, both the elemental and isotopic leachabilities showed varying amounts and rates during the test period of each set. These results reflect varied chemical and physical stabilities and subsequently, different long-term durabilities for the final waste forms containing NBA and EBA which should be considered significantly during the design of radioactive waste disposal facilities.

T09: Radioactivity monitoring and emergency monitoring

RADIOLOGICAL PROTECTION ASSESSMENT USING MONTE CARLO SIMULATION CODE

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The Extreme Light Infrastructure – Nuclear Physics (ELI-NP) is one of the most advanced facility in the world using radiological installations with uncommon parameters. ELI-NP hosts experiments with high-power lasers, that can generate on two front ends very short pulses of 10 PW power each and a brilliant variable energy gamma beam system that has unique spectral characteristics. At ELI-NP are performed, in several designated areas, experiments based on the ultra-short high-power lasers, experiments based on the high-intensity gamma beam and also combined experiments with both installations.

The facility hosts a dosimetry laboratory, currently under development, where the radiation safety group employs several types of detectors for monitoring the personnel, environment and public exposure to ionizing radiation generated in experiments performed.

The ELI-NP facility has been designed based on the radiological protection assessments performed using Monte Carlo simulations. Poster presents an example of an assessment using the FLUKA code for one of our experimental area where a diagnostic system for variable energy gamma beam is set up. The purpose was to create a shielding design for an attenuator system that is placed in front of the beam. The shield is required in order to reduce the secondary particles produced in the attenuator, which may severely damage the HPGe detector used for primary beam diagnostic purposes. Calculations were performed for the gamma beam energy distribution spreading from 1 MeV and up to 20 MeV.

RADIATION SURVEY AT THE REMEDIED DUMPS OF MINE NO.2 OF THE LERMONTOV PRODUCTION ASSOCIATION "ALMAZ"

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Keywords: gamma radiation, natural radionuclides, radiation survey, remediation, the specific activity

The extraction of uranium ore at mine No. 2 of the Lermontov Production Association "Almaz" was carried out from 1954 to 1991.

The elimination of mine No. 2 was passed until 1994. Additional work was carried out in 1997-2009 to maintain a safe state of rock dumps, eliminated and mothballed adits.

Dumps of adits of mine No. 2 over the years since the closing of the enterprise have been subject to shedding or washing away by flood waters.

Works on additional remediation of LPA "Almaz" facilities were included in the Federal Target Program "Assuring Nuclear and Radiation Safety for 2008 and for the period up to 2015".

The assessment of the radiation situation in the mine area was carried out in 2019-2021.

During the research, the following parameters of the radiation situation were measured:

1) ambient dose equivalent rate of gamma radiation at a height of 1 m from the soil surface;

2) the specific activity of radionuclides in the surface soil layer.

It is shown that on all dumps, except for the territory close to adits No. 9, 10 and 11, the ambient dose equivalent rate of gamma radiation does not exceed 0.5 μSv/h.

On the territory near adit No. 10, the ambient dose equivalent rate of gamma radiation reaches 5 μSv/h, in the area of adit No. 11 — 0.3 μSv/h, and in the area of adit No. 9 — 0.5 μSv/h. In a small area close to adit No. 10, the content of radionuclides in the soil exceeds the criteria for classification as solid radioactive waste by 5 times.

Thus, after remediation of the territory in the area of all adits, with the exception of adits No. 9, 10 and 11, the radiation situation complies with the requirements established in the remediation project in accordance with the Health Rules for Elimination, Conservation, and Changing Functions of Facilities for Radioactive Ore Mining and Milling.

RADIATION PROTECTION ASPECTS OF NUCLEAR ACCIDENT PREPAREDNESS IN HUNGARY

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Keywords: disaster management, industrial safety, nuclear accident preparedness, radiation protection

The peaceful use of nuclear energy in Hungary is essential for the energy safety of the country. However, there is a risk of nuclear emergencies, which could release radioactive materials into the environment, endangering the health of workers and the general public, damaging the environment and causing significant economic damage. The basis for nuclear emergency response system is the National Nuclear Accident Prevention Action Plan. The plan provide prevention and response measures linked with emergencies arising from activities with nuclear and radioactive materials. In order to provide the information necessary for the decision-making activities of the governmental coordination body, a National Radiation Monitoring, Signaling and Control System is in place. The aim of the system is to establish the radiation protection of the measures necessary for the maintenance of the living and working conditions of the population, the protection of material assets and the prevention of nuclear accidents (Kátai-Urbán, L, 2014). The national disaster management organization operates the Nuclear Accident Information and Assessment Center, which performs the country's early warning tasks in the field of nuclear accident prevention, and the tasks of the national center of the international radiological monitoring data exchange system. The Radiological Telemetry Network continuously monitors the country's environmental radiation dose rate and key local meteorological parameters. The disaster management organisation operates the so-called RODOS system for simulating a nuclear emergency situations (Kátai-Urbán, L, Vass, Gy. 2016). The application of the nuclear accident prevention system in Hungary makes it possible to ensure a high level of protection against possible emergencies caused by nuclear accidents.

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MOBILE APPS FOR RADIATION DOSES, HEALTH AND WELL-BEING AFTER A NUCLEAR ACCIDENT: RECOMMENDATIONS FOR USERS, DEVELOPERS AND PUBLIC AUTHORITIES

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Keywords: recovery after accident, radiation protection, mobile apps, citizen involvement, health & well-being, dose measurements

SHAMISEN (Nuclear Emergency Situations - Improvement of dosimetric, Medical And Health Surveillance) - Stakeholder INvolvement in Generating Science (SINGS) aimed to enhance Citizen Participation in preparedness and response to a radiation accident through mobile apps to support data collection on radiation measurements, health and well-being indicators.

The stakeholder' (including general public) opinions on needs, awareness and willingness to use mobile apps for dose and health/well-being indicators were gathered through the anonymous survey and discussed at national and international workshops (Liutsko et al., 2021; Ohba et al., 2021).

Dose measurements from available mobile apps were compared with those obtained using professional tools. Infographics for general public "How to use your mobile phone to measure radiation" were created in 7 languages: English, French, Spanish, Russian, Italian, Ukrainian and Japanese and a short video tutorial to accompany them.

In parallel, apps for health and welfare monitoring as well as questionnaires currently used, and in particular in the regions of Fukushima, were reviewed critically. The results helped to develop recommendations for information to be collected in the case of an accident.

Data management plan and ethical issues concerned the data collection and further use are also discussed. The results describe the possible benefits on individual and societal level.

The summarized final results of the SHAMISEN SINGS project can be downloaded and printed a pdf version of the booklet "*Mobile apps for monitoring radiation doses, health and welfare in the context of a nuclear or radiological accident: Guidelines and recommendations for users, developers and public authorities*" (Liutsko et al., 2020). The SHAMISEN SINGS project contributes to strengthening the role of social sciences and humanities in radiation protection research by engaging more stakeholders in preparedness and response to a nuclear/radiological accident.

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Ohba, T. et al. 2021. Tailoring Digital Tools to Address the Radiation and Health Information Needs of Returnees after a Nuclear Accident. Int. J. Environ. Res. Public Health, 18(23), 12704

SHAMISEN-SINGS is part of CONCERT. This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 662287.

RADIATION PROTECTION CHALLENGES AT SWISSFEL

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Keywords: accelerator, neutron radiation, research facility, free-electron laser

The Paul Scherrer Institute (PSI) consists of a wide range of different activities in different facilities such as accelerator facilities, nuclear facilities and radioactive waste treatment. The newest large research facility at PSI is the electron accelerator SwissFEL. It produces an X-ray laser light that can make structure and dynamics of matter visible. The beam is very short pulsed with a maximum frequency of 100 Hz. The electrons reach a maximum energy of 7 GeV with a charge of 800 pC per pulse. The facility has a length of 740 m and consists of an injector (gun and booster) three linear accelerators, two parallel undulators for the two beam lines Aramis and Athos and several experimental areas.

The main radiation protection issue is the generated secondary neutron radiation of the stray radiation field, which is monitored and shielded. The so-called Dose Rate Protection System (DRPS), which consists of more than 50 detectors, surveys the neutron dose rate inside the beam tunnel and switches the beam off if the dose exceeds a certain limit. Another radiation protection aspect of this facility is the activation of materials and air inside the beam tunnel. At every opening of the tunnel, the whole beam line gets measured and all activated components will be documented. This is also important for a later dismantling. The radiation protection team carries out a variety of different measures to comply with legal requirements and to ensure a safe operation of the accelerator.

The faced challenges and problems as well as the experience of the first years of operating SwissFEL in a radiation protection point of view will be discussed and presented.

PRACTICAL ASPECTS OF ASSESSING THE PERFORMANCE CHARACTERISTICS OF ENVIRONMENTAL RADIATION MEASUREMENTS

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Keywords: environmental radiation monitoring, measurement uncertainty, characteristic limits, uncertainty propagation, stochastic evaluation, Monte Carlo method

Reliable characterization of the radiation conditions in the environment requires adequate evaluation and statistical analysis of the environmental measurement results. The approval criteria for environmental radiation monitoring services generally include the need to comply with quality assurance systems, which require the evaluation of measurement uncertainty to ensure the validity and metrological traceability of results. In addition, the characteristic limits, such as decision threshold, detection limit and limits of coverage interval are also important performance characteristics of the measurement processes and should be determined and set in line with the objective of achieving reasonably low level of detection capability of measurement systems. Methods based on different principles may be used to determine the performance characteristics, but their adequacy and the reliability of their results must be assessed considering the conditions under which the used approach is valid.

In this study, the applicability of the most widespread uncertainty propagation-based and stochastic, Monte Carlo method-based measurement evaluation approaches for the most prevalent environmental radiation measurements, dose and dose rate measurements and nuclear analysis of environmental samples, was investigated. In addition to the conditions of application, procedures to support the practical usability of the corresponding evaluation methods and to simplify the calculations are presented. Methods for reducing measurement uncertainty and characteristic limits in routine and accidental environmental monitoring are also described.

THE ENVIROMENTAL MONITORING PROGRAMME OF THE REGIONAL LABORATORY (TOLNA COUNTY) OF THE RAMDAN

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Keywords: environmental monitoring, RAMDAN, radiohygiene, NERMS

Article 35 of the Euratom Treaty orders that each Member State has to establish facilities to carry out continuous monitoring of the level of radioactivity in air, water and soil. Over all there is necessity of maintaining facilities to check the levels of environmental radioactivity on the territory of the Member State. National Environmental Radiation Monitoring System (NERMS) upholds the radiation monitoring networks and the NERMS Information Centre. This centre collects and processes the measurement data of the different individual monitoring networks.

RAMDAN is the Radiological Monitoring and Data Acquisition Network of the public health authorities. The regional laboratories of this network are incorporated into the regional competent departments for public health of the County Government Offices.

The Regional Radiohygiene Laboratory of the Department of Public Health of the Tolna County Government Office plays role in the independent monitoring around the Paks NPP and also provides environmental radiological data for 4 county, namely Tolna, Fejér, Somogy and Baranya.

The monitoring program covers samples taken from soil, grass, living water (Danube), drinking water, aerosol, fall-out; milk, dairy products, corn, bread, meat, fruits, vegetables. Radioanalysis is based on gross beta measurement, gamma spectrometry and – in some cases – determination of Sr-90.

2018 Annual Report of the National Environmental Radiation Monitoring System; 2020

THE FIRST INTEGRATED GEODYNAMIC STATION IN CENTRAL EUROPE

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Keywords: radon, monitoring, CO_2, geodynamics, soil

In July of 2021 the first Integrated Geodynamic Station (IGS) of Central Europe started its operation in Badacsonytördemic, Hungary. The goal of the IGS is to monitor the possible link between local diffuse gas emanations and seismic activity in the Bakony–Balaton Highland region that is hypothesized based on previous studies. For this purpose, the station continuously monitors the concentration of infrared active soil gases and the activity of radon in the soil gas. The most important analyzed gas is the CO_2 because of its great abundance and because it can serve as a carrier gas for the radon. The importance of the radon measurement in this case is its strictly inorganic origin, whereas CO_2 can have both organic and inorganic sources. However, an elevated concentration of both gases can be measured, it cannot be ruled out a deeper, non-organic origin for both CO_2 and radon.

For the analysis of the soil gases, we use a PerkinElmer Fourier Transform Infrared Spectrometer integrated into an Automatic Gas Sampling System Developed by Redshift srl.

The radon activity measurements are done by using the Bertim AlphaGuard device in 1-minute flow mode, attached to a soil gas probe and an external pump working with 0.5 liter/min flux.

In case of CO_2, we measured few thousands ppm and as for radon around 30000 Bq/m^3 consistently over long timespans.

In addition, a weather and a seismic station are also installed to measure the local weather conditions and the regional seismic activity. We expect that our approach is useful to understand the links among the pedosphere, atmosphere and seismic activity of lithosphere and can reveal fingerprints preceeding earthquakes.

Our work was supported by the NKFH-NN128629 Topo-Transylvania grant and MTA FI Pannon LitH2Oscope Momentum Research Group.

RADIOACTIVITY MONITORING AFTER DIRTY BOMB EXPLOSION SIMULATION

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Keywords: gama spectrometric measurement, dirty bomb, radioactivity monitoring, ^{99m}Tc

Two experiments simulating radioactive dirty bomb explosions in an urban area were provided at the National Institute of NBC Protection (SUJCHBO v.v.i.), Czech Republic.

A model of a 100 m^2 square with four adjacent streets was built in an open space. Its surface was covered with filters to capture radioactive aerosol' particles after the dirty bomb explosion.

A solution containing radionuclide ^{99m}Tc of activity ca. 1GBq was dispersed during the experiments using an explosive device. The radionuclide was chosen due to its short half-life, absence of alpha or beta rays and gamma rays of low energy.

After the explosion, contaminated filters were collected into measuring vessels and spectra of gamma rays were measured by a hand-held NaI(Tl) spectrometer and laboratory HPGe spectrometers. The ambient dose equivalent rate at measuring vessels was set as well.

Two different geometries were used for both detectors: a Marinelli beaker of volume 450 ml, containing a contaminated filter of dimensions 30 x 40 cm, and a gallipot of volume 90 ml, containing a contaminated filter of dimensions 20 x 25 cm.

Self-made standards had been prepared by dripping a defined amount of ^{99m}Tc solution uniformly on the filters, subsequently inserted into the measuring vessels to set the ^{99m}Tc surface activity of measured samples.

Measured values of ^{99m}Tc surface activity at individual filters, gained by the three above mentioned measurement methods, were recalculated to the time of the explosion and compared. A map of radioactive contamination of the model was set using previously determined filters' location.

The defined amount of ^{99m}Tc solution was dripped non-homogenously on some filters, used for self-made standards (i.e. at the filters' centre or the filters' border only) to estimate the impact of non-homogenous filters' coverage by radioactive aerosol' particles. The non-homogenous standards ^{99m}Tc surface activity deviation from the homogenous standards ^{99m}Tc surface activity was determined.

MEASUREMENTS OF IODINE AND TECHNETIUM CONTENT IN THYROID OF OCCUPATIONALLY EXPOSED PERSONNEL

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Keywords: occupational monitoring, radioiodine, radiotechnetium

The I-131 and Tc-99m content in the thyroid of staff members working with radioiodine has been measured in some Departments of Nuclear Medicine performing therapy and diagnosis of thyroid disease in Poland. In the period 2011-2020 the measurements of I-131 and Tc-99m content in the thyroid of staff members working with radioiodine has been measured in Nuclear Medicine Units performing therapy and diagnosis of thyroid and others organs disease.

The measurements were performed with mobile detection unit for „in situ" measurements of radioiodine and technetium. The counting configuration for monitoring personnel was identical to that used in the calibration procedure. Typically, detector set at a neck - to - detector distance of 10 , using a 300 seconds counting time. The background was measured with detector placed 10 cm away from the RSD neck phantom, prior to or just following the count performed on the person. The measurements were performed in selected as low as possible background places. The MDA for mobile unit ranges from 10 – 70 Bq at the time measurement of 300 seconds and depends on background condition in particular units.

The measured personnel can be divided into some categories according to internal contamination risk to unsealed sources of I-131:

1. Technical staff mainly performing routine diagnostic investigation,
2. Nuclear medicine staff (physician, nurse) working with *in vivo* administration of I-131 to patients,
3. Hospital services staff (orderlies, cleaners) performing auxiliary activities to the patients (cleaning of the rooms, changing of bedclothes).

All individuals actively working with iodine and technetium show measurable amounts of this isotopes in their thyroids. The average measured activity in the thyroid of the nuclear medicine staff was found to be equal at average 650 Bq within the range from 60 Bq to 50 kBq. The average and range of I-131 activity measured in thyroids for all medical units were: 1500 Bq, (100 Bq – 50 kBq), 400 Bq, (30 Bq - 3000 Bq), 150 Bq, (50 Bq - 1000 Bq) for technical staff, nuclear medicine staff and hospital services staff respectively. There is no apparent correlation between the measured I-131 levels and risk categories. Nevertheless the technical and nuclear medicine staff show higher I-131 thyroid level comparing to hospital services staff.

Base on results of measurements, the Effective Dose Equivalent for particular person due to inhalation of I-131 and Tc-99m was calculated. Calculated average Effective Dose Equivalent for particular exposed person is below 50 per cent of 20 mSv/year.

A REMOTE AND REAL-TIME OPTICAL DETECTION OF ALPHA_EMITTING RADIONUCLIDS IN THE ENVIRONMENT

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Keywords: alpha particles, remote detection, optical system, air luminescence

Radiological emergencies involving accidental or intentional dispersal of alpha-emitting radionuclides in the environment can cause significant harm to people and societies in general. A detection system for measuring large-scale contamination with these radionuclides is currently not available and new remote detection techniques which overcome shortcomings of traditional detectors are needed. This contribution will present the objectives of the EMPIR (European Metrology Programme for Innovation and Research) project 19ENV02 RemoteALPHA[*], which focuses on the application of alpha-radioluminescence technique to quantify large-scale contamination with alpha emitters in the outdoor environment. RemoteALPHA aims to develop new techniques and technologies that enable sensing of a radiological threat at safe distance, without putting first respond personnel and equipment in harm's way. These techniques aim at ensuring an adequate level of preparedness and response, to assist the on-site incident management, creation of evacuation plans as well as in developing strategies for protecting public from harm. These measures are required by the European Union (EU) legislations defined in the Council Directive 2013/59/EURATOM and are compulsory for all EU Member States.

[*] This project 19ENV02 RemoteALPHA has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme. 19ENV02 RemoteALPHA denotes the EMPIR project reference.

THE *SIREN* PROJECT: DEVELOPMENT OF A REAL TIME SYSTEM TO REPORT AND COLLECT DATA FOR THE DOSE ASSESSMENT OF OPERATORS IN ABNORMAL EVENTS IN NUCLEAR MEDICINE THERAPY

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Keywords: dose assessment, nuclear medicine, radiological incidents

The SIREN Project (2020-2022) aims to develop procedures for reporting abnormal events in the nuclear medicine therapy wards by the implementation of a system based on a Internet of Things (IoT) monitoring system and a mobile application. This system shall allow the operator to report quickly, easily and as accurately as possible abnormal events. The system will also acquire data for the exposure scenario reconstruction, for the dose assessment and for the proactive monitoring of the medical and paramedical staff for the patient assistance, providing useful data both to reconstruct the event dynamics, and to facilitate the proactive approach to risk management. The prototype of the system will have to meet the following objectives: i) to simplify entering data of the reporting anomalies and incidents procedure and reduce the time; ii) to increase the quality of data and information collected, improving the reconstruction of the scenarios and the dose estimation; iii) to increase the number of reports of accidents, including those not leading to undue doses; iv) to simplify the subsequent classification of data and information for proactive risk monitoring. The innovative aspects of the proposed methodology compared to existing procedures are: the involvement of operators in the design of the system; an IoT monitoring system for real-time collection of data about the event dynamics and the exposure level; the use of social science methodologies for obtaining reliable descriptions of events. At the moment, the preliminary phase of research has been completed by a cycle of interviews with users, which made it possible to collect the needs and expectations of various actors (radioprotection expert, doctors, physicists, technicians and nuclear medicine nurses). The detection system of the environmental dose and the dose estimation of operator are being designed and the application –by the definition of requirement analysis- and app mockups are being developed.

RADIOLOGICAL ASSESSMENT OF IRRIGATION WATER USED IN RUSTENBURG, SOUTH AFRICA

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Keywords: water, agriculture, radiation

Water is an essential input in agricultural production, playing an important role in food security. According to the world bank water, irrigated agriculture represents about 20% of the total cultivated land and 40% of the total food produced globally. This makes water a direct and indirect route of radiation exposure to humans via contact, ingestion, and consumption of agricultural products. Radiological assessment of irrigation water around Rustenburg, one of the mining and industrial cities in South Africa, is investigated in this study. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in irrigation water samples was determined using the total mass elemental concentrations of uranium, thorium, and potassium, measured using inductively coupled plasma mass spectroscopy. The activity concentration of ^{238}U and ^{40}K range from 1.24×10^{-04} Bq/l to 1.09×10^{-02} Bq/l, and 7.07×10^{00} Bq/l to $1.32 \times 10^{+01}$ Bq/l, with mean activity concentration of 2.78×10^{-03} Bq/l, and $1.16 \times 10^{+01}$ Bq/l, respectively. The activity concentration of ^{232}Th was found below detection level in all sampled irrigation water. Estimated radium equivalent, absorbed dose rate, annual effective dose rate, external hazard index and annual effective dose due to ingestion due to ^{238}U and ^{40}K were also found to be below permissible level of 370 Bq/l, 60 nGy/yr, 1 mSy/yr, 2.9×10^{-4} and 2.4 mSv/yr reported by United Nations on Scientific on the Effects of Atomic Radiation. The estimated radiation dose and health hazard indices indicate insignificant radiological risk, making irrigation water in the study area safe for domestic and agriculture purposes.

MONTE CARLO SIMULATION OF MEASUREMENTS OF ^{131}I IN AGE-DEPENDENT THYROID MODEL

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Keywords: Monte Carlo simulation, efficiency calibration, age-dependent thyroid, comparison

Within the response to nuclear emergency the in vivo measurements of ^{131}I activity in a thyroid are purpose. Necessary instruments need to be suitably calibrated in order to convert measured count rates to activity. For this appropriate anthropomorphic phantoms filled with a known activity of the radionuclide of interest are used for efficiency calibration. Nevertheless several factors influence the compliance of the calibration and actual counting efficiency, among them the individual anatomic parameters and counting geometry. In order to take into account the age-dependent anatomical differences, phantoms with different sizes and geometries should be used when measuring children to reduce uncertainties.

An international intercomparison of age-dependent thyroid phantoms used for calibration of in in-vivo monitoring laboratories was proposed within the Task Group on "Internal Dosimetry for Emergency" of Working Group 7 on Internal Dosimetry of the EURADOS (European radiation Dosimetry Group). The measurements of the phantoms were performed with Broad Energy Germanium Detector (BE Ge) detector the CIEMAT Whole Body Counter (WBC) in Madrid, Spain. The measurements were complemented with numerical simulations of a counting geometry. Technical information about thyroid phantoms measured was collected from all participant and Monte Carlo simulation has been performed to investigate variations in the detection efficiency with detector-thyroid distance and the age-dependent thyroid volume. Main outcomes of the simulations are presented in this paper, and results of the measurements and simulations are also compared.

GROSS ALPHA BETA METHOD AND DOSE ESTIMATION

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Keywords: radioactivity, drinking water, uranium, thorium, potassium, liquid-scintillation spectrometry, gross alpha beta, screening method, γ-ray spectrometry, radiochemistry, indicative dose, effective dose

Total Indicative Dose (TID) of drinking water is adopted by several organizations and regulatory bodies as a measure for risk assessment. This quantity is calculated using specific dose conversion factors, consumption rates and radionuclide specific activity concentration. Calculation of the dose estimate from the measurement results of the screening method for determination of gross activities of α and β-ray emitters (GAB) will be presented. The simplicity and speed of GAB compared to high-resolution γ-ray spectrometry and radiochemical analyzes are the main motivations for this study.

Different radionuclides have different spectrum shapes depending on the energy of the decay particles and the number of daughter radionuclides and this affects calibration of liquid scintillation counters. Counting efficiencies for different radionuclides of LSC counters were used for the determination of conversion factors, which allows comparison of the activity concentration results determined by specific analyzes with the activity equivalents obtained by the GAB method. The calculation was tested on water samples from 20 sampling points of drinking water supply systems, which were chosen over a wide area of Slovenia and measured by the GAB method and specific analyzes. The total specific activities of α and β-ray emitters were also calculated from the activity concentrations of individual radionuclides, which were reported for the same samples and obtained by high-resolution γ-ray spectrometry and radiochemical analyzes. The measurements turned out to match well with each other. TID-s were calculated from the results of specific analyzes and the dose estimate from GAB measurements.

Comparison of calculated doses and dose estimates shows that data on the total specific activities of α and β-ray emitters could be used to estimate the indicative dose of drinking water, using the dose factors for the total specific α or β-ray emitters which are also one of results of this study.

VISUALIZATION SOFTWARE FOR RADIOACTIVE CONTAMINATION BASED ON COMPTON CAMERA: COMRIS

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Keywords: software, radiation imaging, Compton camera, SLAM

Visualizing the location and distribution of radioactive substances is important to reduce the exposure dose of workers at the decommissioning site of the Fukushima Daiichi Nuclear Power Station (FDNPS) and to improve radiation protection functions at many sites where radioactive substances are handled. When radioactive substances are leaked and scattered, and are deposited on many structures and rubble, it is desirable to visualize the distribution of radioactive substances in 3D in order to understand their distribution in detail. However, although the gamma-ray imager is a promising device for visualizing the distribution of radioactive substances, that device alone can only identify their location and distribution in 2D.

Sato, one of the authors, proposed the concept of the integrated Radiation Imaging System (iRIS), which combines gamma-ray imagers with Simultaneous Localization and Mapping (SLAM) device or robots to measure radioactive substances from multiple viewpoints and visualize their location and distribution in 3D. As one of the demonstration examples, a system combining a Compton camera, a kind of gamma-ray imager, and a SLAM device based on 3D-LiDAR has successfully drawn a 3D map of the work environment visualizing the highly contaminated region at the bottom of the Unit 1/2 exhaust stack of the FDNPS (Sato and Terasaka, 2021).

In this study, we have developed GUI based software, COMRIS (COMpton camera for Radiation Imaging System), to draw a 3D map visualizing radioactive substances using gamma-ray detection data acquired by a Compton camera and information acquired by a SLAM device combined with the Compton camera as input data (V.I.C. Inc., and Sato, Y. 2022). The SLAM device acquires not only the 3D model data of the work environment, but also the self-position and posture information of the Compton camera each time. We will introduce the principle of the software and show the results of radiation-source visualization.

Sato, Y., and Terasaka, Y. 2021. Radiation imaging using an integrated Radiation Imaging System based on a compact Compton camera under unit 1/2 exhaust stack of Fukushima Daiichi Nuclear Power Station. J Nucl Sci Technol. in press. doi:10.1080/00223131.2021.2001391.
V.I.C. Inc., and Sato, Y. 2022. COMRIS: COMpton camera for Radiation Imaging System. V.I.C. Inc., web site. http://vic.co.jp/?page_id=15#COMRIS. [in Japanese]

T10: Regulation

AVOIDING MULTIPLE CONSERVATIVE ASSUMPTIONS: A CASE ON A LABORATORY RULE

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Keywords: ALARA, radionuclide laboratory, realistic assumptions

In the Netherlands the 35 year old rule for maximizing the amount of activity used in a radionuclide laboratory is now reconsidered.

This rule was formulated in 1985 using "multiple conservative assumptions". The past years, IRPA started a discussion on the subject of applying ALARA using "realistic assumptions".

This use of realistic assumptions is the topic of this contribution.

First the current 35 year old rule for maximizing the amount of activity, A_{max}, is explained; that is, the way A_{max} should be calculated using a formula that contains a parameter for the radiotoxicity, e(50), and for the three risk associated parameters p, q and r.

Then it is shown how this old rule was based on multiple conservative assumptions, aiming to result in a dose for which it was sure that is was lower than $1/10^{th}$ of the yearly limit.

After that, using realistic assumptions it is calculated that, using the old A_{max} formula, the actual yearly dose caused by inhalation for a worker in a radionuclide lab turns out not to be around the aimed 2 mSv but to be a factor thousand less.

This is felt as being too cautious.

Then the issue is discussed what level is not "too cautious". Following the line of thought as explained in the Seoul 2021 contribution 1), it turns out that a yearly dose of 25 μSv is acceptable, but only if used in combination with implementing not-to-costly ALARA measures below this dose.

Using this 25 μSv and using realistic assumptions, new values for the parameters in the formula for A_{max} can be calculated, to obtain an A_{max} that will result in a yearly dose that will be about 25 μSv.

The discussion on this alternative ALARA-approach, applied on this laboratory rule, is still ongoing in the Netherlands: the various items and opinions on this issue are presented and discussed.

Eijnde J. van den, Huikeshoven M. 2021. Using the alpha value to check overspending. IRPA 15 Congress Seoul.

DOSE RATE CALCULATIONS FOR A NEW RADIOACTIVE WASTE INTERIM STORAGE FACILITY AT PSI

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Keywords: waste, storage, dose rate

The Paul Scherrer Institute (PSI) operates the federal collection point for radioactive waste that is subject to mandatory delivery according to the Swiss Radiation Protection Ordinance (RPO). This radioactive waste stems from medicine, research, industry as well as from federal sources. PSI accepts this waste and takes care of its stacking, treatment and interim storage which currently takes place at the federal interim storage facility BZL.

Since the storage capacities of the BZL will be exhausted in the near future, PSI is planning a new storage facility "BZL II" next to the BZL. Its purpose will be the interim storage of predominantly concrete containers of type KC-T12 / 30 of low- and intermediate-level radioactive waste.

The Federal Nuclear Safety Inspectorate (ENSI) is the designated supervisory authority to verify whether the planned BZL II nuclear installation meets the legal and official requirements with regard to nuclear safety and security. To facilitate approval of a radiation protection concept, the dose rate in and around the planned BZL II during and after storage operations has been estimated from dose rate calculations in MicroShield 9.07. The calculations were based on the assumption of an optimized storage of the containers with regard to radiation protection. The computational approach and results as well as the impact on a container storage strategy are presented.

T11: Radiobiology

CANCER-RELATED CHANGES IN CELLS EXPOSED TO ALPHA RADIATION IN COMBINATION WITH NICOTINE

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Keywords: radon, cigarette smoke, lung cancer, alpha particle, nicotine

The carcinogenic effect of radon - the second largest cause of lung cancer - has encouraged the European Commission to fund the RadoNorm project. One of its aims is to reduce uncertainties in radiation risk management by assessing biological mechanisms underlying radon interaction with other stressors such as smoking. Smoking is the dominant cause of lung cancer; thus, an understanding of the interaction between smoking and radon in the development of lung cancer is required for making a risk estimate and establishing a reference level for indoor radon exposure to the general population. The present study aims to assess the underlying mechanisms of nicotine interaction with alpha particles. Bronchial epithelial BEAS2B cells were pretreated with 2 μM nicotine for 16 h and then given different doses of alpha particles ranging from 0, 0.5, 1 to 2 Gy. The interaction was assessed at different time points. During the first 24 h, γH2AX analysis was performed to analyze the direct effects on DNA damage response after single exposures or the combination, and differential response patterns were indicated. At the level of gamma-H2AX foci the result indicated the formation of large foci in alpha particle irradiated cells, confirming the formation of more complex damage, while nicotine-treated cells did not induce any prominent number of foci. The repair kinetic curve showed a biphasic response in response to alpha particles with peaks after 1 h and 6 h, whereas the combined exposure produced a delayed, flattened response, where more foci remained unrepaired after 24 hours. During a 10-day time period post exposure the cell viability kinetics showed a faster recovery in irradiated cells with nicotine pretreatment. This study is a newly started research project with some preliminary data and will further investigate combination treatments using clonogenic survival, gene expression analysis for radiation-induced DNA damage response genes, as well as the proinflammatory marker assays.

IONIZING RADIATION ALTERS MALE *(Acheta domesticus)* COURTSHIP SONGS THAT ARE CRITICAL FOR MATING SUCCESS

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Keywords: Acoustics, Behaviour, Cricket, Insect, Mating, Radiation, Stress

The impact of ionizing radiation on overall ecosystem health has become a topic of great interest in recent years due to both several nuclear disasters as well as the growing concern over the normal operating waste associated with nuclear power sites. Here, we aimed to analyze how radiation impacts essential characteristics of invertebrate sexual communication including acoustic signaling, and the subsequent impacts to mating success. Specifically, we looked at adult male crickets *(Acheta domesticus)* courtship songs, which are vital for this species' successful reproduction. We analyzed the spectral and temporal patterns of non-irradiated and irradiated male songs (0-27.8Gy at 4th instar) as well as several mating parameters to determine possible impacts of song variation on male mating success. Results indicate alterations of several song parameters in irradiated males, with most variation occurring in low frequency trills: peak and mean frequency, length of pulse, and average entropy were significantly altered in doses 16.2Gy and above. Mating success at these doses (16.2Gy, 23.2Gy, and 27.8Gy) was consequently significantly impacted, with other mating parameters being only significantly altered at the highest radiation doses. Declines in mating parameters were evident at lower doses but were not significant. Here we show that radiation exposure in early stages of development can result in detrimental impacts to vital components of male acoustic signaling which may be a key or contributing factor to the evident reduction in the ability for males to successful mate. These impacts are also vital in understanding the potential impact of radiation contamination sites where populations are being chronically exposed over many generations.

REACTIVE OXYGEN METABOLITES IN MURINE RADIATION-INDUCED ACUTE MYELOID LEUKEMIA

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Keywords: acute myeloid leukemia, extracellular vesicles, gene expression, oxidative stress, reactive oxygen metabolites

Oxidative stress can be defined as an imbalance between the production of reactive oxygen species and the ability of the cells to detoxify them. Higher level of oxidative stress has been described after exposure to ionizing radiation and in many diseases, including cancer. Both high-dose (radiation therapy) and low-dose (computed tomography scans) ionizing radiation have been shown to increase the risk of acute myeloid leukemia (AML), which is characterised by the rapid propagation of incompletely differentiated hematopoietic cells of the myeloid lineage. In this study we evaluated if the extent of oxidative damage in mice suffering from AML depends on the origin of the disease. Male CBA mice were irradiated with low- (0.1 Gy) or high-dose (3 Gy) X-rays at the age of 10-12 weeks or injected with extracellular vesicles (EVs) derived from the bone marrow of irradiated mice or they received both treatments. Blood samples and bone marrow cells were collected from mice when the symptoms of AML appeared. AML was diagnosed based on flow cytometric analysis of bone marrow cells and genetic analyses. Blood serum was analysed with the d-ROM test that measures circulating levels of reactive oxygen metabolites (ROMs; mainly hydroperoxides). Gene expression was analysed from bone marrow cells with real-time polymerase chain reaction (qPCR). There was a significantly higher serum ROM level and a modified expression of antioxidant enzyme genes in mice with AML when symptoms appeared. Leukemic mice that were irradiated or received both irradiation and EV-treatment showed higher level of oxidative damage than leukemic mice that were treated only with EVs. Our data indicate that AML resulted in an oxidative imbalance, which appeared to be more pronounced in mice that were directly exposed to ionizing radiation.

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PROINFLAMMATORY CYTOKINE OF HUMAN TNF-ALPHA IN THE BLOOD PLASMA OF MEDICAL WORKERS OCCUPATIONALLY EXPOSED TO RADIATION

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Keywords: biological effects, radiation exposure, radiation workers, tumor necrosis factor alpha

The biological effects of radiation exposure accumulate at the cellular, cytogenetic, and tissue levels. The body will naturally eliminate and repair the damage caused by radiation exposure, through the mechanism of secretion of various types of cytokines, one of which is Tumor Necrosis Factor Alpha (TNFα), which is a multifunctional cytokine mainly secreted by macrophages, lymphocytes, and natural killer cells (NK). TNFα is known to be released in response to high doses of radiation. This study was conducted to analyze the circulating levels of TNFα in the blood plasma of radiation-exposed workers. The method used to determine TNF- level was Enzyme-Linked Immunosorbent Assay (ELISA), by detecting the binding between TNFα antigen and antibody contained in 20 blood plasma samples of medical workers occupationally exposed to low-dose gamma radiation and 20 samples of controls (medical workers who do not receive gamma radiation exposure). The TNFα level in radiation-exposed workers is significantly lower than controls (3.85 vs 4.36 ng/mL, p value=0.023). The effects of radiation exposure are not the only factors that increase TNFα levels. The higher level of TNFα in the controls group are caused by other factors such as stress, age, gender, smoking habits, food intake, infections, and interaction with dangerous and toxic chemicals. The recovery process from illness or infection also can increase the TNFα level. This study may represent an important step in establishing a reliable set of biomarkers for assessing the health risks of population cohorts exposed to low doses of radiation.

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HARMONIZATION PROTOCOL ON THE QUALITY OF THE MICRONUCLEUS SAMPLES THAT ARE SCORED AUTOMATICALLY

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Keywords: automatization, micronucleus assay, biodosimetry, harmonization

In case of a radiation or nuclear emergency the workers and inhabitants may be affected by unintended and unknown radiation dose. In those situations where victims are not monitored by a physical personal dosimeter cytokinesis-blocked micronucleus assay (CBMN) is one of the well-established biodosimetry methods that is used for retrospective dose assessment.

Following the International Atomic Energy Agency protocol (IAEA, 2011) for the sample preparation of the CBMN samples, the appearance of the slides is similar enough to assure the reproducibility of the visually scored results. However, the definition of the stable sample quality demanded by a certain automated scoring system can significantly differ from the requirement of the traditional visual scoring. Generally, the first is stricter than the latter and strongly depends on the applied image processing method.

A sample quality harmonization protocol was designed whose key element is a quantitative index which reflects the suitability for automated scoring of a certain micronucleus (MN) sample. It was shown that the introduced index correlates with the difference between the automatically scored MN frequency and the reference MN frequency. A threshold was identified below which the sample can be accepted for fully automatic scoring. Above the threshold, it is advised to proceed with an additional cleaning step on the stored blood suspension. Alternatively, by using the sample quality index a correction on the estimated dose can be applied which results in the decrease of the error of the estimated dose.

The parameters of the introduced sample quality harmonization protocol were optimized to the dedicated automatized microscopic system manufactured by Radosys Ltd. (Hülber et al, 2020). However, it has a possibility to adapt the protocol to other automated scoring systems also that are developed for CBMN samples stained by non-fluorescent staining.

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NECTAR: A NEW HORIZON TO ADDRESS ALZHEIMER'S TREATMENT

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Keywords: Alzheimer's disease, neural cells, microglial cells, alpha particle, ionizing radiation

Approximately 50 million people globally suffer from Alzheimer's disease (AD) and no effective cure exists for this neurodegenerative disorder up to now. Neutron Enhanced Capture Treatment of Neurotoxic Amyloid AggRegates project (NECTAR) aims to develop, test and prove the feasibility, safety and effectiveness of a novel and revolutionary approach based on Capture-Enhanced Neutron Irradiation (CENI) for disintegration of amyloid-beta (Aβ) aggregates. We focus on the radiation safety aspects and assess effects of high linear energy transfer (LET) radiation (α-particles, α) and low LET radiation (X-ray, X) alone and in combination on human microglial cells. HMC3 cells were irradiated with different doses of α- (0.5-2.0 Gy), X-ray-radiation (0.5-2.0 Gy) alone as well as mixed beam radiation (0.5 α + 0.5 X; 1.0 α + 1.0 X; 1.5 α + 0.5 X; 0.5 α + 1.5 X Gy). We first characterized the formation of DNA double strand breaks in cells exposed to various irradiation modalities by quantifying γ-H2AX foci. We observed that the total number of foci is higher in the mixed beam irradiated cells as compared to cells that obtained similar doses of single mixed-beam components. Corresponding experiments exhibited a significant decrease in cell viability and survival of HMC3 cells after exposure to more than 1.0 Gy of α and X-ray alone or mixed beam. However, there was no significant difference between mixed beam irradiated cells in comparison with those irradiated with similar total doses of single mixed-beam components in terms of cell viability and survival. Gene expression of two cytokines, IL-6 and IL-1β, was measured by qRT-PCR 24 h after irradiation. We observed an increase in gene expression of both cytokines; however, no significant difference between mixed beam- and alpha-irradiation alone was observed. Further studies are on the way.

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BIOLOGICAL MARKERS OF IONIZING RADIATION

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Keywords: biological markers, ionizing radiations

Humans are exposed to ionizing radiation not only through background radiation but also through the ubiquitous presence of devices and sources that generate radiation. With the expanded use of radiation in day-to-day life, the chances of accidents or misuse only increase. Therefore, a thorough understanding of the dynamic effects of radiation exposure on biological entities is necessary. The biological effects of radiation exposure on human cells depend on much variability such as level of exposure, dose rate, and the physiological state of the cells. During potential scenarios of a large-scale radiological event which results in mass casualties, dose estimates are essential to assign medical attention according to individual needs. Many attempts have been made to identify biomarkers which can be used for high throughput biodosimetry screening.

Occupational or accidental radiological or nuclear exposure can cause serious health effects. The nuclear disasters of Chernobyl and Fukushima Daiichi incidences clearly illustrate a critical need for suitable biomarkers for personalized radiation dose assessment, which can be useful not only for appropriate medical/clinical management but also for predicting delayed stochastic (no threshold) effects such as genomic instability and cancer. We aimed to identify an algorithm for assessing the level of exposure to ionizing radiation of participants in reducing the consequences of the Chernobyl nuclear accident (PRCCNA) and their descendants by using biological markers.

Method: In terms of clinical, cytogenetic, immunological and genetic-molecular parameters, the health of PRCCNA and their offspring was assessed. Immune status based on monoclonal antibodies with the calculation of the immune index was analyzed. DNA was extracted to perform biological-molecular analyzes. A number of 201-second generation descendants of PRCCNA and 190 children from the control group served as research materials. The PRCCNA number varied depending on the type of study from 23 (cytogenetic study) to 800 (clinical study).

Results: According to the frequencies of the dicentrics ─ considered markers of ionizing radiation, the PRCCNA retrobiodosimetry was performed. Compromised immune status was established in PRCCNA children compared to the control group. Results confirm the data in the literature showing that ionizing irradiation of parents induces genome instability in children and is closely related to the risk of carcinogenesis.

Conclusions: Children whose parents have been exposed to ionizing radiation constitute the group of major genetic risk and require continuous surveillance. Biological markers facilitate the study of the mentioned group in the dynamics. The mechanisms of tumor predisposition and the mechanisms of genome instability in the offspring of parents irradiated with ionizing radiation are not yet clear. Probably the "target" of these effects may be the so-called minisatellite loci of DNA, which show greater variability than the loci of single genes.

ROLE OF INDIVIDUAL CHARACTERISTICS IN THYROID DOSE ESTIMATION

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Keywords: iodine, thyroid, biokinetic models, internal dose estimation

Iodine is a key component of the thyroid hormones, which regulate several essential processes in the human body. The iodine intake of the human thyroid gland can be tens of micrograms per day. In case of a nuclear reactor accident, iodine-131 is one of the most dominant contributor to internal dose of the public. Measurement of its activity in the human body and dose estimation based on the measured values has a particularly important role.

For adequate dose estimation the iodine metabolism is essential, biokinetic models are widely used for iodine dose estimation. However, these models usually do not consider individual and health factors sufficiently. Several factors influence the functionality of the thyroid and the daily uptake of iodine, such us age, diseases, lifestyle, and diet. Both iodine deficiency and iodine excess can cause changes to the morphology and function of the thyroid influencing also the iodine uptake of the body.

Biokinetic models previously published in the literature for thyroid dose estimation were summarized and compared, their advantages and disadvantages were analyzed, and a new mathematical model based on them was developed for the studies. The time dependent distribution of iodine in the body has been determined, factors influencing the thyroid function were collected. Key factors applied in biokinetic models were identified and their contribution in dose estimation were studied. Uncertainty arising from the variation in individual characteristics was studied, consequences of thyroid malfunctioning were also analyzed. Aim of the investigation is a more detailed model for thyroid dose estimation with taking into account the specific characteristics of the person in concern.

PERFORMANCES OF A BINARY BLOOD ASSAY FOR PREDICTING RADIOSENSITIVITY

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Keywords: radiosensitivity, pATM, biomarker, cancer

Purpose. Radiation therapy (RT) plays an essential role in the treatment of most cancers its side-effects are not rare, and can sometimes lead to the suspension of the treatment. Recent studies have stressed the discrimination power of pATM protein in predicting individual radiosensitivity and a unified model based on Radio-Induced ATM Nucleoshuttling (RIANS) has been proposed. From this model, one test developed first on skin samples has been shown to predict both individual radiosensitivity and severity of radiotherapy adverse events. In order to obtain a faster and less invasive assay, we developed a new assay, named RADIODTECT© based on the quantification of total pATM on blood lymphocytes to predict the risk of toxicity. **Methods.** A blind pilot retrospective study was performed on 255 blood lymphocytes of patients with different cancer types. Patients were divided into 2 groups, according to their observed side effects, classified according to the CTCAEV 4.0. 135 patients with acute side effects graded <2 were considered as radioresistant (RR) and 120 patients with acute side effects graded ≥2 were considered as radiosensitive (RS). The global quantity of pATM molecules was assessed by ELISA method on extracted patient lymphocytes. **Results.** Quantities of pATM molecules in each sample were found in agreement with the observed CTCAE grades. ROC analysis was performed on pATM elisa results combined to chemotherapy data($p < 0{,}001$). Statistical results showed the following mean values concerning the classification into RR or RS performances: sensitivity=0.88, specificity=0.64, PPV=75%, NPV=62% and AUC=0.73.

Conclusions: This study, based on a single blood sample, provides the basis of an easy to perform to be potentially proposed to every patient intending to be treated with RT.

DEVELOPEMENT OF MICROFLUIDIC CHIPS TO IMMOBILIZE *C.ELEGANS* FOR NERVOUS SYSTEM IRRADIATION WITH PROTON MICROBEAM

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Keywords: C.elegans, microfluidics, nervous system, proton, microbeam, mitochondria

Regardless of its source (space, environment, medical, nuclear accident), all forms of ionizing radiation, from massless photons (X rays and γ) to heavy charged particles (protons or carbon ions), can induce toxicity in the central nervous system. Despite the growth of the scientific and clinical literature production giving better understanding of how radiation causes brain injury, the precise mechanisms of neurotoxicity and neurodegeneration following ionizing radiation exposure remains poorly understood from a biological perspective, in particular regarding mitochondrial and DNA damage. Since targeted microbeam irradiation allows the effective knockdown of specific regions, thus helping to identify their roles in processes such as neurodegeneration, we decided to study the consequences of proton exposure, using the IRSN ion microbeam facility MIRCOM, at the molecular and tissue level in the nervous system of *C.elegans*. This new facility, introduced by IRSN in 2018, allows to target cellular or sub-cellular components and therefore the fraction of the cell targeted by the particles, the number of particles for each target, and their location can be known accurately. In order to immobilize *C.elegans* worms without anesthesia, we developed ultra-thin, ion-penetrable, PDMS microfluidic chips and glass chips, and identified suitable conditions to maintain *the worms* in the microfluidic channels of both devices. In the PDMS system, owing to the self-adsorption capacity of the PDMS, worms can be sealed in the channels by injecting suspension containing these worms at the inlets of the chips and aspirating the fluid at the bottom outlet. Thus, worms pass through the channels and can be trapped facing the microbeam. In the glass chips, a first chamber is used to inject the solution containing worms and a second chamber to inject a chemoattractant, allowing the adult worms to pass by capillarity into 15 channels separated by 2 mm. As the surface of both chips is covered with a thin 4 um cover film of polypropylene, worms can be easily collected by removing the cover film. Furthermore, the chips are able to retain water and thus allowing microscopic observation as well as microbeam irradiation for long periods under live conditions for *C. elegans*. In addition, the chips are thin, allowing ions such as proton of 4 MeV to pass through the polypropylene membrane containing the worms. As an example of the application of those chips, we targeted neurons and analyzed the mitochondrial activities of immobilized animals using OH441 transgene and mitochondrial dyes. As a conclusion, compared to actual techniques, those improved chips will become a powerful tool for prolonged immobilizing of *C. elegans* and microbeam irradiation without the use of anesthesia and will help to target specific neurological pathways and study the related mitochondrial dysfunction.

RADIOPROTECTIVE EFFECT OF GREEN BARLEY JUICE ON RAT TESTIS

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Keywords: double-strand breaks, biodosimetry, γ-H2AX, whole-body irradiation, antioxidant

DNA damage, either directly or indirectly through free radical release, accounts for most biological effects of ionizing radiation. Antioxidants have been shown to exhibit DNA damage protective activity. Natural SOD® is a green barley juice product with antioxidant properties produced by Cantacuzino National Medico-Military Institute for Research and Development.

Our aim is to estimate the radioprotective effect of Natural SOD® by assessing the DNA damage in Wistar rats' testes following the exposure to ionizing radiation, with and without administration of Natural SOD®.

Wistar rats (n=15) were equally divided into 3 groups: study, sham and control groups. Rats in the study group were administered orally 5 mL Natural SOD® for 14 days, while rats in the sham group received saline solution instead. Rats in both these groups were afterwards subjected to a single dose of 6 Gy X-ray whole-body irradiation. Control group did not receive any treatment and was not irradiated. Shortly after irradiation, all rats were sacrificed and testes were collected. Gamma-H2AX-based biodosimetry and histopathological assessment were performed.

Samples from all rats exposed to X-rays showed double-strand DNA breaks–marked by γ-H2AX foci–in all cells of the seminiferous epithelium, particularly in spermatocytes and spermatids. In non-irradiated rats, only physiologically apoptotic cells were identified. Rats given Natural SOD® had a lower number of γ-H2AX foci compared to rats in sham group. Using H&E staining we observed anisokarya in spermatocytes, spermatogonial and Sertoli cells, with rare atypical mitoses (stellate, ring chromatin) in rats from sham group. Rats given Natural SOD® exhibited anisokarya in spermatocytes and spermatogonial cells, without nuclear atypia.

Our results indicate a potential prophylactic radioprotective effect of Natural SOD® in rat testes. Further studies are needed to determine which compound or combination of compounds in Natural SOD® is responsible for the radioprotective effect.

T12: Industry & NPP

FEASIBILITY STUDY OF 3D GAMMA IMAGING FOR IMPROVING RADIOLOGICAL PROTECTION AT SIZEWELL B NUCLEAR POWER PLANT

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Keywords: source term visualization, ALARP

Nuclear Power Plants are continuously looking to optimize their radiological monitoring and visualization techniques. At Sizewell B Nuclear Power Plant, a trial was carried out to judge the feasibility of a radiation characterization system to provide accurate visual representation of source terms on an operational Pressurized Water Reactor. The technology has so far been deployed at Fukushima, on decommissioning sites, and operational Nuclear Power Plants in the US, with this being the first trial on an operational Nuclear Power Plant in the UK.

Data were collected through a series of scans taken inside a Residual Heat Removal (RHR) Heat Exchanger room in a Radiological Controlled Area at Sizewell B and used to generate a radiation heat map and 3D radiation model.

Preliminary results of the trial have shown promising visualizations with identification of major source terms.

The potential benefits of applying this technology to operational plants include:

- High quality, detailed collection of survey data;
- An intuitive visual guide to work area source terms for use in pre-jobs briefs;
- Reduced requirement for in-person radiological surveying by Health Physics Monitors leading to reduced worker dose;
- Optimization of shielding;
- Enhanced source term identification.

The benefits of this system could also be greatly enhanced if considered feasible for new build Nuclear Power Plants. The 3D models of high interest areas could be built during non-active commissioning which would further reduce operator dose.

If proved feasible, this survey type supports As Low As Reasonably Practicable (ALARP) working in areas of high general area doserate.

This poster will present a project overview and discuss the practical value of the technology to a Radiation Protection Program in the context of operational and new build Nuclear Power Plants.

COMPARATIVE ANALYSIS OF POWER SYSTEM OPEN PHASE CONDITIONS IN KOREA'S STANDARD NUCLEAR POWER PLANTS

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Keywords: Open Phase Condition(OPC), Station Blackout(SBO), Electrical Protection

Open Phase Condition(OPC) is a failure in which one (or two) of the three-phases of the power system is maintained open, and the OPC of the nuclear power plant(NPP) may cause station blackout(SBO) and pose a great risk to the integrity of the reactor core. Recently, OPCs have occurred in power systems at NPPs around the world, but many problems have been reported that failures are not detected by the current protection systems [1]. Accordingly, the NPPs in Korea, which have a power system similar to that of overseas NPPs, also need to review the risks to OPCs. In this paper, the occurrence of OPCs was simulated for Korea's standard NPPs using ETAP, and the current protective relays were analyzed and compared for each scenario. It is considered that this paper can be used as a technical background material necessary for improving the on/off-site power protection system of NPPs and establishing related detailed regulatory guidelines in the future.

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EDF'S EYE LENS DOSE STUDY: METHODOLOGY, RESULTS AND STRATEGY CHOSEN FOR INTERVENTIONS IN AN INDUSTRIAL ENVIRONMENT

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Keywords: eye lens dose, dosimetry, NPP, industry, radiation protection

Transposition of Euratom 2013/59 directive into French regulations and in particular the lowering of annual regulatory limit for eye lens dose from 150 mSv to 20 mSv has led EDF to carry out an impact study on its employees. This study complements the work of the "Eye Lens Dose French working group" in 2013. Its aim is to quantify the impact for the nuclear industry and retain a strategy for dosimetric monitoring of eye lens.

As passive equivalent extremity dosimetry, eye lens dosimetry is under responsibility of the employers. As operator of a nuclear electricity production facility, EDF must inform provider companies involved of eye lens risks specific to certain activities.

A first list of activities, called at risk of specific exposure of eye lens, had been identified and characterized during an inter-company "Eye lens WG" in 2013. As a reminder, this WG also aimed to harmonize monitoring practices with all provider companies. IRPA also worked on this topic and provide advice on implementation of eye dose monitoring [1].

In 2018 and 2019, our additional study targeted a sample of EDF employees made up of workers carrying out activities known to be dosing in controlled areas (monthly dose read on the passive whole-body gamma dosimeter greater than 100 µSv). A sample of five to fifteen people per Business Line, on several EDF sites (Dampierre, Flamanville and Gravelines NPP's) and at different levels were selected for this study. Eight professions have been targeted:

- Operations Department: Field operator
- Logistics/waste Department: Waste handlers.
- Mechanical Service: Plumber/Pipefitter and Boilermaker.
- Risk Prevention Department: Radiation protection technicians.
- Mutualized Outage Team: Controlled area technicians, Reactor building Coordinators.

Additional employees from other EDF units have also been introduced in the sample: Mutualized Outage Teams (EMAT - UTO) from 10 to 20 employees per service and teams from the Maintenance Logistics Unit (ULM - DTEAM) from 30 to 50 employees.

Results obtained were shared with the subcontracting companies also carrying out specific eye lens dose studies. The first observation shows that employees (figure 1), in an industrial environment as NPP are not concerned by a predominant exposure to eye lens (table 1).

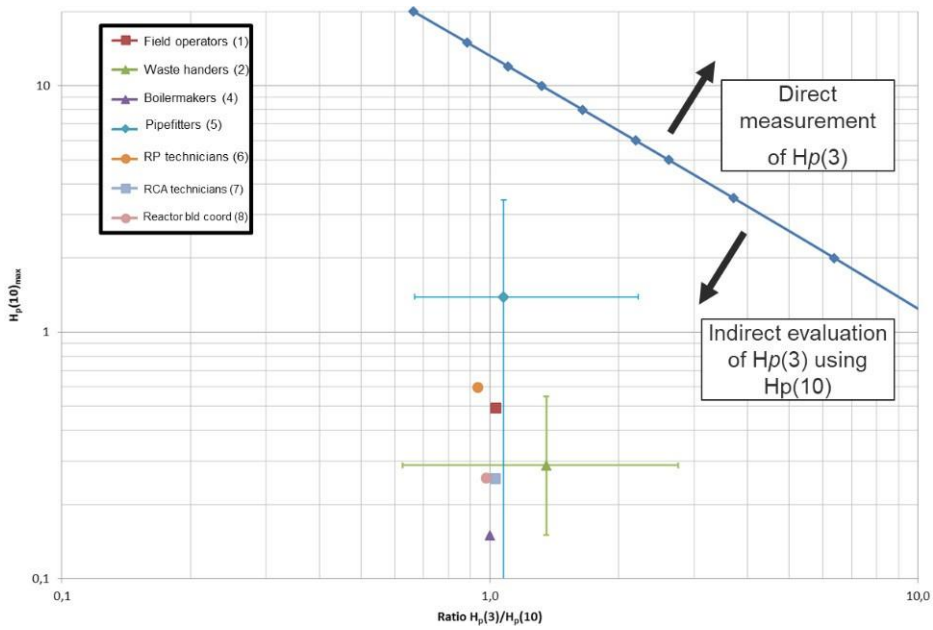

Figure 1: Choice of direct or indirect monitoring of Hp(3) depends on profession.

Professions	Field opérators	Waste handlers	Boilermakers	Plumbers Pipefitters	RP tech.	RCA tech.	Building reactor coordinators
Average Hp(3)/Hp(10) ratio	1,032	1,277	1,000	1,077	0,935	1,026	0,977
Average Hp(10)	0,493	0,293	0,150	1,392	0,600	0,256	0,257

Table 1: Results by profession (Ratio Hp(3)/Hp(10) and Hp(10) average per month)

Our study is based on 526 measurements of one month. For each wearing period whole body dosimetry Hp(10) and eye lens dosimetry Hp(3) were collected. The collected data and results are analyzed according to the LNE-LNHB study [2]. At the end, EDF also propose a schema to decide if employees need to monitor eye lens dosimetry of employees or not.

This methodology allows EDF to ensure that the risk of exposure to eye lens is properly taken into account. This solution will be proposed to WG19 during the revision of the ISO 15382 standard.

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GAMMA SPECTROMETRIC INVESTIGATION OF FISSION PRODUCT ACTIVITY RATIOS TO CALCULATE BURNUP, COOLING TIME AND POWER HISTORY OF SPENT NUCLEAR FUELS

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Keywords: gamma spectrometry, spent fuel, burnup, cooling time, power history

High-resolution gamma spectrometry measurements were carried out on over 100 pieces of VVER-440 type spent fuel assemblies at Paks NPP (Nguyen et al., 2013). The gamma energy spectra were evaluated, and fission product activity ratios were derived using internal efficiency calibration. The focus of this investigation was to analyze the relationship between the various measured activity ratios and some of the key spent fuel parameters, i.e., burnup, cooling time and power history. The results indicate that, in a general case, burnup can be most accurately determined by using the $^{134}Cs^2/(^{106}Ru/^{137}Cs)$ activity ratio, while cooling time can be predicted by either the $^{110m}Ag/^{134}Cs$ or the $^{134}Cs/^{154}Eu$ activity ratios (Kirchknopf et al., 2022). A correspondence between some activity ratios and the fuel power history has been discovered, which enables experimental categorization of the assemblies. These findings agree well with a later measured VVER-440 spent fuel dataset. These results have also been tested by comparison with the data available in the SFCOMPO 2.0 database of other types of assemblies. The work presented here could be applied in Safeguards verification and Nuclear Forensics investigation.

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T14: Other radiation protection

COMPARISON OF THE SECONDARY CANCER RISK INDUCED BY PROSTATE EXTERNAL BEAM RADIOTHERAPY FOR PARTIALLY IN-BEAM ORGANS BETWEEN TWO DIFFERENT REGIMES IN DIFFERENT PATIENT AGE GROUPS

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Keywords: secondary cancer, prostate cancer, VMAT, radiotherapy, radiation-induced cancer

Radiotherapy is a main form of treatment for prostate cancer, which is the most common cancer in males in the UK, while it has a high survival rate. Since the association of malignancy appearance and exposure to ionising radiation is a well-established one, there are concerns regarding the development of secondary radiation-induced cancers to long-term survivors, and especially to bladder and rectum, which are partially inside the primary beam during treatment. (Suit et al., 2007) This work aims to compare the risk of secondary cancer development due to radiation exposure in bladder and rectum, between two different prostate regimes currently in use: conventional and stereotactic ablative body radiotherapy (SABR), to 96 patients, divided in three different age groups.

Anonymised data from past patients treated with one of the two regimes, derived from their personal treatment plan will be used. The risk values for each age group and the whole range of patients, for each regime, will be calculated using alternatives to the linear-no-threshold (LNT) model, developed for high and inhomogeneous doses (Schneider et al., 2011) which, also, take into account sterilisation, repopulation and fractionation effects. The mean estimated risk values will be compared between the two regimes, using independent samples t-test, for all patients and patient groups.

Results of this work will be presented including the estimation of the overall secondary cancer risk for bladder and rectum for each regime and the comparison between them. Additionally, a comparison will be made between the estimated risks and the baseline probability of cancer induction for each patient age group. This work will offer an additional factor to be considered when assigning a patient to the appropriate prostate treatment regime and will become a stepping stone for future research into radiation treatments to other cancer sites or patient groups, where there is a high number of long-term survivors.

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ASSESSMENT OF PEDIATRIC RADIATION DOSE AND CANCER RISK FROM PEDIATRIC ENHANCED CT ABDOMEN EXAMINATION

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Keywords: pediatric imaging, cancer risk, computed tomography, diagnostic radiology, radiation dosimetry

Because of their rapidly dividing tissues, children and pediatricians are more radiosensitive to ionizing radiation and radiogenic hazards than adults. Because younger patients have a longer life expectancy, they are more prone than adults to develop radiogenic cancer. Furthermore, during treatment, children frequently repeated diagnostic procedures, resulting in increased radiation doses. This study investigates pediatric exposure to computed tomography (CT) abdomen and calculates the procedure's radiogenic risk. A total of 87 patients were subjected to a CT-enhanced abdominal examination. The age (years) of the patients' mean, standard deviation, and range are all 134.5. (2-17). The mean and range of the DLP(mGy. cm) and CTDIvol (mGy) per CT abdominal operation were 1740 (157.8-8440.3) (mGy.cm) and 9.8 (2.09-45.77) (mGy), respectively. The effective dosage per procedure has a mean and a range of 34. (3.14-176.8). One cancer incidence per 250 CT enhanced abdominal operations is the average radiogenic risk per procedure. The average and range of total irradiation per operation are 4 (2-8) times. In comparison to previous CT scans, the results of this study revealed that the child risk is high. To avoid unwanted radiation dangers, patients' dose optimization and accurate creation of a diagnostic reference level (DRL) are required.

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OCCUPATIONAL RISK IN TERMS OF MORTALITY

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Keywords: occupational risk, mortality, dose limit, workers

Occupational accident mortality is often taken into account in determining dose limit for workers. In ICRP Publication 60, ICRP compared the risk of the radiation with that of the occupations with high standards of safety; these standards do not exceed 10^{-4} as the average annual mortality rate. This risk level is consistent with the risk after continuous exposure at 20 mSv per year from age 18 to 65 years, which is referred for establishing the dose limit for workers. Occupational mortality is expected to have changed since Publication 60, but has not been assessed in detail recently. In this study, occupational mortality rates in all industries and manufacturing in Japan were analyzed and compared with those in other countries. The mortality rates for all industries and manufacturing calculated from insurance records in Japan were 3.1 and 4.8 times higher than those from labor standards inspection records, respectively. The occupational mortality rates in five countries (France, Germany, Netherlands, UK and USA) were also calculated by referring to ILOSTAT and EUROSTAT. The mortality rate before 2000 was higher for all industries than for manufacturing in each country; however, the mortality rates for all industries and manufacturing were lately equal except in the USA. The average mortality rates were 1.9×10^{-5} and 1.7×10^{-5} for all industries and manufacturing, respectively. The highest mortality rates among six countries as of 2015 were 4.8×10^{-5} and 2.9×10^{-5} for all industries and manufacturing, respectively, which were recorded in the USA. On the other hand, the lowest mortality rates were 0.5×10^{-5} for all industries in the Netherlands and 0.9×10^{-5} for manufacturing in the UK. These values were 9.7 and 3.2 times lower for all industries and manufacturing, respectively. When the mortality rate is referred for determining the dose limit for workers, it is important to take into account not only the time but also the difference in the mortality rate in each country.

GA3C FOR ANOMALOUS RADIATION SOURCE DETECTION

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Keywords: deep reinforcement learning, source searching

In order to reduce the risk of radiation damage that personnel may suffer during operations in the radiation environment, the use of automated guided vehicles to assist or replace on-site personnel in the radiation environment has become a key technology and has become an important trend.

In this paper, we demonstrate our proof of concept for autonomous self-learning radiation source searcher in an unknown environment without a map. The research uses GPU version of Asynchronous Advantage Actor-Critic network (GA3C) of deep reinforcement learning to search for radiation sources. The searcher network, based on GA3C architecture, has self-directed learned and improved how search the anomalous radiation source by training 1 million episodes under three simulation environments. In each episode of training, the radiation source position, the radiation source intensity, starting position, are all set randomly in one simulation environment. The input for searcher network is the fused data from a 2D laser scanner and a RGB-D camera as well as the value of the radiation detector. The output actions are the linear and angular velocities.

The searcher network is trained in a simulation environment to accelerate the learning process. The well-performance searcher network is deployed to the real unmanned vehicle, Dashgo E2, which mounts LIDAR of YDLIDAR G4, RGB-D camera of Intel D455, and radiation detector made by Institute of Nuclear Energy Research. In the field experiment, the unmanned vehicle is enable to search out the radiation source of the 18.5MBq Na-22 by itself and avoid obstacles simultaneously without human interference.

RESPIRATORY PROTECTION STRATEGIES FOR THE PUBLIC IN EMERGENCY RESPONSE

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Keywords: radioactive aerosol, respiratory protection, evacuation, nuclear accident

In the nuclear power plant (NPP) accident, it is necessary to take protective measures to minimize the effects of internal exposure to the respiratory tract by inhaling radioactive aerosols emitted into the environment. After the Fukushima nuclear accident, the public who lived in the evacuation area and beyond area were forced to evacuate and relocate. At the same time, no respiratory protection measures (RPM) were taken for evacuees (Ohba, T et al., 2021). RPMs for all evacuees are not suitable for the optimization of protection recommended by the ICRP. It is necessary to select RPMs considering the distance from the origin of the accident, the elapsed time, the wind direction, and the characteristics of the radioactive aerosol. In the early stage of the accident, it is necessary to take RPMs for the evacuees in the precautionary action zone affected by short-term atmospheric dispersion. As time passed, RPMs should be taken for the evacuees in the zone affected by intermediate-term atmospheric dispersion in consideration of the relatively small aerosol diameter due to the removal mechanism such as dry and wet deposition.

Miyamoto, Y et al., 2014 measured the radioactive aerosol diameters at Tokai, Japan. Their results show that Cs-134, Cs-137, and I-131 radioactive aerosols measured from March 17 to April 1, had particle diameter peaks of 1.5, 6 μm for cesium isotopes and 0.45 μm for I-131. From May 9 to 13, 2011, Cs-134 and Cs-137 had particle diameter peaks of <0.5, 0.8-0.9 μm, and the short-lived nuclide I-131 did not measured. The filtering facepiece respirators (FFR) can be considered an RPM to prevent radioactive aerosols. In emergency response phase, an FFR with filtering efficiency for 0.45 μm particle diameter should be assured to prevent radioactive aerosol inhalation. In evacuating the evacuees with the respirator, external exposure due to radioactive aerosol deposited on the mask should also be considered to minimize the stochastic effect. The replacement cycle should be set to optimize protection measures when the averted internal dose by the RPMs and the projected external dose due to the radioactive aerosols deposited on the filter becomes the same. In addition, evaluate the filtration efficiency of the respirator for <0.5 μm diameter particles considering environment factors, and derive the optimal RPMs in the NPPs accident.

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DEVELOPMENT OF AN AUTOMATIC CALCULATION SYSTEM OF PUBLIC EXPOSURE TO RF IN HUNGARY

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Keywords: RF exposure assessment, public safety, radio stations, modelling, 5G

There are several international examples of electric field strength calculation systems for regulatory supervision purposes. In most cases, these calculations are to support licensing individual radio stations. Thus, they do not take into account environmental exposure from all existing sources.

Therefore, the exposure calculation application developed by National Media and Infocommunications Authority Hungary (NMIAH) takes into account all major environmental radiation sources and generates the calculations automatically.

However the accuracy of the above mass calculation results is not comparable to an individually generated calculation based on user-controlled input data provided by the operator. Therefore, when the preliminary version of the system is launched, it can only be used as an indicator for the proper selection of most sensitive measurement sites.

The aim is to continuously reduce the uncertainty of the calculation modeling based on accurate input data and comparative measurement results.

The computer model will make the system suitable to determine and to calculate safety zones in the ambiance of radio stations. However, increasing calculation accuracy may require a significant financial investment, so several aspects need to be considered.

Although the process of mass computations will start in 2022, the experience gained in the development steps can be utilized for other similar applications. During development and implementing the software the wave propagation model for urban environments was determined in the first phase. The next task was to define a suitable database of maps and usage of radio station data. Practical solution had to be found for several conceptual issues based on available literature and precautionary principle. For example, solutions need to be found to determine the instantaneous emitted power and variable antenna characteristics of 5G mobile base stations due to the beamforming and MIMO operation.

RECENT PROGRESS OF CDZNTE BASED ROOM TEMPERATURE DETECTORS IN INDUSTRIAL APPLICATIONS

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Keywords: CZT, CdZnTe crystal growth, Energy resolution, Tokamak, Barreled Radioactive Waste Analysis, Source Term Analysis

CdZnTe (CZT) has been regarded as the most promising room temperature semiconductor radiation detector. The essay focus on the application of CZT detectors now in the world. We developed and evaluated different kinds of CZT detectors for different applications to different environment. These developments and evaluations are about optimizing the electric geometries for radiation dose test, radiation spectrum analysis, nuclides identification, X-ray photon counting imaging and γ-ray imaging. The performance of the CZT detector is explain on the paper to give a whole picture of the application of room temperature semiconductor.

PAPER PUBLICATION

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All selected and reviewed papers are available here:

https://academic.oup.com/rpd/issue/199/8-9

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One paper is published in this proceeding.

Chia-Yi Liu	GA3C FOR ANOMALOUS RADIATION SOURCE DETECTION

SUBJECT INDEX

GA3C FOR ANOMALOUS RADIATION SOURCE DETECTION

Chia-Yi Liu, Bo-Bin Xiao, Wen-Bin Lin, Hsiang-Ning Wu, Liang-Hsun Huang

In this study, we demonstrate our proof of concept for autonomous self-learning radiation source searcher in an unknown environment without a map. The research uses a GPU version of Asynchronous Advantage Actor-Critic network (GA3C) of deep reinforcement learning to search for radiation sources. The network of GA3C architecture has self-directed learning and improved how search the anomalous radiation source by training 1 million episodes under three simulation environments. The radiation source position, the radiation source intensity, AI agent starting position, are all set randomly in each episode of training. The input data for the network are the laser scanner and the value of the radiation detector. The output actions are the linear and angular velocities. The generalization ability of the best-performance AI model in the training phase is rather great, and it can find out the radiation source as well as avoid obstacles in the brand new environment autonomously.

INTRODUCTION

Considering the danger and particularity of the radiation field, when personnel are working in the environment with radiation, they will be protected by the predefined relevant administrative systems and technological support for radiation protection to guard radiation safety. In order to reduce the risk of radiation damage that personnel may suffer during operations in the radiation environment, the use of automated guided vehicles to assist or replace on-site personnel in the radiation environment has become a key technology and has become an important trend. The technology of automated guided vehicles has become applicable in real, and various applications have been developed in various domains, for example, manufacturing, service industries, and medical institutions. However, in the field of radiation protection, the application of automated guided vehicles to the detection of radiation sources and radiation characteristics investigation is greatly potential but still in development.

When searching for anomalous radiation sources traditionally, radiation detection equipment must be used to measure the radiation intensity of the field, and apply the measurement results to gradually narrow the suspicious area and find out the radiation source. When searching for radiation sources, radiation detection personnel hold radiation detectors to search for radiation sources, but many variables in the search process may cause radiation detection personnel to work under the risk of radiation damage. Therefore, the other measure of radiation source detection is to use a machine by the anomalous radiation source searching algorithm.

The purpose of anomalous radiation source searching algorithms is to estimate the intensity and position of anomalous radiation sources. There are several methods to achieve the goal of anomalous radiation source searching algorithms, such as the uniform searching algorithms [1] which is a predefined path to scan the area of interest, or the maximum likelihood estimation-based methods (MLE methods) [2] which localize a radiation source from the gamma-ray total counts. Additionally, Takuya Kishimoto et al. [3] propose a method for the localization of radiation sources using a mobile robot equipped with an all-around view Compton camera. The method can automatically generate a path planning by performing principal component analysis according to the previous measurement data and accurately localize radiation sources.

However, each of the methods has some different shortcomings when applied to radiation source detection. For instance, it spends too much time on the meaningless path to be high-efficiency, or the radiation detection path cannot be adjusted in real-time according to the measurement result during the searching process. Especially, it is discovered that every algorithm or robot in the above-mentioned study is only applied in the environment without any obstructions.

In March of 2016, DeepMind's AlphaGo, a computer Go-playing program trained by deep reinforcement learning (DRL), defeated the human world champion Go player. People realized that machines are able to make strategies through DRL, and the performance of the strategy may be able to overcome Humans. Reinforcement learning (RL) is used to solve the problem in which the AI agent is in the process of interaction with the environment by learning strategies to maximize returns or achieve specific goals. AI agents can learn the best strategies in a complex environment without human knowledge by properly defining the problem. Hartmut Surmann et al. [4] utilize the GA3C algorithm of RL to enable the robot to avoid obstacles on its path automatically. The Asynchronous Advantage Actor-Critic (A3C) [5] algorithm is one of RL's state-of-the-art algorithms. A3C can be beneficial in experiments that involve some global network optimization with different environments in parallel for generalization purposes. GA3C [6] is a hybrid CPU/GPU version of the A3C algorithm. Due to using GPU, The training speed of GA3C is greatly increasing than A3C.

Therefore, we adopted the GA3C algorithm in the study to achieve the following two targets. First, the agent of a mobile robot enables to search radiation sources automatically through deep reinforcement learning which tests millions of input/output combinations. Also, the agent of a mobile robot not only searches radiation sources automatically but also bypasses obstacles on the path of searching radiation sources simultaneously.

THE SIMULATION

In the training phase, we need to create several simulations in which robot agents can be trained to learn. Figure 1 is three different simulated environments from small-and-simple to large-and-complex. The robot agents are trained on these simulated environments simultaneously in the training phase.

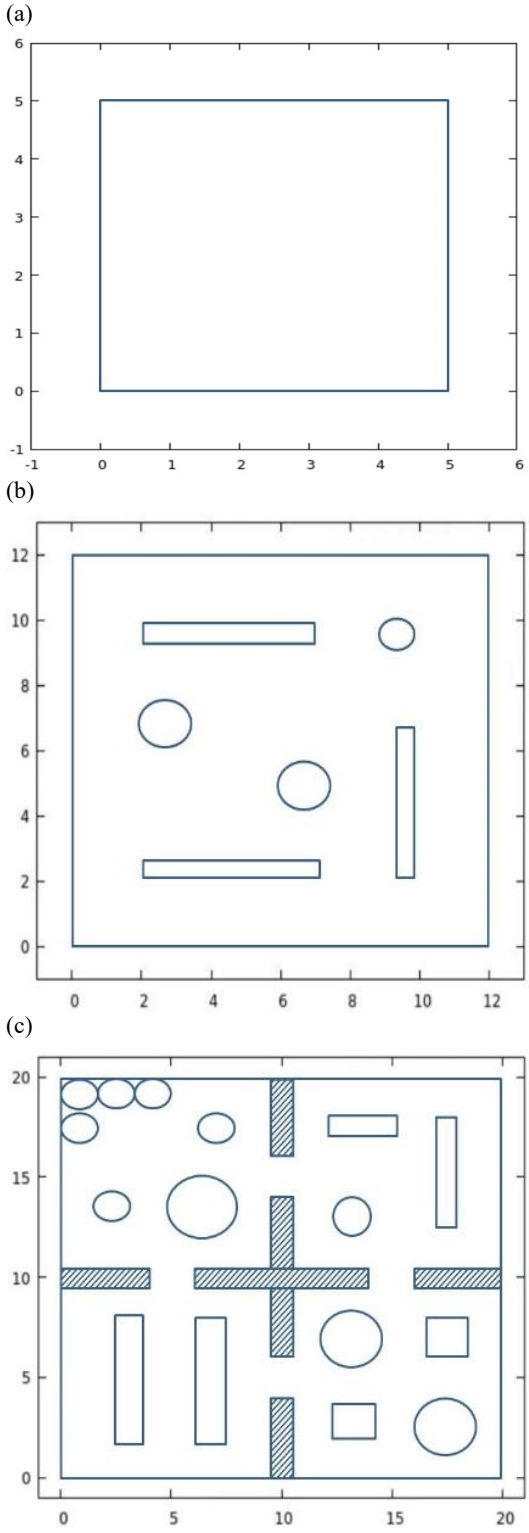


Figure 1. There are three simulated environments from small- and simple to large-and-complex. (a) The simulation is a 5m*5m room without any obstacles. (b) The simulation is a 12m*12m room with 3 rectangular and 3 circular obstacles. (c) The simulation is a 20m*20m spacious space where was divided into four rooms with diverse obstacles. The wall between four rooms is built with lead (the slashed part).

Because the purposes of searching radiation sources and bypassing obstacles need to be achieved, we assume that the robot agent was equipped with a radiation detector and a laser scanner for the simulations. The input data of the robot agents trained in the simulated environments were divided into two-part which the radiation detector part is from the simulated radiation source and the laser scanner part is from the simulated laser, as shown in Figure 2.

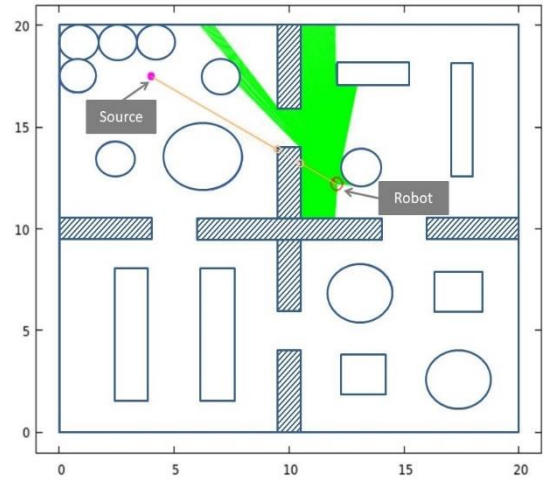


Figure 2. The input data training the robot agents (the hollow circle) come from the simulated radiation source (the red circle) and the simulated laser (the green area).

Regarding the laser scanner part, because the LIDAR is 2D scanner, it can only see the 2D plane if the mobile robot is deployed the LIDAR. For improving the avoiding obstacle ability, the mobile robot not only deploy the LIDAR of 2D scanner, but also the RGB-D camera of 3D scanner, which is for the obstacles outside of the 2D plane. However, as the simulated environments is 2D plane, the fused issue of 2D and 3D is not considered in the simulation. The laser scanner deployed in the robot agent is simulated to have 1088 number of laser beam from 135 degree to -135 degree, and the scan range of laser beam is 0.1-16 m.

The input data of the radiation detector part was calculated with the inverse square law from the simulated radiation source. According to the inverse-square law for electromagnetic radiation, the radiation

intensity is inversely proportional to the square of the distance. In addition, the attenuation of gamma radiation was considered in the most complex simulated environment. Therefore, the radiation intensity in the spot of the robot agent can be then described by the following equation.

$$I_{robot} = b + \frac{I_{source}}{4\pi D^2} * e^{-(\mu x)} \quad (1)$$

Here I_{robot} is the radiation intensity of the agent's current spot. I_{robot} is contributed by two sources: the background radiation intensity b and the simulated radiation source intensity I_{source}.

The D of the equation is the distance between the agent and the radiation source. μ is the linear attenuation coefficient and χ is the material length through gamma-ray, which is the lead wall length between the agent and the radiation source of the simulated four-room environment.

As the radiation detector is deployed to measure the radiation, uncertainty needs to be considered. Uncertainty is the difference between the true average rate of decay and the measured rate. Nuclear transformations are random, independent, and occur at a constant rate. The Poisson distribution is a special case of the binomial distribution in which the probability of an event is small and the sample is large. The Poisson distribution also fits radioactivity very well, since the probability of any one atom transforming is small, and a sample usually consists of a large number of atoms.

The Poisson distribution is crucial for counting radioactive samples. In the simulation, we assume that I_{robot} is the mean of a Poisson distribution, and the square root of I_{robot} is the standard deviation.

THE NETWORK

Mnih et al. [5] proposed an Asynchronous Advantage Actor-Critic algorithm (A3C) based on the AC learning-based method to update the reinforcement learning model. A3C utilizes several agents which let the learning process in multiple environments without interfering with each other. That means A3C has multiple agents for training and learning, during the training phase, in multiple threads, and creates a shared public network. It's worth noting that the agents independently interact with and obtain empirical data in each thread from the agents and environments, and operate independently of each other.

In each thread, when the agents have interacted with the environment to obtain an amount of empirical data, the gradients of the neural network loss function will be calculated in their own threads. The public neural network will be driven and instructed by the information of the loss function to update the weight value inside the neural network. A3C has been implemented in many of the Atari 2600's series gaming test and performs excellent than other traditional deep reinforcement learning models, especially in continuous motion control problems.

NVIDIA introduced the next generation of the GA3C, which makes use of the hybrid CPU/GPU. According to the Babaeizadeh et al [6], due to the generated delay by copying data from the CPU to the GPU and back, GA3C makes smaller networks about 6x faster. However, for larger networks, GA3C generates the same results about 45x faster. The GPU-based parallel learning of A3C is shown in Figure3, which is the multi-thread for actor-critic of Q-learning based algorithm.

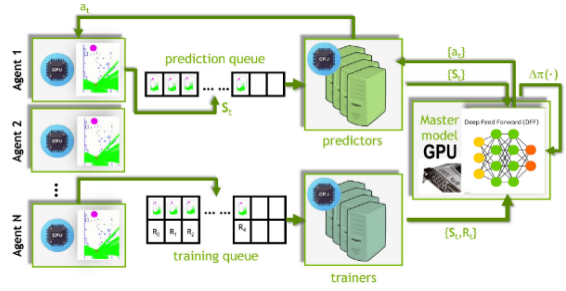


Figure 3. GPU based parallel learning of A3C

Figure 4 shows the architecture of the Deep Neural Network (DNN). The inputs of the network are the last four frames of the laser scan with 1088 laser beam values and the radiation dose value obtained from equation (1). The next two layers of the network are 1D convolutions, 1x9x16 and 1x5x32, and the strides are four and two. The policy layer and the value layer are the actor and the critic, using the dense layer to calculate the policy value and Q-value. The policy value is one-hot encoded and a discrete value as an action. The action in this study is a pair of two values, which consist of angular and linear velocity.

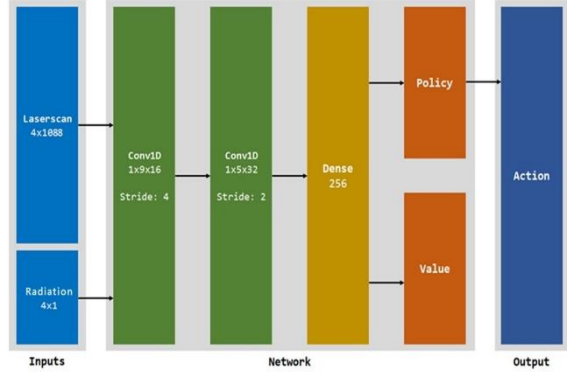


Figure 4. The DNN architecture

TRAINING AND EVALUATION

In an episode, the simulated environment was randomly initialized, and the positions of the radiation source and the agent's position were defined. The intensity of the radiation source was set between 20000-25000cps randomly, and the background radiation intensity was 10cps. When the radiation source was found by the agent, the new radiation source would be reset. This episode would terminate if the agent collided with the obstacle, or the total number of steps is larger than a 300 step limit. The GA3C algorithm was trained for 1 million episodes.

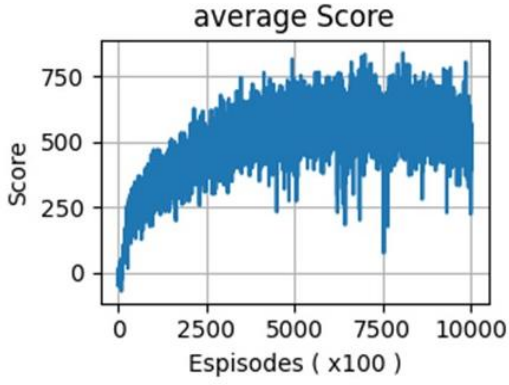
The reward in each step was defined as follows:

$$R_t = \begin{cases} 50, & when\ the\ agent\ finds\ the\ source \\ 6, & if\ the\ agent\ moves\ closer\ to\ the\ source \\ -6, & if\ the\ agent\ moves\ far\ away\ from\ the\ source \\ -50, & when\ the\ agent\ collides\ with\ the\ obstacle \end{cases} \quad (2)$$

The reward of each step of an episode accumulated to a total reward, as called score. Figure 5 illustrates the score between 1 million training episodes. The average score of each 100 episodes is as shown in Figure 5(a), which the average score gradually raises from the start of training to around 0.5 million episodes and then fluctuates from that to the end.

Figure 5(b) represents the average number of steps, which is the average steps of each 100 episodes. Besides the beginning self-spin episodes of Figure 5(b), the graph situation is similar to Figure 5(a), which is from rise to steady. Figure 5 shows out the AI agent is improved continually during the training period. Finally, we picked out the AI model of 828,000 episodes as the ultimate AI model, which is the best-performance AI model, to process the subsequent testing phase.

(a)



(b)

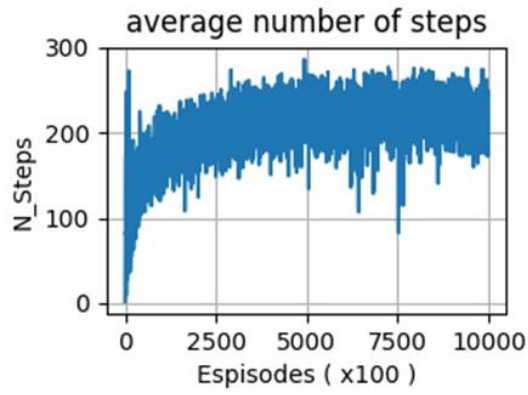
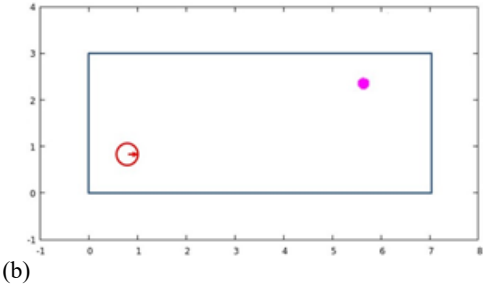


Figure 5. The score conditions of the 1 million training episodes. (a) It represents the average score of every 100 episodes. (b) The graph shows the average step numbers.

After the ultimate AI model was determined, it would be tested in two new simulations that the AI model never had seen during the training phase to understand the generalization ability of the ultimate AI agent. Figure 6 is the two new testing simulations one is a 3m*7m room without obstacles and another is a 5m*5m room with 3 different rectangle obstacles.

(a)



(b)

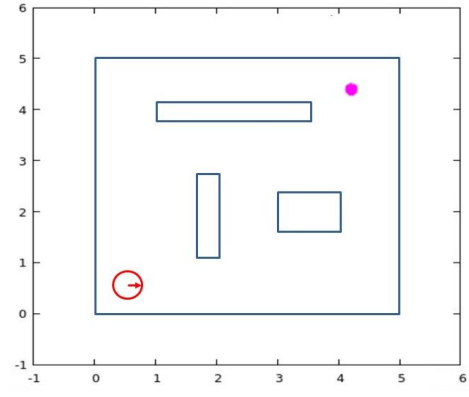


Figure 6. There are two testing simulated environments that test the ultimate AI model. The hollow and red circles represent the ultimate AI agent and the radiation source, separately. (a) The environment is a 3m*7m room without any obstacles. (b) The environment is a 5m*5m room with 3 various rectangular obstacles.

We tested the ultimate AI agent 20 times in each testing environment. The positions of the radiation source and the ultimate AI agent were set at the fixed locations as the Figure 6 during the testing phase. The radiation source's intensity was set at 6 different cps in testing phase which are 10000cps, 15000cps, 20000cps, 25000cps, 30000cps, and 35000cps. As the radiation source's intensity was set between 20000-25000cps during the training phase, it would be tested the generalization ability of the ultimate AI agent when the intensity in the testing phase is larger than it in the training phase.

The testing results of the ultimate AI agent are summarized as shown in Figure 7 and Figure 8. In the box plot, the upper line and lower line mean the maximum and minimum respectively, the upper and lower boundary correspond to 75th and 25th percentile, and the line in the middle of the box is the median.

Figure 7 is the box plot of the path length, which the ultimate AI agent was tested 20 times in a 3m*7m room without any obstacles, which is Figure6 (a). The linear distance between the ultimate AI agent and radiation source is 5.06 m. It can be seen that the stronger the radiation source's intensity is, the longer path the ultimate AI agent searches for. Besides that, the distribution range of the searching path length is more along the radiation source intensity increasing. It is observed that the ultimate AI agent almost goes to the radiation source in the straight direction when the source intensity is smaller than 20000 cps. While the radiation source intensity is stronger than 25000 cps, the ultimate AI agent is closer to the radiation source, and it applies even more a circular path rather not a straight path. It could be that the radiation source intensity is never stronger than 25000 cps in the training phase, so the ultimate AI agent applies the roundabout way when the intensity is strong.

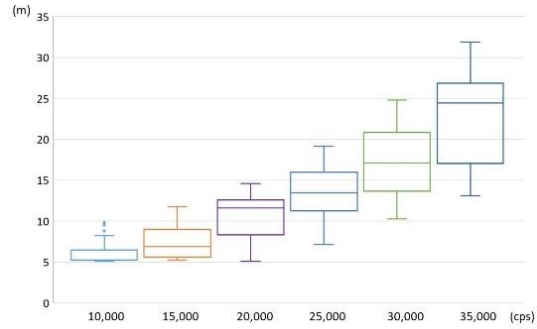
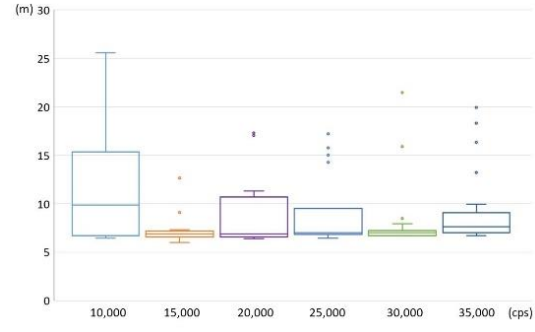


Figure 7. It is the box plot of the path length when the ultimate AI agent is tested in the Figure 6(a) environment with the intensity of the radiation source set from 10000 to 35000 cps.

Figure 8 demonstrates that the box plot of the path length was simulated 20 times in a 5m*5m room including 3 different obstacles. The linear distance between the ultimate AI agent and the radiation source of Figure 6(b) is 5.52m. However, the process path definitely is way longer than 5.52m due to three obstacles existing. The 0th-50th percentile almost is between 6 and 7.6 m except the box plot of 10000 cps. It means that the ultimate AI agent often goes the shortest path to find the radiation source. However, Figure 8 does not present the trend of Figure 7 which it passes longer path with the stronger radiation source intensity. It probably relates the obstacles existing. As the input data of DNN network are 1088 laserscan data and 1 radiation data, the obstacles existing can provide more information to 1088 laserscan data. Otherwise, it gets information only from 1 radiation data.

Figure 8. The box plot of the path length describes that the



ultimate AI agent is tested in the Figure 6(b) environment 20 times at 10000, 15000, 20000, 25000, 30000 and 35000 cps separately.

CONCLUSION

In this study, we definitely demonstrated that GA3C can be applied to the task of radiation source searching and avoiding obstacles simultaneously. Although, due to the input features of the network, the performance of the environment without obstacles is worse than it with obstacles as the intensity of the radiation source increases. However, it is rarely a large area without obstacles in the real world. Otherwise, it is common that the obstacles appear in the path of the mobile robot. Although it has some gap between simulation and reality, the ultimate AI agent is quite meaningful about radiation source detection.

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