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INTERNATIONAL CONFERENCE ON RADIATION APPLICATIONS
IN PHYSICS, CHEMISTRY, BIOLOGY, MEDICAL SCIENCES, ENGINEERING AND ENVIRONMENTAL SCIENCES

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# BOOK OF ABSTRACTS

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INTERNATIONAL CONFERENCE ON RADIATION APPLICATIONS (RAP 2025)
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### INVITED TALKS



### CONFERENCE ABSTRACTS

# Chemical lithography and nanofabrication with monomolecular templates and electron irradiation as the primary tool

**Michael Zharnikov**

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Monomolecular resists and templates provided by self-assembled monolayers (SAMs) represent a versatile platform for electron beam lithography and nanofabrication. Depending on the molecular architecture, these films can serve both as positive and negative resists within the framework of conventional lithography, but also be used as a primary matrix for Chemical Lithography. The latter approach exploits either selective modification of specific tail groups at the SAM-ambient interface (in the case of the aromatic backbone) or irradiation-promoted exchange reaction between the primary SAM and potential molecular substituents (in the case of the aliphatic backbone). An alternative technique is Electron Beam Activation Lithography, which involves activating amino tail groups of the primary SAM template disabled by specific quencher moieties. This method is useful for the fabrication of morphological patterns. Further lithographic techniques, particularly suitable for biological applications, utilize protein-repelling templates. One can either perform direct writing in such a template, which can be both SAM-based and polymer-like, or apply irradiation-promoted exchange reaction. In the latter case, both species bearing specific protein receptors and functionalized ssDNA strands can be introduced into the template. Using the above techniques, chemical patterning and surface engineering on a length scale ranging from cm to nm is possible. Not only simple dot or stripe structures but complex gradient-like and biology-inspired patterns can be fabricated.

# DNA ionization by UV radiation

**Dimitra Markovitsi**

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It is well known that DNA undergoes photoionization when it absorbs UV radiation at wavelengths shorter than 200 nm. But during the past decade it appeared clearly that this phenomenon also takes place at longer wavelengths (lower energies), extending to UVB, albeit with a smaller quantum yield f. This phenomenon is important in respect to the oxidative damage of the genetic code and in relation with the efficiency of spermicidal lamps using UV radiation.

Time-resolved studies, performed on purified DNA in solution, allowed the characterization and the quantification of the resulting ejected electrons and guanine radicals by their absorption spectra. In contrast to the high-energy photoionization, the f of the low-energy process strongly depends on the secondary DNA structure. No photoionization could be detected for mononucleosides ($f < 3\times10^{-4}$). The f determined for genomic calf thymus DNA ($2\times10^{-3}$) is similar to that corresponding to the formation of dimeric pyrimidine photoproducts, considered so far as the main lesions induced by direct absorption of UV radiation. Significantly higher values ($1.5\times10^{-2}$), were found for guanine quadruplexes. The generation of photoinduced charge carriers in these programmable systems renders them promising for the development of optoelectronic biosensors using intrinsic signals of nucleic acids.

# Sediment dynamics investigation using radiometric methods

**Jovan Thereska, Patrick Brisset**

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Radiometric methods help in investigating sediment dynamics providing important parameters for better designing, maintaining, and optimizing civil engineering structures such as beaches, harbours, rivers and dams, which play an important role in human life. The main radiometric methods for sediment dynamics investigation in water bodies are, radioactive tracer method as well as natural gamma radionuclide method.

Radioactive tracer method is used for direct real time quantitative assessment of sediment transport pathways. For 'in situ' measurements, gamma emitting radioisotopes are used. Specific radioactive tracers can be produced of activable glasses, i.e. containing an element (gold, iridium, chromium, scandium) with very low content (0.3 to 0.5%) suitable for be transformed into radionuclide after irradiation by neutrons in a nuclear reactor. The selection of a suitable radioisotope for a particular investigation depends upon half-life, gamma energy, neutron absorption cross-section and radiotoxicity. The half-life of the radioisotope to be used as a tracer, should be long enough for detection till the end of the study and at the same time short enough not to pose environmental hazards. Based on the above considerations, the most used radionuclides for bedload sand transport investigations are Ir-192 and Au-198.

Natural radionuclides of sediments, U-238, Ra-226, Th-232, Ra-228 and K-40, provides interesting information on sediment dynamics. Measuring the distribution of concentration of natural radionuclides of floor sediments in coastal and fluvial areas provides data for sediment dynamics evaluation. Marine gamma-ray spectrometers have been employing for a range of applications in sediment transport studies, such as coastal erosion, optimisation of dumping of dredged material, etc. Careful interpretation of natural gamma radiation mapping of sediments on water bodies floors provides information about direction and distance of transport of fluvial sediments, accretion and erosion zones along the coastline, transport of fine sediments from a dumpsite. In this respect, the natural radioactivity of sediments can be considered as "tracer" for qualitative evaluation of sediment dynamics in water bodies. Radiometric mapping of natural radionuclides $^{232}$Th, $^{238}$U and $^{40}$K have been conducting in many countries and valuable correlation has been founding between natural radioactivity distribution and sediment movement.

Measurement of density of water-sediment mixture using radiation transmission method provides data for in-depth understanding of the silting-up process in dams, controlling dam flush for optimal exploitation of dams. Portable X-ray based instruments are constructed to monitor the density of mud in dams, rivers and harbours worldwide. These instruments allow measuring the navigable depth in the channels of access to the ports and harbour basins. They are daily employed by hydrographers to supplement the indications given by the echo-sounders in muddy zones.

# Evaluating the role of ultraviolet radiation in atmospheric chemistry and indoor air disinfection: Implications and challenges

**Zoran Ristovski**

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Ultraviolet (UV) radiation plays a critical role in the study of aerosols and atmospheric sciences due to its involvement in photochemical processes. In atmospheric chemistry, UV radiation triggers the photolysis of various compounds, affecting the formation of secondary pollutants like ozone and impacting the oxidative capacity of the atmosphere. This activity is essential for understanding aerosol dynamics, including changes in chemical composition and optical properties, which influence both health impacts and climate interactions. Additionally, UV-C radiation is effective in disinfecting airborne pathogens, such as viruses and bacteria, making it vital for infection control in environments with high transmission risks, like hospitals and laboratories. Technologies such as UV air purifiers and upper-room ultraviolet germicidal irradiation (UVGI) systems are utilized to continuously disinfect indoor air, reducing harmful microorganisms.

However, the increased use of germicidal UV (GUV) disinfection has raised concerns about the production of oxidants, including ozone ($O_3$) and hydroxyl radicals (OH), and their byproducts like ultrafine particles. These can exacerbate indoor air pollution, a significant public health issue as highlighted by the World Health Organization (WHO), which estimates 3.8 million deaths annually due to indoor air pollution. The impact of GUV irradiation on indoor air composition and its potential to produce chemical byproducts remains uncertain. This presentation explores key aspects of GUV use for airborne virus disinfection in indoor environments with a special highlight on potential health hazards from GUV exposure in built environments and the risk of forming high-risk secondary chemical byproducts that may harm human health within indoor air.

# Molecular 2D materials *via* low-energy electron-beam induced synthesis: Mechanisms and functional properties

**Andrey Turchanin**

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Two-dimensional (2D) materials, renowned for their unique physical and chemical properties, currently dominate the landscape of natural sciences. While research has largely focused on inorganic 2D materials such as graphene, transition metal dichalcogenides, and hexagonal boron nitride, molecular 2D materials remain relatively underexplored. This is primarily due to their inability to be exfoliated from the naturally existing 3D crystals using top-down methods, necessitating bottom-up synthesis from 1D building blocks. In this talk, I will present our recent advancements in synthesizing molecular 2D materials—nanosheets approximately 1 nm thick—with tailored chemical and physical properties. These materials are fabricated *via* low-energy electron irradiation-induced crosslinking of aromatic self-assembled monolayers.

Specifically, I will discuss:

(i) The fundamental mechanisms of crosslinking [doi.org/10.1039/C9FD00119K];

(ii) Molecular nanosheets with tunable photoresponse [doi.org/10.1039/D0NR07788G, doi.org/10.1002/admi.202102389, *Angewandte Chemie International Edition* 61 (2022) e20220495], gas permeation [doi.org/10.1002/smll.202300282, doi.org/10.1002/smll.202406526], and bio-responsive properties [doi.org/10.1002/adma.202407487];

(iii) Carborane-based nanomembranes [doi.org/10.1021/jacs.3c05530, doi.org/10.1021/acsnano.4c16611].

The functional properties of these 2D materials will be examined in the context of their potential applications in nanoscience and nanotechnology.

# ‘Sun’ and SAMs: How self-assembled monolayers react towards UV irradiation

**Andreas Terfort**

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In the initial days of exploration of self-assembled monolayers (SAMs) of thiolates on gold, it was known that these otherwise quite stable surface layers would deteriorate slowly when exposed to daylight. It could later be shown by us and others that it is indeed the short-wavelength part of the sunlight (blue to ultraviolet), which causes chemical changes in the monolayers. It was also found that the molecular structure of the SAM constituents has a very strong effect on the observed changes, including widely varying cross sections, for which a mechanism is proposed.

The possibility to control the reactions at the surface by molecular design opens the opportunity to attain either molecular deterioration, polymerization and even reversible switching. In addition, the use of light offers the chance for different kinds of lithography. We thus studied several methods for the lateral structuring of SAMs, including the formation of chemical gradients at the surfaces, which in turn can be utilized for biological and biochemical experiments.

# Ion and electron beams for analysis and modification of self-assembled monolayers on metals

**Piotr Cyganik**

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Connecting inorganic and organic materials is mandatory for technologies supporting current development in electronics, biotechnology or new energy sources. This connection inevitable leads to the formation of an inorganic-organic interface which at the nanoscale becomes the most critical element of the respective device. Self-assembled monolayers (SAMs) provide simple and robust way for controlling organic-inorganic interface by formation of chemisorbed organic nanostructures on inorganic substrates. The structure and properties of SAM are largely controlled by the nature of their chemical bonding with the inorganic substrate making this buried interface of key importance for most of their countless applications. However, the analysis of this "hidden" part of SAMs remains most difficult to access both experimentally and theoretically. In the first part of this talk we will present an original experimental approach based on using ion beam to analyze chemical bonding, thermal stability, and charge transfer across this buried interface for model SAMs on metals based on thiols, selenols, carboxylic acids and carbenes. The second part of the talk will be focused on analysis of the impact of this buried interface on electron-beam-induced modification of SAMs, and as a result, formation of carbon nano-membranes (CNMs).

# Carbon nanomembranes: Radiation-induced 2D materials for separation technology

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Clean water is a global challenge, and membrane filtration is a key technology to achieve it. There are growing research efforts to explore the use of 2D carbon materials as nanoconduits for molecular transport and separation. Radiation induced chemistry plays a prominent role in these activities as the electron induced modification of molecular surfaces layers is an important step in the fabrication of nanomembranes. Here, we report on the fabrication and application of carbon nanomembranes (CNMs) [doi.org/10.1002/adma.201670202]. CNMs are two-dimensional membranes (thickness ~1 nm) made by electron-induced cross-linking of aromatic self-assembled monolayers (SAMs). CNMs made from terphenylthiol (TPT) possess sub-nm pores of a density of ~1018 m−2, which corresponds to one sub-nm channel per square nanometer [doi.org/10.1021/acsnano.8b01266]. TPT CNMs let water molecules rapidly pass through, while they efficiently hinder the translocation of ions. TPT CNMs have been utilized as forward osmosis membranes. Their membrane resistance reaches ~104 Ω•cm2 in 1 M Cl− solutions, comparable to lipid bilayers [doi.org/10.1002/adma.201907850]. To investigate molecular transport through the tortuous sub-nm pores of CNMs, we studied the permeation of gases and vapors of different sizes (D2O, He, N2, O2, CO2, CHCl3, C7H8 und C6H14), as well as of binary mixtures of water with the above molecules. In all mixtures the water permeation was much higher than the permeation of the other molecules, resulting in a high selectivity of the CNM. To explain this behavior, models of adsorption-controlled permeation (ACP), and water-assisted permeation are introduced. These describe the kinetics of the permeation process, starting from a molecule that is adsorbing on the membrane surface, diffusing over the surface until it encounters a pore and that is then translocating through the sub-nm pore [doi.org/10.1039/C9CP03038G]. We also found an Anti-Arrhenius behavior during the passage of gaseous molecules through CNMs [doi.org/10.1039/D3CP05705D].

# Determination of the computational bias in criticality safety simulation of SMR version of sodium fast reactor

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An integral aspect of advancing the fourth generation of nuclear reactors involves the evaluation of new and untested concepts by simulation to determine their safety and overall performance. The neutronic simulations different code systems and various methods, each method being developed on a certain number of approximations and assumptions, inherently introducing bias into the process of simulation. Furthermore, the nuclear data utilized in the simulations also fundamentally introduce a certain bias, due to the evaluation and validation processes, and they also introduce a level of uncertainty, which stems from the imperfections of experimental methods. The accuracy of nuclear data can prove insufficient in some cases, such as the simulation of fast systems. Thus, to properly use the simulation tools, the overall bias must be analyzed and the individual contributions to the bias must be estimated. As the criticality safety is paramount in the new generation of nuclear technologies, the performance of individual simulation methods and nuclear data libraries must be assessed through benchmarking exercises.

Under the auspices of EURATOM, the series of European Sodium-cooled Reactor (ESFR) projects was started, developing a concept of a modern GEN IV reactor to further the nuclear energy industry in Europe. As a part of the third, ongoing project ESFR-SIMPLE, two sodium-cooled small fast (SFR-SMR) reactor cores were proposed, as a more economical option. This paper seeks to assess the biases present in the criticality safety simulations of the two SFR-SMR cores Sodium-cooled Fast Reactor (SFR). The ESFR-SIMPLE SF-SMR core models are presented, together with the parameters of calculating the nominal parameters as well as the sodium void and Doppler effect coefficients. The SCALE code system is used for both the calculation of parameters and estimation of the biases.

# Optimizing uranium electrodeposition in aqueous matrices: A tracer-free approach for uranium measurements by Alpha Spectrometry at Nucleco

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Accurate determination and quantification of uranium in radioactive waste are critical for Nucleco SpA, a leading company in Italy specializing in radiological services, radioactive waste management, and nuclear facility decommissioning.

Inductively coupled plasma mass spectrometry (ICP-MS) is commonly used for uranium quantification due to its high sensitivity. However, this technique has notable drawbacks, including high operational costs, frequent maintenance, and the potential for false positives. As an alternative, alpha spectrometry offers both qualitative and quantitative uranium analysis in decommissioning samples.

A key factor in alpha spectrometry is the efficiency of uranium extraction and electrodeposition, which is typically evaluated using a tracer such as $^{232}U$ or natural uranium. To standardize and optimize actinide analysis via alpha spectrometry, a preliminary study was conducted to assess uranium electrodeposition yield in an aqueous matrix. This approach aimed to eliminate the need for a tracer, which could otherwise interfere with the alpha spectrum in the energy region of plutonium and americium ($\geq$ 5 MeV) while minimizing radiochemical interferences such as self-absorption and energy straggling.

The uranium electrodeposition yield in an aqueous matrix was estimated using "virtual" samples spiked with a natural uranium source. The resulting yield was then applied and verified to uranium quantification in real aqueous samples from Nucleco SpA's decommissioning activities and in concrete samples, marking a first step toward extending the tracer-free approach to more complex matrices.

# Operational verification of a hexapod robot system equipped with a Compton camera for visualizing radiation sources while overcoming obstacles

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In the decommissioning of the Fukushima Daiichi Nuclear Power Station, understanding the distribution of radiation sources and the location of radioactive hotspots with localized high concentrations of radiation sources is extremely important for developing a detailed decontamination plan and minimizing worker exposure. We introduced last year at the international conference RAP2024 an autonomous mobility system that automatically moves in the direction of the radiation source. Specifically, the robot system combines a Compton camera, a type of gamma-ray imager, and a mecanum wheel robot. The Compton camera estimates the direction in which the radiation source is located, and a depth camera mounted on the robot detects and avoids obstacles while reaching the radiation source [doi.org/10.1140/epjs/s11734-025-01483-5]. However, the robot system based on the mecanum wheel robot could not step over piping that existed on the floor of the decommissioning work environment, nor could they ascend or descend stairs.

Therefore, we are also developing a radiation source visualization system based on a hexapod robot that can straddle pipes and ascend and descend stairs. We have developed a system that combines a hexapod robot and a Compton camera, and conducted a radioactive contamination visualization test at FUGEN, a nuclear facility owned by Japan Atomic Energy Agency [doi.org/10.1016/j.nima.2024.169300]. However, this demonstration test on FUGEN did not include a test to visualize radiation sources while overcoming obstacles. In this study, a radiation source visualization system based on a hexapod robot was tested to visualize the radiation source while climbing up and down stairs and over steps that cannot be crossed by a mecanum wheel robot, and then the robot moved to the radiation source. The results of these demonstrations will be presented at RAP2025.

# Addressing gaps in calibration and standardization of X-ray measurement systems for medical use

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The medical use of X-rays represents the largest source of artificial ionizing radiation exposure to the global population. To ensure optimal performance and safety in imaging and interventional procedures, quality control is commonly performed by measuring key parameters of the X-ray system, such as air kerma, tube voltage, and half-value layer layer non-invasively from X-ray beam using X-ray multimeters (XMMs). While some parameters benefit from established standardization and metrological support, others still lack a unified and consistent approach. Moreover, there is a shortage of data on the performance of XMMs in varying measurement conditions.

A study was performed to assesses the existing standards and identify calibration and measurement needs by reviewing available guidelines, conducting surveys with clinical medical physicists and calibration laboratories, and analyzing data from the key comparison database.

Calibration services for air kerma are readily available across a broad range of radiation qualities. However, calibration services for other key parameters are scarce, with very few laboratories—primarily manufacturers—able to provide these services. Additionally, gaps in standardization exist, and calibration procedures for these quantities lack harmonization. The surveys also showed that different countries have different requirements for calibration, verification and type testing of XMMs, and that the use of calibration coefficients by medical physicists is very sporadic.

To address these issues, the development of new calibration services with harmonized procedures for X-ray multimeters is essential, particularly for parameters beyond air kerma. These procedures will be formulated within the framework of the TraMeXI project and subsequently shared with standardization bodies, metrology organizations, and the medical physics community. The project also develops procedures for clinical measurements, including the recommendations on the use of calibration coefficients and standardized measurement setups.

**Keywords:** diagnostic radiology, measurement uncertainty, calibration, imaging, harmonization, traceability, quality assurance, x-ray multimeter

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# Establishing new copper filtered radiation qualities in SSDL for general radiography and fluoroscopic applications

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It is good practice that diagnostic dosimeters are calibrated in laboratory conditions, prior to their application in quality control. Clinical need-driven design considerations in X-ray sources have led to numerous technological advancements resulting in a noticeable difference between radiation conditions encountered in clinical applications and those established in calibration laboratories. One of the aims of the Joint Research Project 22NRM01 TraMeXi is development of new calibration qualities and testing procedures, that better reflect clinical conditions. The reference radiation conditions defined for general radiography and fluoroscopy are outlined in IEC 61267:2005 [IEC, 2005]. They include the aluminum (Al) filtered RQR radiation quality series and the copper (Cu) filtered RQC radiation quality series. New X-ray generators encountered in hospitals use total filtrations comprised of aluminum and additional copper filtrations of different thicknesses. Typical total filtration of X-ray generators was investigated via a European scale survey. The largest additional copper thickness encountered in clinical practice is the 0.9 mm Cu (found for stationary C-arms). This shows that the RQC Cu filtration does not fully represent clinical conditions. Therefore, new radiation qualities, termed as Clinically relevant and Physical Representative Radiation Qualities (CPRQ), were established in the Vinca Institute of Nuclear Sciences (VINS) and the Greek Atomic Energy Commission (GAEC) by adding 0.9 mm Cu filtration to selected RQR qualities. Bilateral comparison of Half Value Layers and the homogeneity coefficient was performed. The HVL values were also compared with the values generated by the SpekCalc [Poludniowski et al., 2009] software. Calibration of a semiconductor-based X-ray multimeter was performed in these radiation fields and its energy dependence, in terms of dosimeter relative response normalized to RQR5 radiation quality. Performance evaluation was based on the criteria defined in IEC 61674:2024 [IEC, 2024]. Calibration of dosimeters used in these radiation fields would enhance measurement accuracy and reliability, improving quality assurance and patient dose estimates.

**Keywords:** fluoroscopy, radiography, radiation qualities, dosimeter calibration, dosimeter response

**Acknowledgments:** This work was funded by the International Atomic Energy Agency (IAEA) under the research contract No: 24688, which is part of the IAEA Coordinated Research Project E24024, entitled 'Evaluation of the Dosimetry Needs and Practices for the Update of the Code of Practice for Dosimetry in Diagnostic Radiology (TRS-457)'.

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# Research on online monitoring technology for radioactive xenon in ambient air

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Radioactive xenon is one of the primary gaseous fission products produced by the chain reactions of fissile nuclides such as U-235 and Pu-239. The main sources of radioactive xenon in the global atmospheric environment are routine emissions from nuclear explosions, nuclear power plant reactors, and isotope production reactors. The main isotopes of radioactive xenon include $^{131m}$Xe, $^{133m}$Xe, $^{133}$Xe, and $^{135}$Xe, with $^{133}$Xe having the highest emission levels. Its annual global emissions account for over 50% of the total emissions of radioactive inert gases. Due to its high fission yield, ease of diffusion in a gaseous state, and relatively short half-life (5.24 days), $^{133}$Xe is an important radionuclide for identifying nuclear explosions and assessing the safe operation of reactors. The activity concentration of $^{133}$Xe in ambient air is about 10^-4 Bq/m$^3$. To achieve online measurement of such low levels of $^{133}$Xe in ambient air, the online monitoring system for radioactive xenon in ambient air needs to address two key technologies: xenon separation and purification, and ultra-low background measurement.

The volume concentration of stable xenon in ambient air is approximately 0.087 ppm. The key technology for xenon separation and purification in an online monitoring system for radioactive xenon in ambient air uses a four-stage separation and purification process to increase the xenon content in samples. After the four-stage separation and purification, the volume ratio of xenon in the sample is about 30%, with a separation and concentration factor of approximately 10^6. The xenon separation and purification module consists of a primary membrane separation column and three spherical carbon molecular sieve columns. The membrane separation column initially separates and concentrates trace xenon from air, including gases like oxygen and carbon dioxide, based on differences in gas molecular diameter. The xenon volume concentration in the separated gas is about 1 ppm, the oxygen content is less than 1‰, and the dew point is below -50℃. The gas with low moisture and oxygen levels then enters the three spherical carbon molecular sieve columns for further separation and purification. Based on differences in desorption temperature in the spherical carbon molecular sieve, the separation and concentration factors for xenon in the three columns are on the order of 10^2, 10^2, and 10^1, respectively. After separation and purification, the total activity of $^{133}$Xe in the xenon sample is approximately 10^-2 Bq. Using a low-background shield (shielding lead Pb-210 < 50 Bq/kg) and the β-γ coincidence measurement method, an ultra-low background measurement system for xenon was designed and developed. The 12-hour coincidence background ROI [77-85 keV (γ channel), 10-400 keV (β channel)] measurement result is approximately 5.7. The online monitoring system for radioactive xenon in ambient air samples, separates, and purifies more than 3ml of pure xenon over 24 hours. The xenon ultra-low background measurement system measures for 12 hours, with a detection limit for $^{133}$Xe of about 0.21 mBq/m^3, reaching the detection limit measurement level of similar equipment like SAUNA-3 (0.15 mBq/m^3) and SPALAX-NG (0.2 mBq/m^3).

**Keywords:** radioactive xenon, online monitoring, separation and purification, β-γ coincidence measurement

# Evaluation of Compton suppression for enhancing trace element identification in Neutron Activation Analysis of reference materials

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Neutron Activation Analysis (NAA) is a powerful technique for identifying and quantifying trace elements in materials. However, challenges such as high dead times, spectral interferences, and high Compton continuum often arise. This study employs a Compton suppression system (CSS) to enhance NAA sensitivity by reducing the Compton continuum, thereby improving the peak-to-Compton ratio. Certified reference materials (1633D, 1632C, and TORT-1) were irradiated in an epithermal neutron flux and analyzed using high-resolution gamma-ray spectroscopy with and without Compton suppression. The reduction factor was calculated to evaluate the effectiveness of the CSS, demonstrating significant background reduction and improved detection limits for trace elements. Additional experiments with a Cs-137 point source demonstrated the impact of detector-source geometry on system performance, showing a decrease in the reduction factor as the source was moved further from the NaI detector. An optimum distance between the source and HPGe detector was observed, yielding the highest peak-to-Compton ratio. The results highlight the CSS's ability to minimize spectral interference and enhance elemental identification.

# Monte Carlo simulation study on diaphragm correction factors for free-air ionization chambers: Influence of diaphragm thickness and aperture shape

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**Introduction.** Dosimeters measuring air kerma must be traceable to primary standards. Primary standard laboratories use free-air ionization chambers (FACs) for the primary realization of the unit of the air kerma free-in-air. For this, correction factors for diaphragm effects ($k_{dia}$) must be applied. This study investigated the impact of the geometry of the diaphragm on $k_{dia}$, as established FACs from different metrology institutes employ varying diaphragm geometries. The aim was to find the optimum diaphragm thickness and aperture shape to minimize the required correction.

**Materials and Methods.** Monte Carlo simulations were performed using the EGSnrc user code egs_fac to determine $k_{dia}$. A simplified FAC model with a tungsten diaphragm was simulated at 1 m distance from a point source emitting a 50 keV monoenergetic x-ray beam. The aperture diameter was 5 mm.

To evaluate the impact of the diaphragm thickness, simulations were conducted for air path lengths (i.e., the distance between the reference plane and the middle of the collecting volume) ranging from 40 to 100 mm. For each air path length, the thickness of the diaphragm with a cylindrical aperture varied between 0.4 and 10 mm.

To further explore the influence of the aperture shape, simulations included conical apertures with opening angles ranging from 0.15 ° to 45 °. Additionally, hybrid aperture geometries, where the aperture shape transitions from cylindrical to conical, were examined.

**Results.** For each air path length, $k_{dia}$ had a peak value at a specific diaphragm thickness where the value was closest to 1, indicating a minimal correction for diaphragm effects. This optimal thickness increased with the air path length. For an air path length of 40 mm, the optimal thickness was 0.8 mm, while for 100 mm, it was 1 mm.

At 60 mm air path length and 1 mm diaphragm thickness, $k_{dia}$ was 0.9990 for a cylindrical aperture. Simulations showed improvements in $k_{dia}$ when transitioning to a 0.3 ° aperture angle. The thinner the diaphragm, the smaller the improvements. With a 10 mm thick diaphragm and an aperture angle of 0.3 ° $k_{dia}$ was 0.9997. However, for aperture angles greater than 0.3 °, $k_{dia}$ decreased for fully conical and was constant for hybrid aperture geometries.

**Conclusion.** The results showed that the diaphragm thickness and the aperture shape influence $k_{dia}$. The diaphragm needs to be sufficiently thick to prevent transmission yet as thin as possible to reduce scattering at the inner surface of the aperture. Utilizing an aperture angle offers a minor enhancement compared to a cylindrical 1 mm diaphragm, which does not warrant the increased complexity of the diaphragm design.

# Quench correction in the modified LSC method for uranium in water measurements

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A modified standard method ISO 13169:2018(en) “Water quality — Uranium — Test method using alpha liquid scintillation counting” is proven to give good results for the determination of the activity concentration of uranium in water samples by liquid scintillation counting [doi.org/10.1016/j.radphyschem.2024.112406]. For the modification, three different “two-phase” (water immiscible) scintillation cocktails produced by Perkin Elmer: Ultima Gold F, Mineral Oil and Opti Fluor – O were used. In addition to that, a natural uranium liquid calibration source, certified by the Czech Metrology Institute, Prague, was used as both an alpha and beta emitter.

The developed methodology suffers from instability of the prepared calibration sources and samples, since after some time, all the samples become colored instead of transparent. To deal with this issue, a thorough study on color quench correction was conducted, and this paper will present the preliminary results of this study. The quench correction curves were prepared for the known activity of the calibration source with a variety of colors for all three scintillation cocktails. At the end, the activity concentration of the test samples prepared a long time ago was tested and the method confirmed that quench correction improves the validity and precision of the obtained results.

# Analysis of radiation dosimetric properties of a wide bandgap semiconductor aluminum nitride (AlN) wafer prepared by MOCVD using the thermoluminescence method

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The radiation dosimetric properties of the wide-bandgap semiconductor aluminium nitride (AlN) were investigated using the thermoluminescence (TL) method. A $^{90}Sr$-$^{90}Y$ β-beta radiation source was utilized to irradiate an AlN wafer (dimensions: 4 × 4 × 0.4 $mm^3$, weight: 25 mg) at varying dose levels. This wafer, produced via the metal-organic chemical vapor deposition (MOCVD) technique, was obtained from the Tyndall National Institute, Ireland.

Three experiments were conducted in this study. In the dose-response experiment, the wafer was irradiated with doses ranging from 12Gy to 4.6kGy and subsequently read out at a heating rate of 1°C/s, from room temperature to 400°C. The resulting TL glow curve exhibited two peaks at approximately 200°C and 290°C. The saturation dose level was identified between 1.5 kGy and 2.3 kGy. The area under the TL glow curve increased sub-linearly at lower doses and then super-linearly before reaching saturation.

The heating rate experiment was conducted to analyze the dynamic factors affecting the characteristics of the TL glow curve. The wafer, irradiated with 36Gy, was analyzed at five different heating rates (1, 2, 3, 4, and 5°C/s). While the shape of the TL glow curve remained unchanged, it became broader. Additionally, both peak positions shifted to higher temperatures, centering around 237°C and 338°C. The area under the TL glow curve decreased by 65% and 70% at 2°C/s and 3°C/s, respectively, and became nearly constant at 4°C/s and 5°C/s.

Finally, in the repeatability experiment, the wafer was irradiated with 36Gy and read out eight times using a TLD reader at 1°C/s. The results showed no additional distinct TL peaks emerging after repeated readout cycles, confirming the stability of the glow curve over multiple measurements.

# Determination of luminescence properties of newly produced and developed LiF dosimetric material

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In this study, the luminescence properties of newly produced LiF material doped with different ratios of Mg, Cu and P were investigated using the thermoluminescence technique. The thermoluminescence measurements of the material were carried out in the temperature range of 323-773 Kelvin, with a heating rate of 2 Kelvin per second, after the material was irradiated with a beta source. The luminescence properties of the dosimetric material, such as dose response and stability, were investigated. In addition, the luminescence properties of the dosimetric material at different heating rates were determined. The results obtained with these methods were compared and discussed.

# Thermally stimulated luminescence properties of LiF:Mg,Cu,P,B dosimeter

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In this study, thermally stimulated luminescence (TSL) properties of LiF dosimetric material doped with different ratios of Mg, Cu, P, and B have been investigated. It was prepared by sintering method. The TSL glow curves of LiF:Mg,Cu,P,B dosimetric material has 3 peaks. The effect of different heating rates on the TL glow curve of the dosimeter was also examined. Dosimetric characteristics of the material such as dose response and stability. Based on the obtained results, the usability of the dosimeter for medical, personnel, and environmental dosimetry was established.

# New dosimetry audit in Poland – pilot study for tomotherapy

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Modern radiotherapy is a field that constantly evolves, combining advanced technology with precise cancer treatment methods. In recent years, there have been huge advances in radiotherapy techniques, equipment and treatment planning allowing patients to be treated more efficiently and safely. Modern accelerators allow therapy to be tailored to individual patient needs, increasing treatment effectiveness and minimizing side effects. The continuous development of radiotherapy devices and irradiation techniques requires existing dosimetry audits to be adapted to them.

One advanced form of radiotherapy is helical therapy, called tomotherapy. During this therapy, a linear accelerator rotates around the patient delivering radiation in a manner similar to a helical CT scan, allowing precise irradiation of the tumour from different directions. Simultaneous movement of the therapy table while irradiating the patient allows significant areas to be irradiated without the need to combine fields. This is particularly desirable for irradiating gynecological tumours, soft tissue tumours and bone tumours and for implementing special techniques such as HBI (Half Body Irradiation), TBI (Total Body Irradiation) and TMI (Total Marrow Irradiation).

At present, there are 6 tomotherapy devices installed in Poland and further installations are expected in the coming years. The increase in the number of such devices in Poland was the impetus for the development of a dosimetry audit methodology for these devices.

A pilot dosimetry audit for tomotherapy was performed on the RADIXACT device from Accuray installed at the Maria Sklodowska-Curie National Research Institute of Oncology in Warsaw in 2022. Structurally, the tomotherapy device differs from conventional C-arm linear accelerator. During audit it is impossible to achieve reference conditions: SAD of 100 cm and a field of 10 cm x 10 cm. This necessitated a modification of the audit methodology. The size of the tripod used as standard for postal TLD dosimetry audits was adapted to the height of the water phantom supplied with RADIXACT device and the range of table movement. Detector irradiation was performed for a static field of 5 cm x 10 cm and SAD of 85 cm. It was necessary to determine the TPR value for the audited beam. For this purpose, the $PDD_{10}$ for the 5 cm x 10 cm field was measured and this value was converted to $PDD_{10}$ for the 10 cm x 10 cm field (reference field) according to the formula No. 5 of Thomas et al included in the publication *QA for helical tomotherapy: Report of the AAPM Task Group 148*. All measurements were performed with a dedicated TomoElectrometer dosimetry kit with an A1SL type ionization chamber. The positive result of the pilot audit was one of the conditions under which the tomotherapy device was approved for clinical use.

Dosimetry audits for tomotherapy are a key element in ensuring high quality treatment and patient safety during a helical therapy.

# Comparison of the dosimetry systems for brachytherapy in terms of calibration coefficients

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The use of calibrated radiotherapy electrometers with well- type ionization chambers, traceably to primary standards directly or through secondary standards, is necessary and required by Polish law for the independent verification of brachytherapy source strength. In Poland, these measuring instruments are calibrated at the Secondary Standards Dosimetry Laboratory. Calibrations are made for a dosimetry system composed of a vented well-type chamber, a source holder to position the source inside the well-type chamber, an electrometer and an extension cable. For these dosimetry system calibrations, the internal bias supply of the user electrometer is used to apply polarizing voltage. These calibrations are in the scope of accreditation number AP 155 granted to our laboratory by the Polish Centre of Accreditation on May 28, 2014. This accreditation was granted for the conformity with the requirements of the PN-EN ISO/IEC 17025 standard.

The aim of this study was comparison of 58 dosimetry systems calibrated in period of 2022-2024 in Poland. At that time the most commonly calibrated user well-type chambers were: HDR 1000 PLUS manufactured by Standard Imaging, TM33005 and TM33004 manufactured by PTW.

We compared calibration coefficients values for each of three groups of well type ionization chambers mentioned earlier. The calibration coefficients based on standards of the reference air kerma rate ($N_{RAKR}$) were established in $^{192}$Ir radionuclide in reference conditions defined in the IAEA-TECDOC-1274 and Technical Reports Series No. 492 issued by the International Atomic Energy Agency.

The arithmetic mean value, the median value and the standard deviation value (expressed as a percentage of the arithmetic mean value of calibration coefficients for each group of dosimetry systems) and the ratio of the largest and the smallest calibration coefficients in each group will be presented in this study. We will also present other detailed results of descriptive statistics.

The obtained results indicate that the maximum differences in the calibration coefficients of the analyzed dosimetry systems for brachytherapy do not exceed 4% in the type of the chamber. Therefore, it should be remembered that use of each dosimetry system in clinical work must always be preceded by its calibration in a competent calibration laboratory. This will enable verification of brachytherapy source strength with the expected accuracy.

# Inter-employee comparisons in the determination of absorbed dose to water during dosimetry audit in radiotherapy

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Dosimetry audit in radiotherapy is a key element of quality assurance (QA) and safety in the treatment of patients with ionising radiation. It aims to verify and confirm that radiation doses delivered to patients are in line with therapeutic intent and meet specified quality standards.

According to section 7.7.1 of the ISO/IEC 17025:2017 standard "General requirements for the competence of testing and calibration laboratories", accredited laboratory shall have a procedure for monitoring the validity of results. This monitoring shall be planned and reviewed and shall include, but not be limited to replicate tests using the same method. And according to section 7.7.3 of the standard data from monitoring activities shall be analysed and used to both control and improve the laboratory's activities. These requirements are crucial in any laboratory activities.

In this work, we will present the ways of implementing the aforementioned requirements at the Secondary Standards Dosimetry Laboratory in Warsaw in Poland accredited by the Polish Centre of Accreditation (accreditation No. AB 1499). In particular, we will discuss the procedure of the inter-employee comparisons in the determination of absorbed dose to water by thermoluminescent dosimetry method. These measurements are the basis for performing a dosimetry audit in radiotherapy. In addition, we will highlight the most important aspects of these replicate tests, such as the establishment of acceptance criteria. Finally, we will give some results from the routine activities of our laboratory and analyze these results according to the dispositions in our procedure. Comparisons of results between staff performing dosimetry audits are an important tool in the quality assurance process and to confirm the validity of the results.

# Assessing the long-term stability of $N_{D,w}$ calibration coefficient for Markus-type ionization chambers in radiotherapy

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The safety of the patient undergoing a course of radiotherapy has always been of the highest priority. Modern, highly personalized radiotherapy techniques require more than ever a high level of confidence in the precision and certainty that the dose delivered to the target volume is consistent with the dose planned for that volume. Only when several key factors are met a high level of confidence can be achieved. These include proper training of medical physicists, development of and adherence to proper procedures, and use of properly calibrated equipment.

The risk of malfunction does not depend on the age or type of dosimetry set used, including the electrometer and ionization chamber. Even the slightest malfunction may affect the reliability of the results obtained. Therefore, regular calibration of dosimetry equipment by an independent laboratory is essential. In Poland this service is provided by the Secondary Standards Dosimetry Laboratory (SSDL). The Polish SSDL fully complies with ISO/IEC 17025 standard and has been accredited by the Polish Centre for Accreditation since May 28, 2014 (accreditation certificate number AP 155).

Calibration of the medical linear accelerators is the process of determining the absorbed dose to water or delivered to the patient during treatment sessions, measured in Gray (Gy) units, with the monitor units (MU) used as the reference scale of the linear accelerators. To ensure consistency between the planned and delivered radiation dose, proper calibration is essential. The methods of measurement and the reference conditions are specified in the Code of Practice, issued by the IAEA.

For electron beam measurements, the Markus-type ionization chamber is the gold standard. According to its specification it can also be used to measure proton beams. Its volume allows good spatial resolution to be obtained. Special design features reduce the influence of scattered radiation.

Calibration of dosimetry equipment is the comparison of the measured dose using a reference setup with a calibrated setup provided by the user. The dose is measured using gamma rays produced by the $^{60}$Co decay. Identical geometric and atmospheric conditions are used for both measurements. In the calculation of the measured dose for each setup, any possible influences of variable atmospheric pressure and temperature are taken into account. The calibration factor, $N_{D,w}$, is defined as the quotient of the dose measured by the reference setup and the dose measured by the calibrated setup.

The stability of the $N_{D,w}$ coefficient was analysed based on the experience of the Polish SSDL. This study focuses on Markus-type ionization chambers, widely used for electron beam dosimetry in radiotherapy.

# Evaluation of TLD-200 sensitivity and comparison with TLD-100 and statistical analysis

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This study aims to evaluate the dosimetric performance of TLD-200 thermoluminescent dosimeters and compare them with TLD-100, evaluating their suitability for radiation monitoring applications. The research relies on key dosimetric features, including linearity, temperature sensitivity, fading, and reproducibility. All experiments were conducted under controlled environmental conditions, adhering to the ambient temperature and relative humidity specifications provided by the manufacturer.

Our work began with the calibration and validation of the Harshaw 6600 TLD reader in order to ensure accurate dose measurements. A total of 200 dosimeters were used to obtain statistically significant results. Linearity was evaluated for various dose levels provided by the internal Sr-90 beta irradiator, while fading effects were investigated to determine signal attenuation over time. Additionally, temperature sensitivity tests were performed to evaluate the impact of thermal variations on dosimetric response.

Advanced statistical techniques were employed to assess measurement repeatability and reproducibility. The results demonstrate that both TLD-100 and TLD-200 display reliable performance, with notable variations in sensitivity and stability under different dose ranges and environmental conditions. The overall uncertainty in dose estimation was evaluated ensuring compliance with radiation protection standards. These outcomes confirm the suitability of the TLD-100 and TLD-200 dosimeters for accurate radiation monitoring and contribute in optimization of dosimetric protocols for routine applications in research, medical, and industrial settings.

# Calibration of radiation protection dosimeters – influence of long-term stability

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International measurement system is a chain of calibration laboratories, measurement standards and calibrations that make sure that all the measurements in the whole world are traceable to the SI units, and that all the measurements are comparable within the measurement uncertainty. Primary Standards Dosimetry Laboratories (PSDL) establish primary standards, based on the absolute measurements of SI units, and disseminate the units typically to the Secondary Standards Dosimetry Laboratories (SSDL) – by calibrating their secondary standards. SSDLs calibrate dosimeters owned by the end users, completing the measurement chain from the end user to the SI.

Results of these calibrations are calibration coefficients with associated measurement uncertainties that can be used to correct the measurement results. However, a calibration coefficient is valid only at the time of calibration and in reference conditions. All measurements must be corrected for real measurement conditions, and instrument stability must be taken into account. The experience shows that the response of all dosimeter changes over time, due to different factors such as ambient environmental parameters (air pressure, temperature, and relative air humidity), battery level, dosimeter aging, or other stochastic or systematic effects that are unknown or can't be corrected for.

Stability checks can be performed using check sources or repeated calibrations or other measurements in reproducible conditions. They can be used to estimate the uncertainty contribution of the dosimeter long-term stability. Stability checks can also be used to detect dosimeter failure. Three secondary standards were followed for over 15 years in the SSDL of Vinca Institute, making sure that their stability is within the requirements of the standard ISO 4037. During this period, two failures of the standards happened, and this was reflected in large changes in response. In addition, two survey meters (one professional and one low cost) were monitored over 3 months, showing much larger uncertainty due to stability.

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# The influence of backscatter radiation from the image detector on air kerma measurements in mammography

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Calibration and routine QC testing in mammography present rather challenging procedures, given the geometry of the X-ray unit and the associated factors that affect the measurements. Some of these factors include the positioning of dosimeters at their respective reference points, backscatter from the image detector, and the presence of the compression paddle in the primary beam. Dosimeters used in calibration and QC procedures are ionization chambers (ICs) or semiconductor X-ray multimeters (XMMs). The main difference is that XMMs have lead shielding on the backside that prevents backscattered radiation from the image detector from reaching the active volume of the dosimeter, while the ICs might be sensitive to backscattered radiation since they can detect radiation from all directions.

Mammography X-ray units have a vertical beam with an image detector in place, while calibration laboratories mostly use horizontal beam configurations free-in-air, which may make reproducing realistic clinical conditions difficult. The presence of the image detector cannot be avoided in clinical setups. In opposite, most calibration laboratories don't use or have an actual image detector that could be used to mimic the realistic clinical conditions. Routine laboratory calibrations are done in terms of air kerma free-in-air which does not take backscattered radiation into consideration.

In the scope of the 22NRM01 TraMeXI project, the transfer of calibration procedures from laboratories to clinics is being developed. For this purpose, an image detector has been introduced to the laboratory calibration setup. The measurements in terms of air kerma free-in air have been done with and without the presence of the image detector, to evaluate the influence on measured value. This effect was studied for different positions of dosimeters (3 ICs and 3 XMMs) relative to the image detector. The results can be used to better estimate the uncertainty related to the impact of backscatter.

**Keywords:** mammography, backscatter radiation, ionization chambers, X-ray multimeters

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# Evaluation of an in-situ procedure for calibration of well-type brachytherapy chambers in hospitals

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Brachytherapy is a specialized form of radiation therapy in which small encapsulated radiation sources are placed directly within or near the target area, with known ability to deliver a high radiation dose to the tumor tissue while minimizing exposure to surrounding healthy tissues. Dosimetry protocols for photon-emitting sources in brachytherapy typically rely on reference air kerma rate (RAKR) or air kerma strength (AKS) standards, along with transfer instruments. A well-type ionization chamber, or re-entrant well-type chamber, is the recommended method for measuring the strength of primary brachytherapy sources.

In Serbia, no calibration services for brachytherapy ionization chambers were previously available. To address this, the Secondary Standards Dosimetry Laboratory (SSDL) at the Vinca Institute of Nuclear Sciences has initiated the establishment of a calibration service for high dose rate (HDR) brachytherapy sources using a reference well-type chamber, Standard Imaging HDR-1000 Plus, coupled with a PTW Unidos Webline electrometer. The chamber's 20 mm thick aluminum outer wall helps reduce the influence of scattered radiation. A unique source holder is provided for each radiation source to ensure reproducible geometry within the chamber well.

The calibration of the system can be done either as a whole (system calibration) or separately (component calibration). In system calibration, both the well-type chamber and the electrometer are calibrated together, while in component calibration the chamber and electrometer are individually calibrated and the overall calibration is derived from the two separate calibrations.

Due to the lack of a radiation source generator for brachytherapy at the SSDL, calibrations are performed on-site, using sources and dose delivery systems that are available. The calibration procedure for high-dose-rate brachytherapy (HDRBT) is conducted using the substitution method, in which the user's well-type ionization chamber is calibrated against the reference HDR-1000 Plus chamber.

The calibration process includes several steps: prior to measurements the ionization chambers need to be in thermal equilibrium with the ambient conditions, conducting a dummy source test, pre-irradiating the well-type chamber, measuring the first leakage, determining the "sweet spot" of the chamber, recording reference and measured values, measuring the second leakage, and applying corrections to the measured values. If the ionization chamber is used with different holders or catheters, calibration must be performed for each configuration, and it is crucial to specify the conditions under which the calibration coefficient was determined.

In accordance with the guidelines outlined in the IAEA document *"Calibration of Photon and Beta Ray Sources Used in Brachytherapy (IAEA TRS 492:2023)"*, well-type ionization chambers should undergo periodic stability checks to ensure consistent and reliable performance. These checks are an essential part of maintaining the accuracy of brachytherapy dosimetry and should be conducted at regular intervals to adhere to established quality assurance standards.

**Keywords:** brachytherapy, HDR, dosimeters, calibration

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# Performance of dosimeters used for quality control in X-ray diagnostic radiology

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The predominant cause of exposure to man-made ionizing radiation is X-ray imaging procedures. The quality control, installation and acceptance tests of X-ray imaging devices are performed using ionization chambers or semiconductors-based X-ray multimeters (XMMs). XMMs have become the prevalent choice due to their uncomplicated functionality and the capacity to assess not solely air kerma but also other quantities such as air kerma rate, peak voltage, half value layer, exposure time, and total filtration. Dosimeters used for air kerma measurements in such tests should comply with the requirements defined in IEC 61674. The aim of this work was to perform a selection of compliance tests defined in IEC 61674 for an ionization chamber (Exradin A3) and two commercially available XMMs (IBA Magic Max, Quart didoNeo). The IEC requirements apply only to air kerma/air kerma rate. In this work, the other quantities were also evaluated for the XMMs.

The compliance tests performed were for energy dependence, repeatability, linearity, stabilization time, and field size. These tests were conducted under RQR radiation conditions (IEC 61267), established at the Physikalisch-Technische Bundesanstalt (PTB), which maintains primary standards for air kerma and voltage.

The variation of the devices' responses with radiation quality for the quantity air kerma was less than 5 %. However, the variation was greater than 5 % for the quantities peak voltage, half-value layer, and total filtration. This exceeded the uncertainty limits stated by the manufacturers. Repeatability was verified, and the results obtained were within the IEC 61674 limit of 3 %. The linearity of the response was determined for air kerma. Here, the ionization chamber showed a better linearity than the XMMs, which showed large deviations from linearity for low air kerma rates. The influence of stabilization times greater than 5 min on the response of the devices was less than ± 2 % for all quantities. The influence of field size on the response of the devices was significant for air kerma and air kerma rate, where the response increased linearly for beam diameters ranging from 6.7 cm to 16.7 cm.

The results obtained for the compliance tests were within the IEC limits for air kerma measurements. For other quantities, the IEC limits stated for air kerma cannot be hold and in some cases the uncertainties given by the manufacturers did not cover the observed deviations from the reference values.

**Keywords:** compliance tests, ionization chamber, semiconductors-based X-ray multimeters (XMMs)

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# Nonlinearity of photomultiplier tubes

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Scintillation detectors equipped with photomultipliers (PMTs) are extensively used in gamma and neutron spectrometry due to their high sensitivity and fast response. For accurate spectrometric measurements, it is crucial to ensure good linearity of the photomultiplier response as a function of the detected particle rate over time. However, at high count rates, nonlinearities may arise due to limitations in the photomultiplier tube's electronic response, particularly from the voltage divider that supplies the dynode chain.

The design of the photomultiplier voltage divider significantly influences the detector's performance, affecting gain stability, pulse shape, and ultimately, the accuracy of energy determination. Commonly available voltage dividers often fail to provide optimal conditions, especially at high count rates, leading to saturation effects, signal compression, and deviations in energy calibration. By carefully adjusting the divider parameters - such as resistor values, capacitor coupling, and optimized current supply - substantial improvements in linearity can be achieved, allowing the detector to operate reliably even at rates exceeding 100,000 counts per second (cps).

This study presents a detailed analysis of the impact of voltage divider configurations on photomultiplier performance. Experimental results obtained with a Cs-137 gamma source demonstrate the effectiveness of the proposed modifications.

# Determination of the fluence response matrix of an extended Bonner sphere spectrometer using different nuclear data libraries

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So-called Bonner sphere spectrometer (BSS) is considered among the essential metrological equipment of neutron laboratories. BSS is a device used to determine the energy spectrum of neutrons from thermal to neutrons with energies of several MeV. The method was designed in 1960. The main part, the detector of thermal neutrons, is placed in the center of each sphere. Different types of detectors such as scintillators, activation foils or proportional detectors can be used as thermal neutron detectors. The measured responses of the detector in different spheres together with the calculated of response function matrix allows the reconstruction of the neutron spectral fluence. The limitation of the original version of the BSS is that it cannot provide spectrometric information for neutrons energies above 20 MeV. To overcome this obstacle, the extended Bonner sphere (EBS) was designed. EBS spheres consist of PE moderator and heavy material such as copper, lead and tungsten. EBS response matrix can be calculated by various Monte Carlo transport codes. The response matrix also depends on the materials used, resp. from the nuclear data libraries that were used in simulations. It can be very interesting to benchmark the resulting response matrices determined using different libraries, especially in the high energy neutron region.

# Progress in 3D Si technology for HEP and medical research

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In the first part of this contribution, we will overview the state-of-the-art 3D Si technologies for HEP and medical research. In the second part of the contribution, we will address the technological issues and the current research with focus on the most recent experimental data on CNM 3D Si Column technology investigated by Two-Photon Absorption - Technique of Transient Currents at ELI Beamlines where we investigated the spread of the arrival time of signal as a function of temperature, bias, and radiation fluency.

# Lifetime study of a single-crystalline diamond detector for neutron measurements

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Diamond detectors are extensively studied over the last decades and especially polycrystalline diamond sensors are worldwide developed and mostly used for beam monitor purposes. In comparison, single-crystalline diamond sensors offer significant advantages in terms of uniformity, resolution, and fundamental material properties. Due to characteristics such as its thermal conductivity and extreme hardness diamond detectors show great potential when it comes to radiation applications in harsh environmental conditions. Radiation resistance is one of the most important requirements for the usage of these sensors, especially when it comes to neutron detection. However, up to now it has been poorly studied for single-crystal detectors. The estimated lifespan for 50 μm diamond thickness is ~$10^{15}$ (14 MeV neutrons)/cm$^2$ but has not been experimentally proven.

This work takes advantage of the mixed field neutron beam at the NEAR station of the n_TOF facility at CERN. Due to the proximity of the NEAR station to the Pb spallation target (approximately 2.5 m), a high instantaneous neutron flux is produced (~$10^{10}$/cm$^2$ neutrons for a proton bunch). These hard environmental conditions provide an ideal setting for an in-depth investigation into the degradation of the sensor. The single-crystalline diamond detector used in this work, along with its associated electronics, was specifically developed by CIVIDEC Instrumentation. The detector was exposed to the neutron beam at the NEAR station where the neutron events were recorded and the degradation was studied through parameters such as the amplitude, the FWHM, and the area of the signals. The preliminary results of this study will be presented and discussed.

# Recent results from CERN-DRD3 collaboration

**Gregor Kramberger**
**on behalf of the CERN-DRD3 collaboration**

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CERN-DRD3 is a large international collaboration engaged in development of semiconductor particle detectors. Primar focus is the use of the detectors in particle physics experiments, but synergies and developments in other fields of science such as medicine, nuclear, fusion and space applications are pursued. Framework of the collaboration together with recent results in hybrid and monolithic silicon sensor technologies as well as in other wide band gap semiconductor materials such as SiC and diamond will be presented. The key focus of the recent years was achieving high spatial (few microns) and temporal resolution (few tens of ps) at the same time, the so-called 4D detectors. A key requirement is achieving gain in highly segmented devices with a fully active detector surface. Apart from silicon detectors, where intensive progress was made in recent years, gain SiC detectors are also showing rapid progress.

# Assessment of underwater radiation detector at radioactive contaminated area in Fukushima

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Following a nuclear power plant (NPP) accident, radioactive materials can be dispersed into the air, leading to severe contamination of nearby areas. As a result of the Fukushima accident, although much of the land has been cleaned through decontamination efforts, many rivers, reservoirs, and lakes are contaminated with accumulated radioactive cesium. This is due to the challenges of decontaminating underwater environments. In response to the need for monitoring the underwater contamination, an in situ underwater radiation detector was developed to estimate radioactivity in aquatic environments.

The detector consists of a 3-inch NaI(Tl) scintillator, a signal processing unit, and a multi-channel analyzer (MCA) to measure the gamma radiation spectrum. A cylindrical lead shield is designed to focus on the underwater bottom by attenuation gamma radiations from the lateral position. A Monte Carlo simulation was conducted to determine the effective source volume of a cylindrical shape with a radius of 30 cm and a depth of 20 cm. The detection efficiency for the system was calculated through the simulation, focusing on Cs-134 and Cs-137 in the source.

In situ surveys were conducted at contaminated rivers and reservoirs in the Fukushima Prefecture to verify the detector performance. Measurements were taken at the underwater bottom to measure the gamma spectrum. Sediment samples were then collected from the measurement sites and analyzed with a high-purity germanium (HPGe) detector to measure the radioactivity of the samples. The measured count rates were compared to the sample activity to evaluate the detector's accuracy.

The count rates at 662 keV demonstrated a linear correlation with the Cs-137 radioactivity in the sediment samples, which ranged from 273 Bq/kg to 6231 Bq/kg. The radioactivity in the sediment was estimated through simulation, and the comparison with the sample activity showed a good correlation, with an error margin of about 13%. These results indicate that the detector is effective for rapid measurements in contaminated areas and can be utilized for radiation monitoring in aquatic environments.

# Characterization of nLGAD detectors under low-penetration radiation

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nLGADs (n-type Low Gain Avalanche Detectors) are a novel advanced technology designed to offer stable and moderate gain, allowing for an improved S/N ratio, targeting the detection of low-penetration radiation. Unlike standard LGADs (built on a p-type substrate), they are particularly effective in applications requiring precise detection of shallow-penetration radiation, with the ultimate goal of achieving sensitivity in the soft X-ray range for imaging applications.

In this study, we present a detailed characterization of nLGADs under deep and near-UV radiation (250–390 nm), performed at the Extreme Light Infrastructure (ELI ERIC) facility (Prague, Czech Republic). Our results demonstrate that nLGADs can detect radiation as short as 250 nm, corresponding to a penetration depth of 5 nm, with a gain of approximately 15. Based on these results, we discuss the necessary improvements to enhance nLGADs for soft X-ray photon sensitivity, including refining the dead layer and developing ultra-shallow junctions. These optimizations are essential to achieve photon counting capabilities, particularly in the water window (282–533 eV).

We also discuss the tentative applications of nLGADs in detecting shallow-penetrating ions, alpha particles in neutron environments, and other radiation scenarios, highlighting their versatility in various detection tasks.

# Exercising work in radiation field by using the Virtual Radioactive Source System (VRSS)

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The presentation presents the possibilities of working in virtual high-dose rate following a procedure developed at the Nuclear Security Department of the Centre for Energy Research (EK NSD). Practicing the radiation survey and radiation search to radiation risk assessment, monitoring surface contamination, to find a lost radioactive source, as well as localization of materials outside of regulatory control e.g. at a radiological crime scene and monitoring is only possible in inactive conditions or in low-dose rate environment according to the ALARA principle. A Virtual Radioactive Source System (VRSS) developed at the NSD makes it possible to simulate “measured” values very close to reality even in a high dose-rate environment but without real radiation hazard for the trainees.

# The study of fading of the PADC detectors irradiated by fast neutrons

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The presented study introduces an observation of the fading of the signal from Solid-State Nuclear Track Detectors made of Poly-Allil Diglycol Carbonate (PADC), which are passive radiation detectors highly sensitive to ions and fast neutrons. The main principle of detection is that the incident particle disrupts the structure of the PADC monomer, resulting in the formation of a latent track along its path. The subsequent etching of the irradiated detector leads to the enlargement of the latent track, creating a cone-shaped hole, visible by the optical microscope as an ellipse-like object on the surface. The number of etched tracks is directly proportional to the measured dose. The set of detectors was irradiated at the Slovak Institute of Metrology with the Pu-Be neutron source under the same conditions and processed under the same conditions for the experiment. Afterward, the detectors were separated into three groups and stored under different conditions; the first, the reference group, was stored under recommended conditions, i.e., at the temperature of -18 °C, the second group was stored at room temperature, sealed in the opaque bag, and the third group was stored at the room temperature exposed to sunlight. The study presents the statistical comparison of the data retrieved from the detectors during the one and half years of analyses.

# Innovative directional detector with 360° source localization coverage

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In the modern landscape of homeland security, the potential acquisition and use of radiological materials by terrorist organizations—primarily in the form of radiological dispersion devices (RDDs), commonly known as “dirty bombs”—remain a pressing concern. Unlike conventional threats, areas susceptible to such attacks lack defined entry and exit points, necessitating the development of efficient methods for detecting and localizing radioactive sources within open and unstructured environments. This task is particularly challenging due to several uncontrollable factors, including the presence of benign radioactive materials, variations in background radiation across time and space, and physical obstructions that may attenuate or scatter emitted radiation.

To address these challenges, we propose a directional γ-ray detection system capable of full 360° source localization. The system is based on a scintillator crystal, read out by an array of silicon photomultipliers (SiPMs) positioned at its base. A specialized algorithm has been developed to estimate the direction of an incident radioactive source by computing the weighted barycenter of the detected counts across the SiPM array. This approach enables precise angular localization while leveraging the compact design and high sensitivity of the system.

Simulation studies demonstrate that the detector effectively identifies a broad range of radioactive sources, covering energies from a few tens of keV to 1.4 MeV, across a full 360° azimuthal range. Given its cost-effective design, particularly with NaI as the scintillation medium, the system is well-suited for large-scale production and deployment in homeland security applications. Additionally, its versatile architecture allows for integration into both ground-based and airborne platforms, facilitating large-area radiation surveillance with minimal operational costs.

A prototype of the directional detector, constructed with a CsI scintillator, was experimentally tested using a $^{60}$Co source placed at a distance of 8 cm. The algorithm’s performance in estimating the source’s azimuthal angle (φ) demonstrate a resolution of approximately 8°. These results highlight the system’s potential for real-world implementation in security and environmental monitoring applications.

More tests are under way examining larger source distances, different source type together with the development of more sophisticated ML localization algorithms.

# Engineering of emission properties of Ce-doped yttrium aluminum gallium garnet by varying gallium content

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Scintillation response time becomes currently the bottleneck property of scintillators to be exploited in fast scintillator detectors for many applications in coming high energy physics experiments and high-spatial-resolution medical imaging devices. Cerium-doped yttrium aluminum garnet (YAG:Ce) is an efficient phosphor in white LEDs but its application as a fast scintillator suffers from the response delay and loss in efficiency due to electron trapping. Burying the trapping levels in the conduction band by introduction of Ga in the garnet lattice and increasing the energy barrier for the thermal depopulation of the emitting $Ce^{3+}$ ions by introducing Gd led to the development of Ce-doped gadolinium aluminum gallium garnet (GAGG:Ce) exhibiting an excellent efficiency. Meanwhile, a faster luminescence decay time of this scintillator is desirable. We report on the results of our study of the influence of Ga content in the multicomponent garnet on the positions of energy levels and luminescence properties of the scintillator.

A set of 8 samples of $Y_3(Al_{1-x}Ga_x)_5O_{12}$:Ce (YAGG:Ce) single crystals with Ga content $x$ ranging from 0 to 1 were prepared by the Czochralski method. Time-resolved photoluminescence (PL) spectroscopy experiments with an overall time resolution of 200 ps were performed at the excitation by a femtosecond laser and using time correlated single photon counting. The internal quantum efficiency (IQE) was estimated by using the three-measurement method for measurements in an integrating sphere. Time-resolved cathodoluminescence (CL) spectroscopy experiments were carried out with temporal resolution of 100 ps using spectrometric system *Attolight Chronos*.

The PL and CL spectra evidenced the dominance of $Ce^{3+}$ emission in the entire $x$ range except of $x = 1$. The temperature dependences of PL intensity and decay time measured in the temperature range from 80 to 600 K can be fitted by the Arrhenius formula only for the samples with low Ga content ($x < 0.6$). For these samples, the increase in $x$ results in a slight increase of IQE and a decrease of the decay time at a similar rate. In YAGG:Ce with $x > 0.6$, the decay deviates from exponential and becomes substantially faster, however, at the expense of IQE. As the Ga content increases up to $x \approx 0.8$, CL intensity and decay time decrease relatively slowly, whereas both drop down sharply afterwards.

The spectroscopic results revealed a linear dependence of the band gap on Ga content, enabled us to estimate the energy barriers for thermal depopulation of the emitting level in $Ce^{3+}$, and provide information for choosing an appropriate tradeoff between the emission efficiency and decay rate.

# MUltipurpose handy Dosimetric Device (MUDDy)

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For many years, various recombination detectors, methods and dosimetric systems have been developed in National Centre for Nuclear Research and used in various applications. Development can be split into three areas:

- detectors suitable for neutron and gamma indication (in general discrimination radiation by linear energy transfer which means that not only neutrons can be registered),
- surrounding system: electrometers, high voltage supplied by battery systems and control module,
- control module which consists of remote communication, an integrated acquisition system and the main function of build-in mathematical algorithm for separation radiation by its quality index.

The article will describe the developed **MU**ltipurpose handy **D**osimetric **D**evice (MUDDy). As an introduction, an overview of dosimetric devices will be presented. The body of the article will be devoted to the components building the system with connection to the system functionality, dosimetric methods and operational radiation information. To demonstrate the usefulness of MUDDy, the results of measurements performed in calibration-reference gamma (Co, Cs) and neutron fields (Pu-Be, Cf) as well as real tests in places with potential exposure to workers and civilians in a nuclear center (MARIA reactor), by an accelerator, and in medical centers will be shown.

In a separate section, historical worldwide use of recombination techniques in various applications will summarize the subject with scientific references Also a short overview with references concerning the recombination phenomenon will be included. To underline the importance of recombination process used in presented dosimetric system one must know that recombination of ions in gases occurs immediately after ionization. One of recombination phenomena, named local recombination depends very strictly on the type of radiation causing ionization (in scientific terms: it depends on linear energy transfer, LET). This can be used for the separation of components in mixed radiation fields and provides information of radiation quality index due to the different biological effectiveness of the radiation in matter (for this reason tissue equivalent materials and specific gas fillings are used for constructing recombination detectors to be representative to radiation protection applications and treatment planning systems).

# Experimental evaluation of mixed lutetium-based scintillators for nuclear medicine detectors

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Many modern photonic technologies used for radiation detection owe their development to a variety of scintillation materials. Among these, solid-state crystalline substances play a key role in detecting γ-quanta in various medical applications, where they convert high-energy photons into visible light. LFS (Lutetium Fine Silicates) crystals, from Zecotek Photonics Inc., are a bright and fast scintillation material suitable for medical imaging systems and high-energy photon experiments. They retain the beneficial properties of LSO (Lutetium Orthosilicates), such as non-hygroscopicity, high density (7.35 g/cm$^3$), decay constant (25-33 ns), and high light yield (~40 photons/keV). Additionally, their spectral response is compatible with the spectral detection of various photomultipliers (SiPMs, PMTs). These properties result in good energy resolution values (~10%), making them appropriate for PET devices and PET/CT or PET/MRI systems. This study aims to evaluate 3x3 mm$^2$ LFS-3 pixellated crystals of varying thicknesses (from 4 to 20 mm), under 662 keV excitation, by acquiring energy spectra and calculate energy resolution, photofraction and sensitivity values. Each crystal was optically coupled to a SiPM and placed in a light-tight black box. All surfaces of the crystals were wrapped with teflon tape and kept in the dark for 24 hours before measurements to minimize the phosphorescence effect. Digitization, triggering and processing of the pulses were acquired by using a CAEN desktop digitizer and the DPP-CI control software. Results demonstrate excellent values for all parameters studied, indicating that LFS-3 scintillators are highly promising for advanced Nuclear Medical Imaging applications due to their overall performance.

**Keywords:** inorganic scintillators, silicon photomultiplier, energy resolution, photofraction, sensitivity, lutetium fine silicates, lutetium orthosilicates

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# Luminescence efficiency of a single crystal lutetium orthosilicate ($Lu_2SiO_5$:Ce) scintillator under the influence of different temperatures in the radiology energy range

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**Introduction.** Single crystal scintillators find applications, besides from medical imaging, in extreme environmental conditions (i.e. high temperatures or radiation fluxes), such as in nuclear reactor monitoring, non-destructive testing (NDT), pipelines in the oil and gas industry, geophysical probes for drilling, space and marine exploration, etc. In this context, the aim of this study was to examine the effect of temperature on the luminescence performance of a lutetium orthosilicate ($Lu_2SiO_5$:Ce) single-crystal scintillator, which has already been used in positron emission tomography (PET) systems. Its performance was compared with materials that have been previously measured from our laboratory, under similar conditions.

**Materials and Methods.** $Lu_2SiO_5$:Ce has a density of 7.4 g/cm$^3$, a light yield of 30 photons per keV and a maximum of emission at 420 nm, rendering it a very good choice for nuclear medicine detectors. The drawback of this material is its intrinsic radiation background of about 300 cps/cm$^3$. For the experiments, a CPI CMP 200 DR series X-ray tube was set to a constant high voltage (90 kVp) to expose the $Lu_2SiO_5$:Ce sample to X-rays under different temperature conditions (24.8 $^o$C - 171 $^o$C). An additional 20 mm Al was added to the internal filter of the X-ray tube to simulate the attenuation from the human chest. The 10X10X10 mm$^3$ crystal sample was heated using a Perel 3700-9 2000W heat gun. The temperature on the crystal surface was monitored using an Agilent Technologies U1253A digital multimeter, connected to a U1185A (J-Type) thermocouple with a temperature sensing adapter.

**Results.** The luminescence efficiency (LE) of the $Lu_2SiO_5$:Ce crystal decreased by 51.76% with increasing temperature in the examined temperature range. In comparison, with similar materials previously measured by our laboratory, the results for $Lu_2SiO_5$:Ce showed a similar percentage decrease in their luminescence efficiency, with materials such as Lanthanum Chloride ($LaCl_3$:Ce) (46.04% decrease in the produced light per X-ray exposure), smaller than the Cerium Bromide ($CeBr_3$) crystal, which showed a decrease in its luminescence by 74.35% and larger than Lutetium Aluminum Garnet ($Lu_3Al_5O_{12}$:Ce) in which its luminescence efficiency appeared to be unaffected by increasing temperature in the specific temperature range.

**Conclusions.** The data on the thermal behavior of lutetium orthosilicate single crystal showed that the material's luminescence has been reduced by approximately half, in the examined temperature range, showing the significance of such measurements for applications in extreme environments.

# An underwater gamma-ray spectrometer for maritime inspection in terms of nuclear security

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The underwater in-situ gamma-ray spectrometry is a valuable tool for the detection of naturally occurring and anthropogenic radionuclides in the marine environment. At HCMR laboratory a lot of effort has been made to develop reliable medium and low-resolution gamma-ray spectrometers to operate in different marine environments from shallow water masses till the very deep-water masses. In this work, a new gamma-ray spectrometry system is designed to inspect dangerous nuclear materials inside and under the hull of the ships. The benefits of the developed detection system (named mini-KATERINA) are the small dimensions, the light weight, the low power consumption and the capability to be easily integrated in robotic vehicles. The detection system is calibrated using reference sources in the air and in the aquatic environment. The experimental data were reproduced with simulation results. Furthermore, the system is integrated in a marine drone for field operations. Several tests were performed to control the stability of the system and its efficient operation in the marine environment. As a first evaluation, measurements were performed in the seawater using as simulant a natural radioactive source of KCl (inside and outside of the hull). The underwater nuclear detection system integrated in a robotic vehicle will be utilized for nuclear security needs in different areas of interest (e.g. ports).

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# Crystallographic properties of TlBr crystals grown by the Bridgman method for gamma-ray detectors

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Thallium bromide (TlBr) has been recognized as a compound semiconductor material with high atomic number and high density and gamma-ray detectors based on TlBr crystals achieves high detection efficiency and high gamma-ray energy resolution in comparison to previous CdTe and CdZnTe based semiconductor detectors. Melt growth techniques such as Bridgman methods and travelling molten zone method have been employed for growth of TlBr single crystals. TlBr crystals grown along a quartz ampoule and crystallographic orientation and quality of TlBr crystals depend on growth rate, temperature gradient in a furnace, a seed crystal and material purity. In this study, a TlBr crystal with 1 inch in diameter and 10 cm length was grown by the Bridgman method without a seed crystal and 5 ~ 8 mm thick wafers were sliced from the ingot. The pole figure measurements of (110) reflection were carried out by an X-ray diffractometer and crystal orientation and growth direction along the ingot were determined from pole figure mapping of TlBr wafers. In addition, crystallographic uniformity of TlBr wafers has been analyzed by measuring the rocking curves at (110) reflection on the wafers.

# A highly efficient 2”x2” inch cylindrical NaI(Tl) gamma ray detector

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Scintillation detectors based on inorganic crystals of NaI(Tl) and fotomultipliers(PMT) are used in gamma-ray spectrometry due to their advantages. For this was selected a 2”x2” inch NaI(Tl) scintillator probe with a radioactive source of $^{241}$Am placed on the front face of the crystal, inside the detector Aluminium housing. The activity of the radioactive source was 0.1μCi. The photomultiplier type was AVP56 made in France and the high bias voltage had a value of +900V. The signal from this detector was sent to a spectroscopy amplifier N968 CAEN made in Italy. For a fixed fine gain, the coarse gain of the amplifier was set for the four values: 100, 200, 500 and 1k. At the 1k coarse gain, the energy spectra have a small noise and the energy resolution a value of 10.2% at peak energy of 59.54keV. For the smaller coarse gain, the energy resolution increases to bigger values. The full energy peak efficiency was calculated for each energy peak of the used radionuclides ($^{241}$Am,$^{60}$Co,$^{133}$Ba, $^{137}$Cs) which were situated at 2cm from detector, on the symmetry axis. All radioactive sources were point radioactive sources. The calibration efficiency curve was obtained. This scintillation detector allows to perform very good gamma spectra with a multichannel analyzer type MCA 8k N957 from CAEN. The software of acquisition, display and analysis was InterWinner 6.0, which is dedicated for NaI(Tl) detectors.

# Natural radionuclides in groundwater in two different geological regions of Brazil

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Natural radionuclides in groundwater were analyzed in samples collected in two different geological regions of Brazil. Groundwater is a main source of drinking water. Its quality is influenced by natural processes, including continuous interactions between water and rock formations, which can alter its chemical composition and determine its suitability for consumption.

There is very scarce data on the radioactive content of water despite the high demand for drinking water in some regions of the country. Therefore, the objective of this study is to evaluate the physical, chemical and radiological parameters of groundwater from wells in the semi-arid region, with emphasis on the alpha-radioactive isotope of radium ($^{226}$Ra) and the content the radioactivity in water from uranium rich area. The goal is to assess if the observed slightly elevated levels of radioactivity concentrations of some radionuclides in water in the second region result from the artificial process of human exploitation of uranium ore or from natural concentrations of these radionuclides in the soil.

Water samples collected at different locations were analyzed for the activities of $^{226,228}$Ra radium isotopes with the use of ultra-low background TriCarb5110TR from Canberra-Packard liquid scintillation counter.

# Determination of natural radioactivity of wheat flour samples from selected Albanian markets

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In this paper, natural radioactivity levels of $^{226}$Ra, $^{232}$Th and $^{40}$K were determined for sixteen brands of wheat flour samples using HPGe gamma-ray spectrometry. Natural radioactivity measurements in foods are critical for regulating radiation levels to which mankind is directly or indirectly exposed. Since wheat flour is one of the essential foods, the ambition to establish a national baseline of radioactivity exposure from various brands of wheat flour samples that are available in Albania (Tirana City) markets is very important. The average activity concentrations of $^{226}$Ra, $^{232}$Th, and $^{40}$K in wheat flour are found to be (6.3 ± 0.6), (0.25 ± 0.08), and (45.9 ± 2.7) Bq kg$^{-1}$, respectively. The results demonstrate that specific activity concentrations in wheat flour samples are much below the world average values of 30 Bq kg$^{-1}$ for $^{226}$Ra, 45 Bq kg$^{-1}$ for $^{232}$Th, and 420 Bq kg$^{-1}$ for $^{40}$K. The current study plays a special role in the continuation of other similar studies to create a clear picture on radioactivity levels in foodstuffs in Albania.

**Keywords:** natural radionuclides, wheat flour, gamma spectrometry

# Legacy of anthropogenic contaminants on Norwegian glaciers

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Accumulation of contaminants deposited on glacier surfaces is not persistent. Contaminants are eventually evacuated from glacier surfaces with meltwater runoff or via direct melting of glacier ice at glacier termini. Because more than a billion people use water from glaciers for drinking purposes and irrigation, the knowledge of the threats associated with glacier contamination is important. However, even though glaciers in Norway are important components of the landscape, a source of water for rivers, unique ecosystems, and a place of exploration for tourists and alpinists, studies on their contamination are not well developed. In this work, we estimate the sources of contaminants, processes of their bioaccumulation, and the ultimate fate of natural and artificial radionuclides ($^{210}$Pb, $^{137}$Cs, $^{241}$Am, $^{238,239,240}$Pu) and heavy metals (Cd, Pb, Hg, As, Cu, Ni, Zn, Cr, Co) deposited on five Norwegian glaciers (Nigardsbreen, Tuftebreen, Austerdalsbreen, Storbreen, Leirbreen). Three of them belong to the Jostedalsbreen ice cap, which is the largest ice cap in mainland Europe, and are outlet glaciers with large accumulation areas on high-elevation plateaus, while previous research on radioactive contamination focused on relatively small glaciers. Storbreen and Leirbreen are valley glaciers in the western part of the Jotunheimen mountain range. Leirbreen overlooks Sognefjellsvegen, the highest mountain pass road in Scandinavia.

The anthropogenic (artificial) radionuclides were released to the environment from nuclear weapon testing and nuclear accidents (Chernobyl, Fukushima, and many other less severe cases). Our research focuses on the role of cryoconite - a peculiar kind of biogenic sediment formed by wind-borne particles and pigmented microorganisms found on glacier surfaces. Cryoconite is an efficient sink for contaminants on glaciers and a hotspot for microbes living on glacier surfaces.

In our study, we observed that radionuclides and heavy metals concentrations in cryoconite are up to three orders of magnitude higher than the concentrations found in mosses, soils, and lake sediments in the surrounding proglacial environment.

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# Radionuclides present in chemical fertilizers available on the Polish market

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Fertilizers are used in plant cultivation to enrich the soil with nutrients essential for the growth of plants, improve the soil's physicochemical properties and replenish nutrients removed from the soil as a result of agricultural activities. On the other hand, fertilizers may contain traces of heavy metals and isotopes from uranium and thorium chains. They are produced from minerals that may contain increased concentrations of radioisotopes. These isotopes can be absorbed by plants and vegetables and thus incorporated into the human body. Therefore, the aim of the research was to evaluate chemical fertilizers in terms of long-lived radioactive isotopes. Thirty-two fertilizers available on the Polish market were ground, dried and homogenized. Samples were placed in Marinelli containers, weighed, taped to prevent radon leakage, and left for a month to achieve radioactive equilibrium between $^{226}$Ra, $^{228}$Ra and their daughters. The $^{226}$Ra, $^{228}$Ra and $^{40}$K concentrations were determined using a gamma spectrometer with an HPGe detector with a 60.7 mm germanium crystal diameter from Canberra-Packard. The detector is cooled using Cryo-Pulse 5 Plus and an electrically powered cryostat. Subsamples were prepared for $^{234,238}$U determination. Uranium measurements were performed using 7401VR (from Canberra – Packard, USA) and Alpha Analyst™ (from Mirion Technologies, USA) alpha spectrometers. These spectrometers are equipped with silicon semiconductor detectors with 300 and 450 mm$^2$ active area. Before measurements, the samples were subjected to chemical preparation. The samples were digested using a microwave unit and mineralized with hot acids: HF, $HNO_3$, HCl with $H_3BO_3$. Uranium was preconcentrated with iron and then co-precipitated with ammonia. Uranium was separated from other alfa-emitting radionuclides using ion exchange chromatography. The results of measurements of radioactive isotopes in the analyzed fertilizers will be presented, and their impact on the emissions of these isotopes into the environment will be discussed. The radiological hazards connected with the exposure of farmers and factory workers to external gamma radiation emitted from fertilizers were assessed based on various risk indicators.

# Comparing the radioactivity of fertilizers and soil from uncultivated and fertilized fields

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For nearly half a century, Greek farmers utilize a quiver of fertilizers containing different ingredients, primarily phosphorus, nitrogen, and potassium. The composition of the soil of fertilized fields slightly changes through the decades due to the continuous application of these substances. In this study, soil samples from never-cultivated and fertilized fields in Greece, along with samples of commonly used fertilizers, were analyzed using high-energy resolution γ-spectroscopy to determine their composition of natural and anthropogenic radionuclides. An interesting finding was the slightly higher concentrations of natural radioactivity (Ra-226, U-238, and K-40) in fertilized fields compared to neighboring never-cultivated fields. In contrast, the concentration of Cs-137, a radionuclide originating from the Chernobyl disaster, was higher in the upper soil layer of never-cultivated fields. Additional measurements of radioactivity concentrations in fertilizers commonly used in Greek agriculture showed a correlation with the radioactivity levels observed in fertilized soil.

# Analyses of water samples from former uranium mining sites in Central Asia and Germany: Results and lessons learned

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The Central Asian region has a long history of uranium mining. Almost with the beginning of development and production of nuclear weapons, the extraction of raw materials in the region has begun. Before the advent of underground leaching, all works were carried out using the mining method in this period. As a result, sites with large amounts of radioactive waste were created, posing a threat to the public and the environment. After the collapse of the Soviet Union, these sites were hastily closed and, in some cases, simply abandoned. Remediation of this legacy requires significant methodological, personnel, technical and financial investment, which the Central Asian countries often do not have.

The international community direct efforts to mitigate and improve the radiation situation in the region. This paper describes the approach and results of a series of practical training courses aimed to identify the concepts followed and potentials to implement an appropriate long-term monitoring and improve the capabilities of laboratories in Central Asian countries in conducting of water monitoring. The general focus aroused from the fact that the procedures followed during the water sampling and analyses are a relevant source of errors if harmonized procedures do not follow. Due to the fact that cross-border transfer of water pollution is acute in the region, the establishment of unified procedures as well as the exchange of expert knowledge across the national borders of countries within catchment areas containing uranium mining and milling legacies are important. The training included practical field work at uranium mining sites in the host country (Uzbekistan) and in Germany as well as laboratory analyses. Comparative analyses were carried out during these courses, the comparison and discussion of which allowed to understand the limits of the various procedures followed and derive lessons learned in order to align and optimize the long-term monitoring in neighboring countries and the respective participating national institutions in a comparable way.

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# TENORM nuclide trophic transfer in the Danube Delta

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Natural radioactivity is present in every ecosystem on the face of the planet, and since the second half of the 20th century we deal with Technologically Enhanced Naturally Occurring Radioactive Materials in most of the cases, even if the anthropogenic contributions are often low. Gamma spectrometry is a powerful method for environmental sample analysis and enables precise quantitative determinations with low detection limits, which suits tracking radioelement accumulation, would they be natural series, non-chain or artificial.

The Danube Delta, with its huge natural reservations, is well known for its uniqueness, diversity, but also fragility of the ecosystems, which are subject to extended interdisciplinary research activities. However, in terms of radioactivity analysis, there is a lack of information, at least from the spectroscopic perspective. The Gorgova natural reservation provides interesting specimens for studying trophic transfer and bioaccumulation, which we investigate by means of gamma analysis, in order to evaluate radionuclide dynamics.

We present the results of this study - to the best of our knowledge the first of its kind in the area - and the interpretation meant to allow better comprehension of human activity impact in the area and implicitly potential mitigation methods. The correlations arising from transfer factor and trophic transfer studies need to be analyzed in order to set the basis of our next goal, namely using the ecosystem itself as a local natural radioactivity monitoring system.

# Phosphogypsum valorisation through circular economy processes: review of the state of the art and perspectives from the FIC-FIGHTERS project

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Phosphogypsum is a by-product of the wet production process of phosphoric acid from phosphate minerals. Since the 1950s, many industries in Europe have used this process for the production of fertilizers and detergents. Processing residues and waste were often dumped near production facilities or dispersed in sensitive areas such as river estuaries or coastal lagoons, resulting in the release of toxic substances into the environment and damage to the ecosystem. In Europe, to this day, there are still many areas with unconfined phosphogypsum deposits, which pose significant environmental, social and economic problems. Phosphogypsum is mainly composed of a calcium sulphate matrix and contains natural radionuclides (mainly $^{226}$Ra, $^{210}$Pb, $^{210}$Po) in different concentrations, depending on the composition of the starting mineral; it can also contain elements such as phosphorus and fluorine, heavy metals as zinc, copper, chromium, cadmium and also some Rare Earth Elements (REEs). From the perspective of the circular economy, they are therefore increasingly considered a resource from which extract new raw materials.

The project FIC-FIGHTERS (HORIZON-CL6-2023-CIRCBIO-2) (To a Fair, Inclusive, Circular and Health cities: Transformation of Phosphogypsum (PG) into commercial products through sustainable and zero-waste processes) aims to test and demonstrate circular economy solutions for the recovery of phosphogypsum dumps in Europe by transforming them from waste to valuable resources. The Project promotes interdisciplinary and international cooperation through case studies in six European sites. In particular, it aims to valorise phosphogypsum in key sectors such as the battery, construction, packaging, detergent and fertilizer industries. The project involves the construction of a pilot plant to demonstrate the sustainable production of raw materials like Rare Earth Elements (REEs), phosphorus, sodium sulphate, aluminium hydroxide, ammonium sulphate and calcium carbonate starting from phosphogypsum. The ICMATE-CNR Radiochemistry and Radioecology Group is involved as the only Italian partner supporting the scientific and technological research of the project and as a reference for the Italian case studies. In this work, the main options currently under study for the valorisation of phosphogypsum through circular economy processes are presented, evaluated and the activities planned within the Horizon Fic-Fighters project are presented.

**Acknowledgments:** This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement N° 101135157 https://fic-fighters.eu/.

# Application of a pedestrian gamma spectrometric survey when assessing the radioecological situation of mothballed uranium mines in Northern Kazakhstan

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The development of uranium deposits in the Republic of Kazakhstan began in the 40s-50s of XX century. Until the mid-90s, uranium in Kazakhstan was mainly mined in the North Kazakhstan uranium ore province, where the main uranium inventory of endogenous deposits is concentrated. By the mid-90s, owing to the crash in prices of uranium mining products followed by the suspension of production, virtually all waste storage areas of facilities (mines) that were developing uranium mining deposits proved to be unattended.

Currently, studies are ongoing under the grant project of the Ministry of Education and Science of the Republic of Kazakhstan AP19674615 to assess the consequences of the developed uranium deposits in the southern North Kazakhstan region. As planned, at the initial stage of the project, a reconnaissance (preliminary) survey was conducted at a number of mothballed uranium mining facilities (MUMF). According to the reconnaissance survey data, the vicinity of the Grachevskoye MUMF and the village of Saumalkol were selected for a detailed survey. One of the main techniques of radioecological survey is a pedestrian gamma spectrometry. This technique was applied to survey the premises of the Grachevskoye and Kosachinoye MYMF as well as the settlements of Saumalkol, Sarytobek and Novoukrainka. In addition, a gamma-ray survey was carried out along 3 routes in the section of ore transportation from the Grachevskoye MUMF to the Saumalkol railway station and along the railway.

No sites of elevated cps values were found on the premises of the Kosachinoye mine and in the territory of the Sarytobek settlement. Within the Grachevskoye MUMF, the total activity values ranged from 153 to 974.5 cps. Zones of outliers cover as large as 40% of the surveyed area and are mostly developed in the northern and southern parts of the site. The zone of maxima within the site is spotty and is identified in the southern part of the site. Within the data, the EDR values reach 2.2 μSv/hour.

In the territory of the Novoukrainka village, the total activity values ranged from 153 to 550.5 cps. The zones of outliers up to 500 cps are round-shaped and are in the western and southeastern parts of the village. In the territory of the Saumalkol settlement, a survey was carried out at 10 0.2 km² sites. The total activity values ranged from 153 to 706.5 cps. The zones of outliers up to 500 cps are identified at 4 sites in the northwestern part of the settlement.

According to the results of the route gamma spectrometric survey, sites of the elevated total activity up to 480 cps were detected.

According to the preliminary data, the detected sites of the elevated total activity resulted from the outcropping weathering crust of hard rocks containing the elevated concentrations of naturally occurring radionuclides.

# Assessment of the effect of Sr-90 on the conductive tissues of the common bean (*Phaseolus vulgaris*)

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Stress in plants is a condition in which, under the influence of an external factor on the body, first there is a violation of the functional state, then its normalization, and a final increase in resistance. Studying the effect of radioactive soil contamination on conductive tissues will make it possible to understand the mechanisms of adaptation and protection of plants from the negative effects of radiation pollution. Common beans (*Phaseolus vulgaris*) were used as an experimental crop. The choice of the studied crop is due to the short growing season, and resistance to pests and diseases. Beans were grown under controlled conditions in an experimental greenhouse on soil samples from the site "4A". The main contaminant in the soil of this site is the radionuclide Sr-90, whose activity reaches $5\times10^8$ Bq/kg. For 3 consecutive generations of beans, significant changes in the thickness of conductive tissues were established (at $p<0.05$). The maximum values were noted in the 1st generation: the thickness of the xylem and phloem of the stem was 202 and 187, and the thickness of the leaf was 101 and 88 μm. Lower values were noted for stem and leaf tissues of the 2nd and 3rd generations. The thickness of the stem xylem was 189 and 120 μm, and the phloem was 175 and 109 μm. The leaves of the 2nd and 3rd generations had xylem thicknesses of 91 and 74, and phloem thicknesses of 85 and 71 μm, respectively. Minimum were noted for the control group: the thickness of the xylem of the stem and leaf was 119 and 71, and the thickness of the phloem of the stem and leaf was 107 and 68 μm. A comparative analysis showed that the thickness of the xylem of the stem and leaf in the experimental group of the 1st, 2nd, and 3rd generation was higher than in the control group by an average of 42, 37, 2, and 29, 23, and 6%, respectively. The difference in the thickness of the phloem of the stem and leaf of the 1st, 2nd, and 3rd generation relative to the control was 43, 38, 2%, and 22, 3, 3%, respectively. It should be noted that the thickness of the conductive bean tissues of the 3rd generation practically did not differ from the control. As a result of the study, it was found that a high level of specific activity of Sr-90 in the soil significantly affects the thickness of the conductive tissues of the bean. The thickness of the conductive tissues in 3 consecutive generations of beans varied in descending order: 1st generation > 2nd generation > 3rd generation ≥ control group. The established increase in the thickness of the conductive tissues of the bean stem and leaf is a stress response aimed at maintaining homeostasis at the tissue level of the biological organization. The obtained patterns characterize the mechanisms of plant adaptation to a high level of soil contamination with Sr-90 radionuclide.

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# Comparative assessment of HTO aerial uptake by different agricultural crops

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In the period from 2019 to 2021, a series of experiments were conducted to study the absorption of $^{3}H$ by agricultural crops in an area heavily polluted with atmospheric HTO at the former nuclear test site in Kazakhstan. A quantitative assessment of the absorption of $^{3}H$ by typical crops (lettuce, tomatoes, peppers and beans) grown throughout Kazakhstan, in the case of short-term exposure to HTO vapors, is given. Plant samples were collected during and after exposure and analyzed for their $^{3}H$ content. $^{3}H$ in plants was considered in two chemical forms: as the "tissues free water tritium" (TFWT) and "organically-bound tritium" (OBT). During the entire exposure period, the concentration of $^{3}H$ in the water contained in the leaves and in the surrounding air was of the same order. The concentration of $^{3}H$ in the water contained in the stems and edible parts was 1-2 orders of magnitude lower than in the ambient air. The average value of the TFWT/HTO ratio in the leaves and the edible part was (0.73 = 0.2) and (0.04 = 0.002), respectively. The concentration of OBT is 1-2 orders of magnitude lower than that of $^{3}H$ in the free water of tissues. Upon absorption of HTO from the air, the distribution of $^{3}H$ in non-leaf crops was as follows: leaves - stems - fruits (decreasing row). After exposure, a small amount of $^{3}H$ is firmly retained in plants for a long time. The concentration of tritium in tissue water correlates closely with atmospheric HTO ($r$=0.8), weakly correlates with temperature ($r$=0.4) and relative humidity ($r$=-0.4), and moderately correlates with solar radiation intensity ($r$=0.6) at a confidence level of 0.05. No reliable relationship was found between OBT to water and atmospheric HTO. The concentration of tritium in free water in the leaves is closely correlated with its concentrations in stems ($r$ = 0.9) and fruit ($r$ =0.8). The concentration of organically bound tritium in the leaves also correlates closely with the concentrations in the stem and fruits ($r$ = 0.9).

The results of the study should be taken into account when assessing the impact of HTO emissions on the population living near nuclear power plants and other radiation-hazardous facilities.

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# Assessment of radioecological risks for Siberian roe deer (*Capreolus Pygargus* Pal., 1771) inhabiting the Semipalatinsk Test Site

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The Semipalatinsk Test Site (STS) has long been a place for testing of nuclear weapons and the damaging effects of radioactive warfare agents (RWA). After the closure of the test site, great emphasis was placed on assessing the radioecological situation of the STS area and a large amount of work was carried out to secure of the most dangerous sites. However, the complete remediation of such sites requires large financial and labor costs and cannot be fully resolved in the shortest possible time. Therefore, it is necessary to determine priorities in carrying out such work. Research aimed at assessing the impact of the effects of the tests conducted at the STS make it possible to assess the most dangerous sites and focus special efforts on them. One of the methods of such an assessment is the calculation of radiation dose exposure on biota, which is widely used in the world as a method for assessing the probability of risks of various effects in representatives of biota. Of particular interest are the large ungulates that inhabit in the STS area, some species of which are consumed by humans. One of the common species at the STS is the Siberian roe deer (*Capreolus pygargus* Pal., 1771). The calculation of the radiation dose exposure to this species may reflect the possible radiation dose exposure to other species of ungulates inhabiting the STS area. Therefore, the purpose of the conducted surveys was to determine the possible risks to the Siberian roe deer population (*Capreolus pygargus* Pal., 1771) inhabiting various parts of the STS area.

In the course of the conducted surveys, the calculated expected dose rate for roe deer inhabiting the “conditionally background” of the STS area will not exceed 3.6 μGy/day, and for roe deer inhabiting the area of radioactive fallout in the form of traces in the STS area will not exceed 144 μGy/day. The main part of the dose is formed due to internal irradiation from the $^{90}$Sr. According to the scale of radiation effects on biota, depending on the dose rate of chronic exposure of representatives of various animal species, the calculated dose for the “conditionally background” STS areas correspond to the natural radiation background. The expected dose in the area of radioactive fallout in the form of traces at the STS may reach the threshold for a minor increase in cytogenetic effects and stimulation of sensitive vertebrate species. In turn, in the area of STS sites, the maximum possible doses can vary between $1.6\times10^4$-$17\times10^7$ μGy/day. There are risks of a fairly wide range of effects, including fatal radiation sickness (at the Experimental Field, 4 and 4A sites). According to the risk of various effects, the surveyed areas can be arranged in the following decreasing series: RWA test sites (4 and 4A) > Experimental Field site> Degelen site > Balapan site > Sary-Uzen site > areas of radioactive fallout in the form of traces at the STS > “conditionally-background” STS areas.

# Artificial radionuclides in the plant cover when monitoring NFC facilities

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The development of up-to-date technologies allows for the improvement and optimization of many processes in the human life, including in the field of atomic energy regarding the radiation safety at NFC facilities. Plants are known to be usable while monitoring NFC facilities. Studies of the parameters of the accumulation of artificial $^{137}$Cs, $^{90}$Sr, $^{241}$Am, $^{239+240}$Pu from the soil by plants, as well as the features of the content of $^{3}$H (FWT and OBT) in the vegetation cover were conducted at NFC facilities in the territory of the Semipalatinsk Test Site (STS).

To assess the content of artificial radionuclides in the vegetation cover, the complex of the research reactors of the pulsed graphite reactor (RRF IGR) and the research high-temperature gas-cooled reactor of the Baikal-1 (RRF 'Baikal-1') located at the STS were selected. Sampling plant points are located across the perimeter of both facilities at an equal distance from one another (~ 30 meters). The samples were collected at the summertime (June, July, August) for three years. Measurements of radiometric parameters showed that β-particle fluence in the study area is <0.10 part/(cm$^2$×min), the equivalent gamma dose rate on the soil surface varies on average from 0.10 to 0.14 μSv/h.

The content of $^{241}$Am, $^{137}$Cs in the vegetation cover across the perimeter of the RRF IGR is below the detection limit of the methodological hardware in use. The exception are 2 points with numerical values of $^{137}$Cs content (0.6±0.1 and 0.5±0.1 Bq/kg). The radionuclide content in the vegetation cover across the perimeter of the RRF 'Baikal-1': $^{241}$Am – from <0.1 to 0.9±0.2 Bq/kg, $^{137}$Cs – <0.2 to 1.7±0.3 Bq/kg, $^{239+240}$Pu – <0.1 to 0.5±0.1 Bq/kg, $^{90}$Sr – below the limit detection of the methodological hardware in use.

The activity concentration of FWT in the vegetation cover across the perimeter of the RRF IGR ranges from <4 to 17 ± 3 Bq/kg, RRF 'Baikal-1' – <4 to 50±7 Bq/kg. At the same time, July accounts for the peak content of FWT in plants in the vicinity of the RRF IGR and Baikal-1 – up to 17±3 Bq/kg and up to 50±7 Bq/kg, respectively. Quantitative values have also been determined for OBT – from <4 to 50±12 Bq/kg in the vicinity of the RRF IGR, from <4 to 35±9 Bq/kg in the vicinity of the RRF 'Baikal-1'. The quantitative values detected for the activity concentrations of radionuclides in plants across the perimeters of the facilities, in general, point to their possible presence in the adjoint media from the perspective of accumulative bioindication.

# Determination of selected radionuclides by gamma spectrometric analysis through soil profiles in Fojnica area, B&H

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Monitoring the migration of natural and artificial radionuclides through soil is a particular challenge. Therefore, this study aimed to evaluate the vertical distribution of radionuclides ($^{232}$Th, $^{226}$Ra, $^{40}$K and $^{137}$Cs) through selected soil depths (0-10, 10-20, 20-30 cm) at three sampling sites in the Fojnica area in order to evaluate the possible effect of the presence of radioactive thermal water on the radionuclide content of the surrounding soil. The activity concentration values obtained for $^{137}$C showed that sites 1 and 2 had untreated soils, while at site 3 the soil was treated. Furthermore, the measured activity concentrations of $^{137}$C were low (from 1.52 to 53.75 Bq/kg) and in correlation with the values obtained at different sites in B&H and the region. Among the three natural radionuclides tested, $^{40}$K was the most abundant, with activity concentrations ranging from 251.97 to 852.19 Bq/kg, with a slight tendency to increase with soil depth. Activity concentrations of $^{232}$Th ranged from 19.74 to 84.70 Bq/kg and that of $^{226}$Ra from 47.65 to 850.15 Bq/kg for all soil samples examined. The values obtained for the activity concentrations of $^{226}$Ra were higher than those of the other radionuclides tested, which can be attributed to the naturally occurring uranium in the soil and the migration of uranium from the thermal water into the soil.

# The importance of monitoring radioactivity in surface waters downstream from nuclear power plants

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Radioactivity monitoring in the Republic of Serbia is defined by Law on Radiation and Nuclear Safety and Security (*Official Gazette of RS*, No. 95/2018 and 10/2019), along with a series of Rulebooks, including the Rulebook for Establishing Programme of Systematic Environmental Radioactivity Examination (*Official Gazette of RS*, No. 100/2010), and Rulebook on Radioactivity Monitoring (*Official Gazette of RS*, No. 97/2011). In accordance with these regulations, in Serbia regular and systematic sampling of various environmental matrices, including air, precipitation, soil, vegetation, foodstuffs, drinking water, surface waters are conducts. Surface water monitoring plays a critical role in Serbia's radiological surveillance system due to the country's geographical position downstream from two operational nuclear power plants: Nuclear Power Plant Krško in Slovenia, and Nuclear Power Plant Paks in Hungary. In the event of a radiological incident, these upstream facilities could impact major rivers flowing through Serbia, primarily the Sava and the Danube River Basin. The radioactivity monitoring program focuses on measuring the concentrations of naturally occurred radionuclides as well as artificial such as Cs-137, Sr-90, and tritium.

Additionally, following the signing of the Agreement between the Government of the Republic of Serbia and the Government of Hungary on Cooperation in the Field of Sustainable Management of Transboundary Waters and River Basins of Common Interest, radioactivity monitoring has been established in the Danube River at the transboundary section with Hungary, specifically at monitoring stations located in Bezdan (Serbia) and Mohács (Hungary). This monitoring represents a key component of transboundary water quality control and plays an important role in the early detection of potential radiological impacts originating upstream, including those associated with the operation of nuclear power plants such as Paks in Hungary.

Monitoring radioactivity in surface waters is of critical importance for environmental protection and public health, particularly in terms of detecting artificial radionuclides. Nuclear power plants, which are primarily located on major rivers, present potential sources of radioactive contamination, especially in the event of accidents or contamination during cooling processes. Artificial radionuclides such as Cs-137 and Sr-90, can have long-term ecological and health impacts. Therefore, early detection of these radionuclides in aquatic ecosystems is essential. Given that rivers serve as the primary watercourses for the cooling systems of nuclear plants, there is a real risk of these pollutants being transferred into broader ecological systems. An effective surface water monitoring system, which includes analyses for artificial radionuclides, enables timely detection and the implementation of preventive measures to mitigate the risk of long-term environmental and health consequences.

**Keywords:** radioactivity monitoring, surface water, NPP, artificial radionuclides

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# U-238 and Th-232 in soil and sand in Montenegro: Correlations and dose rates

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Activity concentrations of $^{238}U$ and $^{232}Th$ in soils and beach sands of Montenegro were analyzed to evaluate their correlations, as well as absorbed dose rates in air coming from these two natural radionuclides. The analysis was based on the data previously obtained using *in situ* gamma spectrometry and standard laboratory HPGe spectrometry. This paper is focused on 20 sand points at the beaches along the Coast of Montenegro, 42 soil points at the territory of entire Montenegro, and additional 12 soil points at the territory of Nikšić – the second largest town in the country, having a complex geological base. Uranium-238 in soil was found to range from 7 to 166 Bq/kg with an average of 29.3 Bq/kg (Montenegro) and from 39.7 to 112 Bq/kg with an average 59.5 Bq/kg (Nikšić), as $^{232}Th$ ranged from 9.3 to 74 Bq/kg with an average of 23.7 Bq/kg (Montenegro) and from 33.9 to 78.6 Bq/kg with an average of 54.4 Bq/kg (Nikšić). Normality of the radionuclide activity distributions is tested by the Q-Q plots and Kolmogorov-Smirnov and Shapiro-Wilk tests, whilst the linear regression analysis showed that 64.8% of the variation in $^{232}Th$ activity concentration in soils of Montenegro could be explained by $^{238}U$. The $^{232}Th$ and $^{238}U$ activity concentrations in soil at the entire Montenegro territory are found to be positively correlated (Pearson correlation coefficient: $r = 0.805$), but not in the Nikšić soil, where statistically significant correlation is found for $^{232}Th$ and $^{226}Ra$ ($r = 0.856$). Very strong positive correlation between $^{232}Th$ and $^{40}K$ was observed for beach sands where the $^{238}U$ (and $^{226}Ra$), $^{232}Th$ and $^{40}K$ activity ranged up to 16 Bq/kg, 16.6 Bq/kg and 305 Bq/kg, respectively. Absorbed dose rate in air coming from $^{238}U$ in soil has average values 13.5 and 27.5 nGy/h for Montenegro and Nikšić, respectively, and that coming from $^{232}Th$ – 14.3 and 32.9 nGy/h, respectively. The dose rates from $^{238}U$ and $^{232}Th$ in beach sands are lower, not exceeding 7.4 nGy ($^{238}U$) and 10 nGy ($^{232}Th$).

# Interaction of microplastics with radionuclides (U-232) in seawater solutions

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Studies on the interaction of radionuclides with microplastics (MPs) under environmental conditions is of fundamental importance in environmental impact assessments and particularly the role of microplastics as radionuclide carries in various environmental compartments, including the biosphere. In this context, the adsorption of the U-232 isotope by MPs in seawater solutions has been investigated as a function of different parameters such as contact time, temperature, MP type and surface alteration (NOM coating). The adsorption efficiency has been evaluated by determining the relative adsorption efficiency (%-radionuclide adsorbed) as well as the linear distribution coefficient ($K_d$), which is the most appropriate method for assessing adsorption efficiencies/affinities, as the concentration of the adsorbate/radionuclide in solution was in the picomole range. The microplastic types used were Polyamide (PN6), Polyethylene terephthalate (PET), Polyethylene and Polyvinyl chloride (PVC). The uranium concentration in solution prior and after adsorption has been determined by alpha spectroscopy (Alpha Analyst, Canberra) after electrodeposition of the radionuclide on stainless steel planchets (using the same analytical set-up) and for comparison also by liquid scintillation counting (Triathler, hidex oy). According to the experimental data the adsorption kinetics in seawater and in the picomolar concentration range is better described by a pseudo-first order kinetics (depends mainly on the radionuclide concentration). The $K_d$ values range between 6 and 316 L/kg, which are significantly lower than the corresponding values determined in laboratory, deionized water solutions ($8 < K_d < 6000$ L/kg), which is attributed to the presence of other competitive cations present in seawater (e.g. $Ca^{2+}$, $Fe^{3+}$) and carbonate anions that stabilize uranium in solution mainly in the form of U(VI)-carbonate complexes (e.g. $UO_2(CO_3)_3^{4-}$). The MP type plays also a significant role since MPs with polar moieties on their surface present much higher adsorption efficiency towards cationic species (e.g. metal ions). Similarly, humic acid coated MPs are better adsorbents than their non-altered counterparts. Furthermore, increasing temperature results generally in higher adsorption efficiencies assuming that the radionuclide adsorption on MPs is an endothermic ($\Delta H^o > 0$) and entropy-driven process.

# Potential ecological risk assessments in marine environment of the Black Sea, Aegean Sea and the Adriatic Sea by $^{210}$Pb and $^{137}$Cs dating

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Marine sediments is a major sink for contaminants and trace/heavy metals in the surrounding ecosystem. The accumulation of trace metals in sediments may cause serious environmental problems in the aquatic system. The sediment dating provides a chronology of these environmental impacts. In particular, $^{210}$Pb is the most common and reliable method during more than 5 decades, through dating of undisturbed sediment cores, to study ecosystem changes during the last 100 - 150 yr. Meanwhile, $^{137}$Cs is used as an independent age control for $^{210}$Pb method.

The influx of nutrients, pesticides, industrial waste from the surroundings, shipping, and debris carried by the rivers, were adversely affected the marine environments. Therefore, there is much interest and research of the marine environment in terms of global sustainable development. Evaluating the current state of sediments is a vital first step in planning for conservation and sustainable management of marine environments.

Hence, the multiple objectives of the present study were:

(1) to establish a reliable geochronology by $^{210}$Pb/$^{137}$Cs dating for historical trends in the heavy metal concentrations of marine sediments from Coastal Areas of Black Sea, Aegean See and Adriatic,

(2) to assess the anthropogenic inputs of heavy metals in the sediments,

(3) to evaluate the environmental status and sediment contamination according to the Sediment Quality Guidelines (SQG) standards,

(4) to use the multivariate data analysis for obtaining general classification scenery of the heavy metal pollution, and

(5) to compare the pollution status of sediments in these semi-enclosed seas and understand the anthropogenic effects, caused by humans.

# Radiological implication due to heavy minerals of alluvial sediments from the upper sector of Grădiștea River, South Carpathians, Romania

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Based on gamma ray intensity measurements, high radioactivity quartz-feldspar gneiss bodies have been identified in the Variscan Lotru Metamorphic Suite in the Grădiștea de Munte area, located in the northern Sebeș Mountains. The high radioactivity is associated with the presence of REE (Y) mineralization associated with Th and U oxides, silicates and phosphates. Rare element minerals have a high content of Th and U, and occur in the host rock as accessory minerals or as veinlets and nests [Hirtopanu, P. & Fairhurst R. J. (2014) s. *Rom. J. Mineral Deposits* (87), (1), 53 – 56].

To identify the heavy minerals and to evaluate their radiological implication along the Grădiștea River and its tributaries Pustiosu, Jerosu and Larga, 22 alluvial sediment samples were collected. Each sample of sediments (weight 10 kg) was dried in an air oven at 110°C and sieved in 9 grain size classes between ø = 4 mm - 0.050 mm. The grain size classes under 2 mm were mineralogical investigated using a tabletop Hitachi TM 3030 SEM scanning electron microscope with energy dispersive spectroscopy (SEM-EDS). operating at an acceleration voltage of 15kV. Identification and quantification of elemental composition was made using a QUANTAX 70 EDS system from Bruker. The activity concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ were measured by gamma ray spectrometry using HPGe detector connected with an MCA (ORTEC) on the <2 mm fraction of each sediment sample, at a counting time of 24,000 s. The HPGe detector was calibrated in efficiency using IAEA reference materials RGU-1, RGTh-1, and RGK-1. Radium equivalent activity, absorbed dose rate, gamma representative level index, and external and internal hazard indices have been used to quantify radiological risk.

Mineralogical analyses indicate the presence of thorite, monazite-cheralite, urano-thorite, fergusonite-(Y), aeschynite-(Y), calciosamarskite, zircon, britholite-apatite in the mass of sediments as the most important Th and U bearing minerals. Zircon is the most abundant heavy mineral, usually occurring intimately associated with Th, U, Y-bearing phases. Radiometrical data shows average specific activity for U-238 of 99.12 Bq/Kg, for Th-232 of 189.21 Bq/Kg, and for K-40 of 543.21 Bq/kg. The highest levels of U are found in sediments from the Pustiosu brook enriched in zircon particles, whereas Th has maximal values in the upper course of the Jerosu brook where the water washes the the REE (Y), Nb, Th, U mineralization. The spatial distribution of radioactive elements indicates the role of transport processes in material mobilization and deposition, mechanical degradation surpassing chemical decomposition. Mechanical migration of U and Th-bearing minerals involves rock particles moving under water pressure and redistributing among alluvial sediments while maintaining native features. All radiological hazard parameters calculated show averages that exceed the median values provided by UNSCEAR.

# Investigation of the sorption properties of zeolite with iron oxyhydroxides for applications in removal of Sr, U and Th

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Activities related to nuclear energy production such as ore mining and milling, fuel fabrication, or fallout accidents can lead to the release of (radio)toxic elements in the environment, which contaminate surface- and groundwater sources and pose threat to human health and the biosphere. Among the techniques employed for decontamination, sorption by naturally derived materials has proven to be simple, efficient, and cost effective. Porous materials with significant presence in the environment like zeolites and various iron oxyhydroxides are especially advantageous for such purposes.

In this study a natural clinoptilolite zeolite from Greece was successfully modified by surface deposition of a mixture of amorphous iron(III) oxyhydroxides (ferrihydrite/goethite) and was fully characterized. Precursor and modified zeolites were used to investigate the sorption of U(VI), Th(IV), and Sr(II) in aqueous solutions and elucidate the influence of iron(III) treatment on their retention capacities. Sorption experiments were conducted using the batch method at ambient temperature (ca. 295 K) by contacting 1.0 g $L^{-1}$ of each sorbent with solutions of varying initial metal concentrations and pH (25-1000 mg $L^{-1}$ at pH 4 for U(VI), 5-100 mg $L^{-1}$ at pH 3 for Th(IV), and 1-250 mg $L^{-1}$ at pH 5 for Sr(II)). Metal concentrations were determined by optical and/or mass spectrometric techniques.

The results showed that oxyhydroxide deposition affected differently the zeolite's sorption capacities for each element examined, ranging from a positive influence as in the case of U(VI), to a negligible or even negative influence as in the cases of Sr(II) and Th(IV) respectively.

The purpose of this study was to explore the effect of a modification procedure with iron compounds in relation to the sorption properties of a natural zeolite. Both these materials are abundant in the environment and can heavily affect the mobility of radionuclides and toxic metals from waste disposal sites, mine tailings, or during nuclear fallout events.

# NORM in building materials and indoor radon: Critical analysis of the existing regulation

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The primary factors of radiation risk are homes and workplaces, as people spend 80-90% of their time indoors. Inside buildings, internal exposure (to radon) and external exposure (to gamma radiation emitted by building materials) are usually higher (and sometimes significantly higher) than outdoors. This risk can be regulated and should be reduced by fundamental guidelines issued by authoritative international organizations such as the IAEA, ICRP, WHO, and the Euratom Community (EU-BSS). The paper discusses several missing points and challenges within the European regulatory system in the field of NORM in building materials and indoor radon, consisting of three interconnecting functional levels: Legislative, Normative, and Methodological.

The Legislative Level refers to laws enacted by a legislative body, such as a parliament or congress. Examples include Basic Safety Standards (EU-BSS) at the Euratom Community level and generally applicable laws at the Member State level, such as national radiation protection laws and internal legal acts like national Radon Action Plans. These laws are based on rules and guidelines developed by international organizations, government agencies, and local administrations to implement and enforce the legislation.

The Normative Level includes documents issued by IAEA, WHO, and ICRP, which establish normative values to protect workers and the public from ionizing radiation, referred to as “Reference Levels” (RLs). The EU-BSS belongs to both Legislative and Normative levels as it also establishes RLs.

The Methodological Level forms the foundational tier of the regulatory pyramid for radiation risk associated with radon and NORM. It includes recommendations, guidelines, and measurement standards designed to ensure conformity with specific radiation safety requirements outlined in the Normative Level.

An analysis indicates that the Normative Level (mid-tier of the hierarchical regulatory pyramid) is satisfactory. However, the Legislative Level, despite incorporating seven Good Regulatory Practices (GRPs), has significant drawbacks that need to be addressed. The Methodological Level is underdeveloped, with several serious deficiencies. This weak development greatly hinders the global implementation of GRPs. It is concluded that enhancing regulation in the field of NORM in building materials and indoor radon can be achieved by developing and globally implementing several pertinent European/International standards and guidelines within rational ISO/IEC concepts. The regulators must refocus their attention on the current challenges and actual needs in developing and implementing harmonized standards for measurements of NORM in building materials and indoor radon.

# Decentralised ventilation with heat recovery as an indoor radon mitigation strategy: Findings from a three-year study

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Indoor radiation risk, particularly in homes and workplaces, is primarily attributed to internal exposure to radon-222. This naturally occurring radioactive gas accumulates in buildings and significantly increases the risk of lung cancer. Following international guidelines (IAEA, WHO) and the European Euratom Directive, the German government has set a reference value of 300 Bq/m³ as the annual mean for the radon activity concentration in indoor workplaces and living spaces. Given that individuals spend most of their time indoors, effective radon mitigation is essential to reduce exposure and associated health risks.

This study evaluates the effectiveness of a decentralised ventilation system with heat recovery as a radon mitigation strategy through a three-year proof-of-concept study. Conducted in the Ore Mountains, known for its abundant ore deposits (U, Bi, Co, Ni, and Ag) and its 800-year mining history, this study examines the impact of the region's geology and post-mining landscape on naturally elevated radon levels. Ventilation experiments were performed in an unoccupied ground-floor flat of a residential building in Aue-Bad Schlema, Germany.

Equipped with decentralised ventilation units with heat recovery (inVENTer GmbH, Germany), the flat was divided into three individually controllable ventilation zones. The ventilation system was controlled by real-time radon activity concentration measurements (Smart Radon Sensors by SARAD GmbH, Germany), enabling a dynamic and demand-driven response. Depending on the measured radon level in each ventilation zone, the system can automatically switch between the three operational modes "Heat Recovery", "Cross-Ventilation" and "Differential Pressure" or deactivate entirely.

This study also examined the relationship between indoor radon levels, meteorological factors such as outdoor temperature and wind speed and site-specific characteristics. Results showed that radon dynamics depend on a complex interplay of geological, meteorological and building-specific factors. Additionally, variations in ventilation modes and fan performance settings led to different radon reductions. In the "Differential Pressure" mode, an over pressure of +5 Pa was created in the flat, reducing radon activity concentration inside the kitchen from 7,000 to 300 Bq/m³. Overall, the decentralised ventilation system demonstrated significant potential, achieving radon reductions of up to 80 %.

These findings highlight the need for customised and site-specific mitigation strategies by integrating environmental and building-specific factors into radon risk assessment and mitigation planning. Furthermore, this study enhances the understanding of radon dynamics to support the development of more effective and automated radon mitigation strategies. Using real-time radon measurements as a control parameter, the system introduces an innovative approach to optimising ventilation for efficient radon reduction with minimal energy consumption.

# NORM-BMI: Investigation of naturally occurring radioactive material (NORM) in building materials in Ireland

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Naturally occurring radioactive materials (NORM) in building materials are a source of indoor radiation exposure, primarily through gamma radiation and radon emissions. As people spend up to 90% of their time indoors, understanding the radiological impact of building materials is critical for both public health and regulatory compliance. This study evaluates the NORM levels in building materials using high-resolution gamma spectrometry, with a focus on calculating the Gamma Index (Iγ) to assess radiation safety, with I$\gamma$ values below 1 deemed safe according to UNSCEAR guidelines.

The NORM-BMI project is a multi-institutional collaboration with partners including the University of Galway (Ireland), University of Cantabria (Spain), University College Dublin (Ireland), and the EPA Radiation Monitoring Lab (Ireland). The study benchmarks measurement techniques, evaluates the variability in NORM concentrations in new building materials and demolition waste, and explores strategies to mitigate radiation exposure from construction materials.

This study investigates NORM levels in various building materials commonly used in Ireland, including concrete, aggregates, cement, gypsum, mortar, and tiles. These materials were selected based on three key criteria: past literature and surveys from 29 different countries, their frequency of use in construction, and their availability for sampling. The materials were cleaned, reduced to a 3 cm grain size, and pulverized to sub-1 mm particles, followed by sieving and storage for analysis.

The EPA Radiation Monitoring Lab utilized Marinelli beakers for sample preparation, with particle sizes sieved to <2 mm. Samples were sealed and stored for 30-days to reach secular equilibrium and 24-hour measurement runs per sample, were employed for accurate results. Detectors used included high-purity HPGe semiconductor spectrometers, with data analysis carried out using Apex Gamma with Genie V3.4, Gespecor V4, and Excel.

The preliminary results for the samples analyzed to date reveal Gamma-Index values for a range of materials from virgin building materials to demolition waste, including Tiles (0.57 – 1.15), Plaster (0.24 – 0.33), Cement (0.18 – 0.22), Aggregates (0.07 – 0.15), Concrete (0.08 – 0.14) and Gypsum (0.02 – 0.03). The results obtained in this study represent the first step in the radiological characterization of building materials in Ireland.

This project will support the EPA's mandate in policy implementation by providing a clear picture of the NORM in building materials landscape in the EU. The extensive review in addition with the pilot sampling programme will facilitate an appropriately scaled and targeted monitoring programme to investigate NORM in building materials in Ireland. Addressing these knowledge gaps and providing recommendations for a monitoring programme in Ireland will ensure there is an improved circularity of construction products and the use of more sustainable materials in construction into the future.

**Keywords:** NORM, building materials, gamma spectrometry, gamma index, radiation safety

# The RadonEye monitor: Benefits and problems

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The monitor called RadonEye made by the South Korean company FTLab has become increasingly popular for some years. Among consumer grade active radon monitors it is the most sensitive one. It is sold for a fair price, currently (March 2025) about 200 Euro for the basic version and it is easy to operate via a Smartphone app through Bluetooth connection. This makes it also very useful for research in the framework of Citizen Science, for example in the context of surveying indoor air, identifying radon priority areas, recording radon time series or measuring radon exhalation. It has been subjected to performance tests by different laboratories, in general showing good results.

The instrument has also drawbacks which should be taken into account for applications which require a higher level of QA, as is usually the case in scientific research. The accurate calibration appears to be an issue: the default calibration factor given by the manufacturer does not appear very accurate and recalibration in a dedicated laboratory can be costly. This can be a problem if the objective is to decide whether a room or a building conforms to radon limitation standards, such as the European 300 Bq/m³ reference value. Another possible problem is sensitivity towards thoron, which however can be a beneficial issue if this is the objective of an investigation. Further, continuous use during more than one year showed the occurrence of isolated anomalous values of unknown origin. Finally, the algorithm which transforms counted pulses into a reported activity concentration is not transparent, which may be problematic in particular for low concentrations.

Four RadonEyes were used for 1 to 3 years in different investigations. Time series were recorded and analyzed and showed reasonable performance. Although not recommended by the manufacturer, using the instrument outdoors (protected against rain and wind) yields plausible results, in particular of the radon dynamics. Statistical results derived of such series and of parallel measurements with two monitors are shown in the presentation. Current projects under way target correlation with meteorological variables, with ambient dose rate and with proxies such as concentrations of air pollutants.

# Comparison of radon in karst area and area with clastic bedrock in Montenegro

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Radon ($^{222}$Rn) was measured in two geologically different rural areas in Montenegro. One of these areas is a karst region in western Montenegro, where researches were conducted at 25 locations covering an area of approximately 800 km$^2$. At the other rural area, with clastic bedrock (sandstones and shales), covering about 570 km$^2$ in northeastern Montenegro, researches were conducted at 30 locations.

At these 55 locations, the annual average radon activity concentration ($C_{Rn,ind}$) was measured using passive devices with CR-39 detectors in the ground floor of primary schools or private houses. The construction characteristics of the examined schools and houses were also recorded. Near the surveyed buildings, radon concentration in soil gas ($c$) was measured at three points at a depth of 80 cm using the RM-2 measuring system. The soil permeability for radon gas ($k$) was also measured at the same three points using the RADON-JOK device. Based on these measured values $c$ and $k$, the location's geogenic radon potential (*GRP*) was calculated, and the corresponding radon index (*RI*) was determined.

For the karst area, with limestone and dolomite as the bedrock, following mean values (AM) and ranges (R) of the measured parameters were found: $c$: AM = 115 kBq/m$^3$, R = (8.9 – 390) kBq/m$^3$; $k$: AM = $153 \cdot 10^{-13}$ m$^2$, R = (3.9 – 180) $\cdot 10^{-13}$ m$^2$; *GRP*: AM = 130, R = 11 – 419; $C_{Rn,ind}$: AM = 977 Bq/m$^3$, R = (219 – 2494) Bq/m$^3$. For the clastic rock area:$c$: AM = 35.3 kBq/m$^3$, R = (7.9 – 95) kBq/m$^3$; $k$: AM = $114 \cdot 10^{-13}$ m$^2$, R = (0.5 – 180) $\cdot 10^{-13}$ m$^2$; *GRP*: AM = 32.4, R = 6.1 – 80; $C_{Rn,ind}$: AM = 148 Bq/m$^3$, R = (32 – 398) Bq/m$^3$.

Pearson's $\chi^2$ tests confirm that there are no statistically significant differences between the building groups in the two examined areas concerning five construction parameters: building type (school or house), construction period, presence of a basement, presence of a filling under the building, and quality of the concrete floor slab. However, significant differences were observed in the following parameters: number of floors, external wall material, and window frames. Among these three parameters, from the perspective of radon migration, only the window frames have a significant impact on radon levels in ground-floor rooms. Therefore, it follows that the two groups of buildings are suitable for comparison the influence of geological substrate on radon concentrations in the ground floors of buildings.

To compare the values of parameters $c$, $k$, *GRP*, and $C_{Rn,ind}$ about the two types of bedrocks (limestone/dolomite and sandstone/shale), descriptive statistics of the measurement results, box-whisker diagrams, and the non-parametric Mann-Whitney U test were used. The analysis clearly shows that the differences in the values of each of these parameters are statistically significant concerning the bedrock type, with values being significantly higher at karst locations than at clastic rock locations.

# Performance evaluation of zeolite materials for Rn-222 adsorption

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Controlling radon release is crucial for minimizing radiation exposure of workers and maintaining a safe working environment. This study investigates the potential of various zeolite materials for Rn-222 adsorption. We evaluated the radon removal capabilities of several different zeolite types (ZEO1, ZEO2, ZEO3) by measuring radon concentrations before and after passing through a zeolite sample. The experiments were conducted in a controlled environment using calibrated radon detectors to monitor Rn-222 concentrations and 3-5% of relative humidity over time.

Our results demonstrate a clear difference in radon adsorption performance among the tested zeolites. ZEO1 exhibited exceptional radon removal efficiency, maintaining radon concentrations at background levels (a few Bq/m$^3$) for an extended period of one week. This suggests a strong and sustained adsorption capacity for ZEO1, crucial for long-term radon control in a production setting. Conversely, ZEO2 and ZEO3 showed significantly lower radon removal performance. While they initially reduced radon concentrations to background levels for approximately one day, the radon concentration subsequently increased, eventually reaching a plateau where the output concentration matched the input concentration. This indicates a limited adsorption capacity and potential saturation of these zeolite materials, making them less suitable for continuous radon control. Further investigations will focus on characterizing the properties of ZEO1, ZEO2, and ZEO3, including their structure, surface area, and pore size distribution, to understand the underlying mechanisms governing their differing adsorption behaviors. This will enable the optimization of zeolite-based radon reduction systems to enhance radiation safety.

# Radon concentration and effective dose assessment in the Brestovská Cave and the Demänovská Cave of Liberty, Slovakia

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In Slovakia, 13 caves operated by the State Nature Conservancy of Slovak Republic - Slovak Caves Administration are open to the public. In all of them radon activity concentration (RAC) is monitored using Ramarn track detectors exposed for 6 months, which change in April and October. The Demänovská Cave of Liberty is one of the most visited caves in Slovakia. The Brestovská Cave was open to the public in September 2016; therefore, no detail RAC monitoring was performed here yet. Radon survey to assess the spatiotemporal variation of radon in both caves was carried out from May 2021 to December 2023, also using Ramarn detectors, but changed after one month exposure. Six monitoring sites were established in the Demänovská Cave of Liberty. In Těsnohlídko Lake station, RAC varied in interval (190 – 1310) Bq/m$^3$, in Crossroad (650 – 6100) Bq/m$^3$, Deep Dome (250 – 2500) Bq/m$^3$, Tricolour Lake (270 – 3310) Bq/m$^3$, Cemetery (190 – 2900) Bq/m$^3$ and in Pink Hall it ranged (1900 – 5400) Bq/m$^3$. The lowest annual average of RAC was found in the Cemetery station (730 Bq/m$^3$) situated close to the cave exit, the highest in the Pink Hall, equal to 3200 Bq/m$^3$. Annual variation was observed at each site, with two maxima per year. The first appeared in the spring months (April-June) and the second in autumn (September-November). With exception of Těsnohlídko Lake, all stations were on or close to the tourist route. In the Brestovská Cave four monitoring stations were situated along the tourist route. RAC was significantly higher than in the Demänovská Cave of Liberty and varied in intervals as follows: Entrance Hall (500-6600) Bq/m$^3$, Chain Hall (1550-10300) Bq/m$^3$, Bivouac Hall (2100-17950) Bq/m$^3$ and Divers Hall (1600-20400 Bq/m$^3$). The lowest annual average of RAC was found in the Entrance Hall (2770 Bq/m$^3$) and highest at the Divers Hall (11390 Bq/m$^3$), which is situated at the most distant part of the tourist route. However, annual average of RAC in the Bivouac Hall, situated in a microclimatically stable part of the cave, reached 10560 Bq/m$^3$. Seasonal variation was observed with maximum in May-October in all sites. Annual effective doses for cave guides and visitors were estimated according to ICRP 137 recommendations. Visitors who completed a short circuit lasting 60 min in the Demänovská Cave of Liberty (without Pink Hall) received (11-38) µSv per visit, who completed a long circuit (90 min) received (20-63) µSv per visit, depending on a different RAC in month of their visit. Cave guides were exposed to annual effective dose in the range 1.5 – 10 mSv, depending to the number of their entries to the cave per month and RAC in that month. Temporary guides employed in tourist season received (1.5-3) mSv. Guests in the Brestovská Cave received after 40 min visit an effective dose ranging (31-117) µSv. Cave guides received annual effective doses of 9-24 mSv, temporary guides received 4-19 mSv.

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# Study of thoron exhalation from soil under different temperature and humidity conditions

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$^{222}$Rn and $^{220}$Rn (called as thoron) are isotopes of radon gas which are alpha emitters and are members of the Uranium and Thorium decay series respectively. Inhalation dose due to radon and thoron progenies contributes nearly 50% to the annual effective dose incurred to the public from exposure to natural background radiation. Thoron, particularly draws more significance in the south-eastern coastal belt of India where heavy minerals rich- beach sand is found to contain higher $^{232}$Th activity. Thoron, due to its short half-life (55 s) and hence small diffusion length (nearly 1cm in soil), is largely released from the top surface of the soil and its spatial distribution in surrounding air is highly non-uniform. It is more concentrated in the region close to the exhaling surface. Soil physical properties are known to affect the thoron emanation from the grains and together with the influence of meteorological parameters (temperature, humidity, precipitation), govern the degree of exhalation from the soil surface.

In the present study, thoron exhalation from beach sand is studied in the controlled environment of a (0.5 $m^3$ volume) radon chamber. The chamber is equipped with air- heater and moisture generator with automated temperature and humidity controller. It has seven sampling ports with flow control valves, one inlet and one outlet port with ball valve. The chamber has an airtight perspex window and an internal fan for air circulation. Beach sand with higher $^{232}$Th activity is spread on the floor of the chamber. The air is sampled from the bottom-most port about 4cm above the floor and connected to online radon/ thoron monitor. Experiments were conducted in the temperature and relative humidity (RH) ranges 35-50°C and 40-60% respectively. For different combinations of temperature and RH, the steady state thoron concentration near the floor was measured and the exhalation rate was estimated by solving the mass balance equation. The thoron exhalation rate varied in the range 459-1931 Bq $m^{-2}$ $h^{-1}$. Common to all levels of RH, the thoron exhalation rate was found to steadily increase with temperature. For a total of 15°C (in steps of 5°C) temperature increase, at RH 45%, the thoron exhalation rate increased by 18% and at RH 60%, the exhalation rate increased by 31%. This can be attributed to increase in thoron diffusion coefficient with temperature. At all temperatures, when the RH increased from 40 to 45%, exhalation rate also increased followed by a dip when RH is further increased to 50%. The observed trend can be explained based on the increase of thoron emanation factor with moisture initially and the decrease in thoron diffusion coefficient with more increase in RH value. Similar observations have been made in previous studies. Above RH 50%, the air in the chamber is increasingly loaded with water vapour which settles down and obstructs the diffusion of thoron upwards concentrating it near the soil surface. Hence, showing higher thoron levels near the surface. This reduces the concentration gradient there by retarding the exhalation rate.

# Geospatial analysis of radon exposure in Slovakia: Insights from radon potential maps

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The worldwide interest in radon, the natural radioactive isotope $^{222}Rn$, is mainly due to its ability to accumulate in enclosed spaces, which in certain situations could pose a health risk to the occupants. To assess the radon risk in a specific area, mapping the so-called radon potential (RP) of the soil could provide an initial information to determine whether additional radon measurements are required. The current reference level (RL) for the annual average indoor radon activity concentration (RAC) in the Slovak Republic is established at 300 Bq/m$^3$, as specified in the Collection of Laws of the Slovak Republic 87/2018.

In our study, based on Neznal RP values, maps of RP and corresponding predicted indoor RAC were created for the Slovak Republic [doi: 10.1093/rpd/ncac131; doi: 10.35815/radon.v5.10375]. For this purpose, a specific rescaling of the RP scale was employed, based on previous experimental measurements of indoor RAC [doi: 10.1007/ s10967-021-07673-4]. The predicted averaged indoor RAC was compared with the experimentally measured indoor RAC (in a total of 19 municipalities so far) located in the areas with all radon risk levels (low, medium, high). Recent results confirmed an approximately linear relationship between these parameters ($R^2 = 0.51$) for the rooms in contact with the subsoil. Even in areas with predicted low radon potential, the measured indoor RAC was found to exceed the RL in some rooms (in 7% of cases). This percentage increases to 15% for medium RP and 44% for high RP areas.

The results obtained from the case studies indicate the reliability of the methodology used for identifying houses with increased indoor radon levels for the purposes of the National Radon Action Plan of the Slovak Republic. The use of rescaled RP maps is a useful method for effectively utilizing measured data on soil air RAC and soil permeability from the SGIoDŠ map server of the Slovak Republic (2025) for rapid and, compared to nationwide indoor RAC measurements, less costly identification of localities with elevated indoor radon levels. At the same time, the average measured indoor RAC for areas with predicted high RP exceeds the national average of 120 Bq/m$^3$ by 2 to 11 times, with an average of 4. The results show good agreement with experimentally measured RAC in dwellings, taking into account uncertainties, and can subsequently be used for predicting effective doses to the population from $^{222}Rn$.

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# Indoor radon survey in Tirana City, Albania

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Indoor radon concentration is investigated in the urban area of Tirana city, the capital of Albania. CR-39 Solid State Nuclear Track Detectors (SSNTDs) are used to survey 147 dwellings and 78 workplaces. In dwellings, the geometric and arithmetic mean of radon concentration is found to be 97 and 71 Bq/m$^3$, while in workplaces 131 and 98 Bq/m$^3$, respectively. Radon concentration on the ground floor in dwellings is higher than that of other floors, while for workplaces no significant difference is found among floors. Radon concentrations in dwellings and workplaces are found to be higher than the reference level for approximately 6% and 9% of cases, respectively. The results are spatially distributed using a grid of 1×1 km$^2$ realizing the indoor radon map showing the number of measurements and the arithmetic mean. This information is used to assess the radiation health risk due to residential exposure to radon indoors.

**Keywords:** Tirana City, indoor radon, dwellings, workplaces, annual dose rate

# Preliminary results on indoor radon concentrations in the buildings of University Aleksandër Moisiu, Durrës (Albania)

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Indoor radon concentrations are measured in the main buildings of the two campus sites of the University Aleksandër Moisiu, Durrës. The measurements are performed using the passive method based on solid-state nuclear track detectors (CR-39) in two seasons' winter and summer, which cover almost the entire period of an academic year. In a few cases, the active method is used to check on diurnal variations of indoor radon concentrations. The Indoor radon concentrations measured in the summer season (67 measurements) and discussed in this preliminary analysis are found to range from 9 up to 113 Bq $m^{-3}$. All the measurements are found to be under the reference level of Albanian legislation for indoor radon concentration in workplaces. No significant differences in radon concentrations are found among buildings and between various floors. The preliminary effective dose is calculated by using ICRP recommendations considering the standard exposure period is found to be 1.5 mSv/year.

**Keywords:** University Aleksandër Moisiu, indoor radon, workplaces, effective dose

# Radon as a tracer for active fault zones: Insights from the Jordan Valley fault

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Comprehensive soil radon measurements were conducted in Jordan Valley along the JV fault, an active tectonic part of the Dead Sea Transform Fault in Jordan. Radon studies were led by prior geophysical, morphotectonic, archaeoseismic, and paleoseismic surveys in the same region, showing tectonic activity in the fault systems. The study found a fault-related radon anomaly with a six- to seven-times rise in concentration, aligning with the surface fault rupture in the northern Jordan Valley. Significant findings of this research include abnormal radon growth corresponding to a seismic gap in Jordan Valley. Anomalies in radon emissions align with the JV rupture fault zone, previously found by combined geophysical and morphotectonic investigations. These findings suggest that radon can be a reliable and sensitive indicator for fault structure characterization and that local active tectonics can significantly increase soil radon emission.

**Keywords:** radon, Jordan Valley, Dead Sea transform, active tectonic

# Measurements of radon gas and daughter concentration in Oman: Initial findings

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Radon gas, a radioactive decay product of uranium and radium, is a significant health concern, contributing to over 15% of global lung cancer cases due to its colorless, odorless nature. In the Sultanate of Oman, where geological studies indicate the presence of uranium and radium in mountainous regions, coupled with rapid industrial expansion since the 1970s, assessing radon concentrations is vital for environmental and public safety. This study aims to assess radon gas and its daughters' concentrations across Oman to map radioactivity levels in air, groundwater, and soil, and to inform risk mitigation strategies. A state-of-the-art Alpha Guard detector is utilized to quantify radon levels with high precision, targeting industrial zones, coastal areas, residential regions, and borders. Complementary spectroscopic analysis identified radioactive sources, with measurements benchmarked against international standards. Initial results reveal that radon radiation levels vary regionally, ranging from a few becquerel/m³ to 30 becquerel/m³, remaining within permissible international limits. Higher concentrations correlate with shale and quartzite-rich areas, reflecting geological influences. Lower levels dominate limestone regions, indicating spatial heterogeneity in radon distribution. This variability underscores the need for a comprehensive radon map to guide urban planning and health protection. The study concludes that while current levels pose no immediate threat, ongoing monitoring is essential given Oman's geological and industrial context. These findings provide a robust baseline for decision-makers to prioritize areas for future surveillance, ensuring proactive management of radon-related risks and safeguarding public health across the Sultanate.

# Monitoring of the radon and its progeny concentration in Slovak caves and mines

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Radon gas and progeny concentrations, and other environmental parameters are continuously evaluated in popular tourist caverns and mines in Slovakia. The primary objective of this work is monitoring an employee exposure to radon and progeny while performing guided tours. In the most popular caves in Slovakia the number of visits is reaching hundreds of thousand visitors per year. In combination of preparatory and maintenance work, the employees can spend several hours per day in the caves, which increase the potential to accrue ionizing radiation dose in excess of the annual effective dose limit. Radon gas concentration is strongly correlated with the air exchange rate, which vary based on seasonal weather change. Introduction of artificial system for air management can influence a natural environment in the caves and mines and thus damage their nature heritage. Therefore, the time management of the employees is the most preferred option how the administrative limits can be fulfilled. Currently four caves – Bystrianska cave, Belianska cave, Staniševská cave and Driny cave, and two mines – Bear mine and Salvator mine, are actively monitored using solid-state alpha-track detectors in combination of continual radon detectors. In total, 34 positions of the guided tour paths are monitored by 102 detectors. The solid-state alpha-track detectors are evaluated at one-month and three-month intervals to obtain seasonal variation. This paper summarizes applied methodology and the results from the first period of the monitoring, where the radon specific activity varies from several hundreds of $Bq/m^3$ to several thousands of $Bq/m^3$ based on location and season period.

# Chaotic environmental radioactivity dynamics of some geosystems: Analyses of the Radon time series

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A study of the phenomenon of stochasticity or chaos in different dynamical systems is provided by a great importance for a whole number of applications, including a necessity of understanding chaotic features in different geophysical (hydrometeorological, environmental, etc.) systems. New field of investigations of the similar systems has been provided by a great progress in a development of a chaos and dynamical systems theory methods [doi.org/10.1103/RevModPhys.65.1331]. In our previous papers [Odessa: TES, 2019, Mathematical and Numerical Aspects of Dynamical Systems Analysis, ARSA Publishing, Lodz, Poland; 2017, vol. 2, pp. 205-214, Dynamical Systems Applications. Politechniki Łódz, 2013, T2:145-152, Perspectives in Dynamical Systems II: Mathematical and Numerical Approaches. Series: Springer Proc. in Mathematics & Statistics, 2021, vol. 363, pp. 79-88 (Springer, Cham)] we have given a review of new methods and algorithms to analysis of different systems of environmental and Earth sciences.

In this work, the fundamentals of a universal complex chaos-geometric approach to deterministic chaos, strange attractors in dynamics of the environmental radioactivity systems are presented. In particular, the atmospheric radon $^{222}$Rn concentration temporal dynamics for some US regions is studied and computed. As many blocks of the used approach have been developed earlier and need only to be reformulated regarding the problem studied in this paper, here we are limited only by the key moments following to Refs. [Odessa: TES, 2019, Dynamical Systems Applications. Politechniki Łódz, 2013, T2:145-152, Perspectives in Dynamical Systems II: Mathematical and Numerical Approaches. Series: Springer Proc. in Mathematics & Statistics, 2021, vol 363. P.79-88 (Springer, Cham)]. In our problem the approach includes a realization of the following blocks: I. Analytical and numerical study of convective transport in a general circulation model; II. Analysis and processing of a number of basic dynamic characteristics of the system, including application of general criteria for the existence of chaos in dynamics (e.g. the known Gottwald- Melbourne test, use of Fourier expansions, spectral methods); III. Reconstruction and determination of the phase space of the system (choice of time lag using the methods of autocorrelation function, average mutual information, application of the methods of correlation integral and nearest neighboring points, fractal geometry); IV. Chaos-cybernetic study of chaos in dynamics and construction of the prediction models: a) determination of chaos parameters, incl. topological, dynamic invariants (such as the Lyapunov's exponents, Kolmogorov entropy etc; b) forecasting temporal evolution of chaotic systems using novel prediction models [Odessa: TES, 2019]. The time series of the atmospheric Rn concentrations extending for a least one year are available from five sites in the Unites States (Environmental Measurement. Lab., USA Dept. of Energy).

The record of the radon concentrations at the Chester cite is by far the most extensive. Measurements had been made round-the-clock 10 m above ground in an open field and data from July 1977 to November 1983 are available as continuous time series of 0.5-3 hour average concentrations (Harlee, 1978,1979; Fisenne, 1980-1985) (see details in [Perspectives in Dynamical Systems II: Mathematical and Numerical Approaches, 2021, vol 363. P.79-88 (Springer, Cham), doi.org/10.3402/tellusb.v42i1.15196]). The results of computing a set of the dynamical and topological invariants, namely: correlation dimension ($d_2$), embedding dimension ($d_E$), first two Lyapunov's exponents, ($l_1$,$l_2$), Kaplan-Yorke dimension ($d_L$), and the Kolmogorov entropy, average limit of predictability ($Pr_{max}$, hours) for the studied $^{222}$Rn time series are listed. Analysis of the data shows that the Kaplan-Yorke dimensions (which are also the attractor dimensions) are smaller than the dimensions obtained by the algorithm of false nearest neighbors. It is very important to pay the attention on the presence of the two (from six) positive (chaos exists!) Lyapunov's exponents $l_i$. One could conclude that the system broadens in the line of two axes and converges along four axes that in the six-dimensional space. Other values of the Lyapunov's exponents $l_i$ are negative.

# Evaluating geometrical parameters in defined solid-angle alpha spectrometry for absolute Rn-222 activity measurement

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Radon (Rn-222) is a naturally occurring radioactive gas in the uranium (U-238) decay chain and a significant contributor to natural occurring radiation exposure. Its alpha-particle emitting progeny attached to airborne particles, posing significant health risks, particularly lung cancer. To mitigate these risks, the European Council Directive 2013/59/EURATOM (EU-BSS) mandates monitoring and mitigation of indoor radon activity concentrations exceeding 300 Bq/m³. However, ensuring regulatory compliance presents metrological challenges, including high uncertainties in low-level radon measurements and the need for accurate calibration of radon monitoring equipment.

Defined Solid Angle (DSA) alpha spectrometry is a high-precision technique for absolute radon activity measurement. By maintaining a fixed geometric relationship between the source and detector, DSA enables accurate, absolute and traceable determination of radon activity with low uncertainty. The method was first introduced by Picolo [doi.org/10.1016/S0168-9002(96)80029-5) and has been successfully implemented at LNE-LNHB [doi.org/10.1016/j.apradiso.2016.09.009), IRA-METAS [doi.org/10.1016/j.nima.2006.07.055) and PTB providing a traceable standard for radon metrology.

This study focuses on the optimization and upgrade of PTB's primary measurement system for absolute Rn-222 activity [doi.org/10.1016/j.apradiso.2003.11.046) using the solid angle technique. The impact of key geometric parameters—diaphragm radius (a), source-diaphragm distance (z), and source radius (b)—on measurement accuracy is systematically analyzed using Knoll and Curtis equations. The relative variation of the geometrical factor is evaluated to determine the most critical parameter influencing uncertainty.

Results demonstrate that diaphragm radius (a) and source–diaphragm distance (z) are the most significant factors, affecting measurement uncertainty. Based on this analysis, optimal configurations for enhanced radon detection are proposed. Strengthening calibration methodologies and improving traceability in radon measurements will support regulatory compliance, enhance radiation protection standards, and contribute to public health and environmental safety.

# Radiosensitivity of lung tissue cells to radon decay products

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According to UNSCEAR, radon and its decay products contribute to more than 55 % of the total radiation dose to the population. They enter the respiratory tract by inhalation and are trapped on its surface. During their radioactive transformation they emit alpha particles with a high ionization capacity and range, which allows them to reach and radiatively damage secretory and basal cells of the lung tissue. Some of the damaged cells are repaired, some die, and the rest undergo oncological transformation.

The probability of lung cancer transformation depends not only on the dose absorbed in individual lung compartments but also on their radiation sensitivity. Therefore, in dosimetric practice, the equivalent lung dose $H$ representing the radiation risk is determined as the sum of the equivalent doses in the bronchial (BB), bronchional (bb) and alveolar (Al) lung regions.

The radiosensitivity of individual parts of the bronchial tree is determined by the abundance of target cells within them. Secretory cells are present in all lung generations, in contrast to basal cells, which are present only in the BB region. According to the ICRP66, these two types of target cells are radiologically equivalent, although some studies have suggested the possibility that their radiosensitivity may differ significantly.

To compare their radiosensitivity, we developed the microdosimetric threshold energy model to analyze epidemiological data on lung cancer incidence. The model is based on the assumption that a bronchial cell is sublethally damaged if it is hit by ionizing radiation and its absorbed dose does not exceed the threshold specific energy.

We used the Monte Carlo method to simulate the interaction of alpha particles emitted from the lung surface with target cells of all generations of the bronchial tree. We determined the fractions of sublethally damaged secretory and basal cells by a microdosimetric model and then found such a ratio between their radiosensitivities that the total number of cancer cells was proportional to the probability of lung cancer according to epidemiological data.

Preliminary analyses show that the currently used assumption of equal radiosensitivity of basal and secretory cells of lung tissue is not correct and that basal cells are most likely several times more sensitive. This warrants a reconsideration of the way the effective dose and radiation risk are calculated, which should take into account the more dominant influence of basal cells.

# Assessment of indoor radon risk as a function of smoking-induced morphometric changes

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Lung cancer now accounts for about one quarter of all malignancies in developed countries. More than 80% of these deaths are caused by smoking. The second most important factor is radon and its decay products. Without an understanding of their synergistic effect on lung cancer, it is not possible to properly assess the radon risk to the general population, including groups of smokers with different daily cigarette consumption. The aim of this work was to investigate the interaction mechanism between these two carcinogens and to propose a microdosimetric model capable of predicting the increase in the oncological effect of radon due to smoking at long-term exposures typical for residential areas.

Several factors must be considered when predicting the risk of lung cancer in residential areas due to smoking and inhalation of radon with an activity concentration of W:

*1. Smoking-induced morphological and physiological changes in the lung*

The radiation-induced biological effect is primarily represented by the absorbed dose, which, however, depends on the morphometric and physiological state of the lung. When cigarette smoke is inhaled, airway irritation leads to hyperproduction of mucus, resulting in a reduction in radiation dose compared to a non-smoker. On the other hand, with prolonged smoking, lung function is impaired, chronic lung obstruction begins to develop, leading to accumulation of radon decay products in lung tissue and subsequent increase in radiation load to target cells. An indicator of these changes is the obstruction factor $\varepsilon$, which determines the increase in bronchial dose of a user smoking for a period $\tau$ with a daily cigarette consumption of $S$, compared to that of a non-smoker under the same radon exposure conditions.

To determine this factor, we used the threshold energy model based on the assumption that a cell is sublethally damaged if it is hit by ionizing radiation and the absorbed dose does not exceed the threshold specific energy.

*2. Risk reduction due to time elapsed since exposure*

The effects of ionizing radiation decrease with the time elapsed since exposure, meaning that the same radon exposure applied at different times leads to different radiation damage. In addition, lung morphometry is affected by smoking; as a result, the same radon exposure applied at different times during smoking leads to different biological responses. Therefore, we divided the exposure period into short sampling intervals, in which we determined the radiation dose from the current value of the obstruction factor.

To assess the predictive ability of the model, we performed several calculations that were compared with epidemiological data. From the comparison of the results, it can be concluded that the proposed model satisfactorily explains the interaction between smoking and radiation. The achieved results will contribute to a more accurate estimate of the radiation load and radon risk of smokers with different smoking habits.

# Outdoor radiation background survey design

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Combined measurements of gamma background and radon outdoors in populated urban areas have not been conducted in Bulgaria. Outdoor measurements are needed to obtain information on natural background concentrations in order to identify and quantify anthropogenic contributions. On the other hand, the level of local outdoor radon concentrations contributes to indoor radon concentrations, and data could be used to identify the radon priority areas. Guided by these goals, the outdoor radiation background survey is planned to be conducted under the project КП-06-ПН 87/14 of the Scientific Research Fund.

For conducting a qualitative study, the survey design is prepared, which is presented in the paper and includes the following: the objective of the survey; identification of the targeted population; sampling method; detectors; data-collection methods.

The article includes results from the applied statistical analyses for sampling design, using the Complex Samples analysis procedures of IBM SPSS. For the target population, all urban sites are used, which is 218. The method of Simple Random Sampling is applied, in which the units are selected with equal probability without replacement. The number of the population is used for the stratification of the general group of urban sites. Stratified sampling allows selecting sites independently within non-overlapping subgroups. The subgroups are: < 5000 people; 5001 - 30000 people and above 30000. For a more detailed analysis, we include the clusters for investigated urban sites based on tectonic units and the altitude of the site. The extracted randomly selected sites are approximately 100 sites. An integrated system will be installed at the selected locations, including passive radon detectors and TLD dosimeters for gamma background measurement, placed in a protective box.

# Assessment of the sampling place for the outdoor radon survey

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For most people, exposure from natural background is much more significant than exposure from man-made sources of ionizing radiation. Radon is a radioactive gas formed as a result of the radioactive decay of radium from the $^{238}U$ decay families. Radon is identified as one of the dominant sources of population exposure.

The study was conducted in the implementation of a national project КП-06-ПН 87/14 of the Scientific Research Fund. The project aims to conduct a study of gamma background and radon outdoors in urban areas, where the sampling location may be different (at different heights and near buildings).

The purpose of the study is the evaluation of the sampling place for the outdoor radon survey based on the measurements of the different heights and distances from the building to assess the influence of these place parameters. On the other hand, the research will allow for correcting the results the requirements of the ISO standard for the sampling place.

Radon measurements were performed in different meteorological conditions. Devices for direct and passive measurements of radon concentration were used. Continuous radon measurements were performed with the TERA radon detection system (Tesla, Czech Republic), containing portable probes TSR4. A portable probe TSR4 basis is a measuring chamber with a semiconductor photodetector. Radon enters the chamber by diffusion through the input filter on the bottom of the probe. The probe saves time and records these radon concentration values, including values of humidity and temperature, within its internal memory (typically at an interval of 1 h). The nuclear track detector, used for the passive measurement, consisted of a CR-39 chip placed on the bottom of the cylindrical diffusion chamber. The CR-39 utilizes NTD and SSNTD technology.

The results established a relationship between outdoor radon concentration and the height at which the measurements were taken. These results, together with future ones, will be used to develop a methodology for the integral assessment of the radiation background from the Earth's surface.

# Evaluation of the health risk associated with radon exposure on the territory of the Republic of Moldova

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Radon represents the most important source of natural radiation of the population, whose harmful effect has a cumulative character and synergism with other risk factors such as tobacco consumption. In the Republic of Moldova, based on a study measuring the radon concentration in a sample of 1,100 homes using RADTRAK2 passive detectors, the population exposure doses to radon were calculated. Following the statistical processing of the collected data, the following results were obtained for a uniform distribution of the data, thus maximum values of 1160 Bq/m$^3$ are recorded for the Center area, 1260 Bq/m$^3$ for the North area and 950 Bq/m$^3$ for the area north. South. The average concentration of radon in the indoor air is 211.67 Bq/m$^3$; 240.55 Bq/m$^3$ and 285.57 Bq/m$^3$ for the Center, North and South respectively, which proves that the average radon values did not exceed the reference values for the country (300 Bq/m$^3$). The share of homes that exceeded the reference level of radon (300 Bq/m$^3$) constituted 25.3% for the Center area, 31.06 - North and 38.58% - South. Studying the dependence of radon concentration on the abiotic factors of the environment of the existence of a close correlation link with the formation of the cluster with the large Euclidean distance, and the linkage distance constituting 4250 for the radon concentration and the maximum air temperature and the soil surface temperature. At the same time, the case-control study on the influence of radon on the occurrence of lung cancer revealed the following concentrations for the experimental group, the average value of the concentration of radon in the indoor air of 194.3 Bq/m$^3$, and the maximum value 857.2 Bq/m$^3$, value. average recorded for the control lot is 165.2 Bq/m$^3$, and the maximum value 922.2 Bq/m$^3$. The fundamental study through cluster analyzes of the “radon x smoking” interaction influence detected significant interactions between the researched factors manifesting trigger capabilities on the onset of lung cancer.

# 22NRM07 GuideRadPROS: A survey on calibration of radiation protection dosimeters in photon reference fields – current practices and standardization and training needs

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12 GUM – Główny Urząd Miar, Warsaw, Poland
13 IMBiH – Institut za mjeriteljstvo Bosne i Hercegovine, Sarajevo, Bosnia and Herzegovina
14 IPQ – Instituto Português da Qualidade, I.P, Lisbon, Portugal
15 Lusofona University RCM2+, Lisbon, Portugal
16 IRB – Ruđer Bošković Institute, Zagreb, Croatia
17 IST – Instituto Superior Técnico, Lisbon, Portugal
18 TENMAK – Türkiye Enerji, Nükleer ve Maden Araştırma Kurumu, Ankara, Turkey
19 Mirion Technologies (RADOS) Oy, Turku, Finland
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Regular calibration of radiation protection dosimeters is of great importance to ensure accurate measurements and the adequate protection of workers and the public. Calibrations are required by the European Legislation (EURATOM directive) and by many individual countries, both in Europe and in other regions. Some countries have additional requirements, such as verification, testing or type testing of dosimeters. All these requirements improve the confidence in measurements and improve overall radiation protection. Photon dosimeters are typically calibrated and tested in reference radiation fields, which are realized in Primary and Secondary Standards Dosimetry Laboratories according to the standard ISO 4037. The standard was updated in 2019, but early adopters reported problems with its implementation and missing data. Especially smaller laboratories needed additional training. This was one of the main reasons to establish a project within European Partnership on Metrology, with the name 22NRM07 GuideRadPROS "Harmonisation, update and implementation of standards related to radiation protection dosimeters for photon radiation". A survey was organized in the project, and 40 replies were received, with 34 answers from 27 European countries. Considering the small number of calibration laboratories and considering that some countries do not have any calibration laboratories, the coverage of Europe was excellent. The survey showed that only half of the respondents completely implemented the new version of ISO 4037. Setting up gamma reference fields is clear to most respondents, but around half of the respondents have problems (unclear requirements, missing information, difficult to implement) with X-ray reference fields, half-value layer measurements and measurement uncertainty. Only a few respondents stated that X-ray tube voltage, spectrometry and Am-241 fields are adequately covered in the standard. A significant number of laboratories expressed training needs in high voltage measurements (27 respondents), spectrometry (24), setting X-ray reference fields (18), measurement uncertainty (18) and other topics. Survey inputs are used by 22NRM07 GuideRadPROS project to develop training courses and e-training materials, and to collate future research needs. The project will generate guidelines on spectrometry and will investigate conversion coefficients and associated uncertainties allowing for a future edition of the ISO 4037 standard.

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# Eye lens dosimetry: does the direction of rotation (vertical or horizontal) play a role in type testing?

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With the International Commission on Radiological Protection (ICRP) lowering the annual dose limit for the eye lens to 20 mSv, precise monitoring of eye lens exposure has become essential. The personal dose equivalent at a depth of 3 mm, $H_p(3)$, is the measurement quantity for monitoring the dose to the lens of the eye. In typical dosemeter type-tests with non-normal angles of radiation incidence ($\alpha \neq 0°$), usually lateral radiation exposure scenarios with radiation incidence from the left or right are used, which requires rotation of the dosemeter-phantom setup around a vertical axis. However, this method does not adequately account for bottom-to-top radiation exposures which are common in real-world situations such as radiation scattered by a patient reaching medical staff.

This study examines oblique radiation exposure conditions using a typical eye lens thermoluminescent dosemeter (TLD), Eye-D, placed on a cylinder phantom (according to ISO 4037-3) to determine the dose response at different angles of radiation incidence and photon energies. The study employs both low-energy (N-30 radiation quality with a photon mean energy of 25 keV) and medium-energy (N-100 radiation quality with a photon mean energy of 83 keV) X-rays at irradiation angles of $\alpha = -60°$, $\alpha = 0°$, and $\alpha = +60°$, measured along the vertical and horizontal rotation axes of the dosemeter-phantom set-up.

The results show no significant difference between the dose response measured at the selected irradiation angles with horizontal and vertical rotation of the dosemeter-phantom setup: recorded relative doses stayed well within ± 1 %, i.e., by far within the attributed combined uncertainty of ± 2 %. Therefore, it was concluded that it is sufficient to carry out type tests of eye lens dosemeters that are rotationally symmetric in the typical, vertical phantom orientation. These findings make additional tests in a horizontal dosemeter-phantom setup unnecessary – at least for rotationally symmetric dosemeters.

A peer-reviewed article describing the details of this study is available in *Journal of Radiological Protection* (https://doi.org/10.1088/1361-6498/adaaff).

# A new personal electronic dosimeter: the PDOZ

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The PDOZ is a Personal Electronic Dosemeter. These devices are employed to calculate the individual exposure to ionizing radiations in research laboratories, hospitals, nuclear power plants and open environments. The PDOZ project aims to detect, discriminate and measure the dose rate and the dose delivered by beta particles, gamma rays and neutrons in real time. Since in the final prototype a particle discrimination algorithm is included, the PDOZ can be used in mixed radiation fields. In line with the radiological equipment standards, in the energy range of interest, the difference in personal dose equivalent response due to the dose rate should remain within 30% referred to $^{137}$Cs 660 keV gamma line for what concerns gamma rays. For beta particles and neutrons, the limits are the same but referring, respectively, to the two energy peaks of $^{90}$Sr and to $^{252}$Cf and $^{241}$Am(Be). To detect the particles, it is used the scintillation process read by SiPMs (silicon photomultipliers). The device is designed to have three different scintillators, each optimized to one kind of particle. A plastic scintillator, the BC408, is used to detect beta particles, a crystal scintillator, the CsI(Tl), is exploited for gamma rays, while the scintillator for neutrons is under study. From the simulations implemented with the Geant4 toolkit, the best choice to detect neutrons is the EJ254 plastic scintillator. Each scintillator has two SiPMs connected at its bottom side, for a total of six SiPMs. A count is gained when both the SiPMs of the same scintillator have a pulse over threshold in coincidence. Thus, false recorded events caused by thermally generated free charge carriers and not triggered by impinging optical photons, are suppressed, and the thermal noise is brought to $10^{-3}$ Hertz. Several simulations were implemented to study the materials and the thicknesses of the scintillators and to find the best configuration to detect gamma rays, beta particles and neutrons. A first simulation of the ICRU sphere is implemented to find the ambient dose equivalent and the fluence to dose equivalent conversion coefficients. In another simulation, the entire device is implemented to calculate the conversion curves and to find the ambient dose equivalent from the SiPMs counts. The same method is applied to study the angular response from -60° to +60° with respect to the direction perpendicular to the scintillator. Currently, the work is focused on the comparison between the simulated results and the experimental data for $^{90}$Sr, $^{60}$Co, $^{137}$Cs sources. Intercalibration are underway for beta and gamma rays with SSL2 class commercial dosimeters. The neutron detection efficiency and gamma/neutron separation capability studies will take place at CERN under the spallation neutron beam during the first half of 2025.

# Occupational exposures of medical workers in a radiotherapy department in Albania

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The application of ionizing radiation is increased in the field of medicine for diagnosis and treatment including: X- ray diagnostics, interventional radiology, nuclear medicine, and radiation therapy. Exposure of medical workers who perform such practices is unavoidable and is one of the largest groups of people in the world exposed occupationally to ionizing radiation.

The aim of this study is analyzing the distribution of average annual effective dose in five years consequently for a staff working in the X-Knife Radiotherapy-Radiosurgery department, at University Hospital 'Mother Teresa, Tirana. Individual external doses have been monitored with thermoluminiscent dosimeter TLD-100. The results provided that average annual effective doses were within recommendations by basic safety standards and national regulations.

**Keywords:** occupational exposure, radiotherapy, TLD dosimeter

# Radiological risk assessment due to the consumption of some varieties of nuts

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This study presents an investigation of radiological risk assessment due to the consumption of some varieties of nuts. This was done by determination of levels of radioactivity and assessment of the annual effective dose in the twenty samples of nuts. Five brands of nuts were taken in this study and for each brand four samples were taken to have a better statistic for their measurement. The most consumed nut brands in Albania are almonds, hazelnuts, peanuts, pistachios and walnuts. These samples of nuts are consumed more often and were purchased from markets of the Tirana city, in Albania. Gamma-ray spectrometry method and a high-resolution HPGe detector were used for the radionuclide's detection. The analysis showed that natural radionuclides of $^{40}$K and $^{226}$Ra were detected in all samples, while the presence of $^{232}$Th was detected in 7 of them at a low level. The artificial radionuclide of $^{137}$Cs was detected only in two samples at low levels.

The range of activity concentration for radionuclide of $^{40}$K is between 119.23 to 276.64 Bq kg$^{-1}$ and for $^{226}$Ra is between 3.28 to 10.96 Bq kg$^{-1}$. For $^{232}$Th the range is from < MDA (Minimum Detection Activity) to 2.01 Bq kg$^{-1}$ and for the artificial radionuclides of $^{137}$Cs is less than 1 Bq kg$^{-1}$. The average annual effective doses due to intake of radionuclides from these brands of nuts for age groups of 2–7 years, 7–12 years, 12–17 years and adults > 17 years was estimated to be 88.67 μSv y$^{-1}$, 82.49 μSv y$^{-1}$, 116.06 μSv y$^{-1}$ and 33.28 μSv y$^{-1}$, respectively.

The results obtained were compared with similar literature and international reference values. The annual effective dose for each age group was lower than the recommended limit of 1 mSv y$^{-1}$ for public exposure by WHO (World Health Organization) and ICRP (International Commission on Radiological Protection) for all age groups. Therefore, all the radiological risk assessments made in this study showed that the consumption of these nuts has an acceptable radiological risk, but none of them had any significant, thus all brands are safe for consumption.

**Keywords:** activity, effective dose, gamma spectrometry, radiological risk

# Radiological classification of materials at CERN: A data-driven approach with machine learning

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The maintenance and dismantling of high-energy particle accelerators generate waste that is potentially radioactive. If the activity levels are negligible, waste can be cleared from regulatory control and possibly reused as conventional material. At CERN, the European Organization for Nuclear Research, the radiological classification of materials as conventional or radioactive is challenging due to the diversity of activation scenarios, expected radionuclides, and material compositions.

We address these challenges by combining machine learning with activation simulations performed with ActiWiz, a CERN-developed software based on FLUKA Monte Carlo simulations. We first simulate tens of thousands of possible activation scenarios and evaluate the corresponding activity levels and dose rates. We then use this data to train predictive models, which we apply to the waste items to be characterized.

This presentation focuses on the application of this methodology to irradiated cables and metallic waste, specifically on the definition of threshold values for measurable quantities (e.g., activity, dose rate, and mass) that determine whether an object qualifies for clearance as conventional waste. Defining these threshold values has a tremendous impact on operational radiation protection, enabling the identification of radioactive materials with a relatively fast and simple radiation measurement.

We develop several classification methods, including logistic regression (simple and multiple) and Bayesian approaches, assessing their performance in classifying materials as conventional or radioactive. We also test a range of possible classification predictors, analyze their correlations, and identify the most reliable ones.

By coupling deterministic activation models and machine learning techniques, this approach improves the accuracy of radiological classification, contributing towards safe and cost-efficient practices of waste management.

# Nonlinear differencing for spatial discretization to estimate the radioactive nuclide concentration in the bioshield region of a pressurized water reactor

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This study has interest in numerical analyses to estimate radiological inventory in decommissioning program for pressurized water reactors. Our previous study investigated the sensitivity of neutron energy spectrum to resolution of space differencing, considering the bioshield region of Kori unit 1, the 1st commercial nuclear power reactor in Korea. The results show that the neutron energy spectrum is very sensitive to the grid size for space differencing in the bioshield region and its variation is not monotonic against the depth of bioshield.

Here, it should be noted that the radioactive nuclide concentration is obtained with the terms of neutron reaction rate, which is the product of the neutron flux and the effective nuclear cross-section. The neutron flux (as the weighting function) decreases more or less exponentially with increasing depths in the bioshield region of Kori unit 1, as shown in our previous study. It is indicated that radiological inventory is highly dependent into magnitude of neutron flux as well as neutron energy spectrum at a certain location. In other words, the main effect of the neutron spectral change on the radiological inventory calculation is dominated by the inside layer of the bioshield because in this averaging process the first few centimeters of the bioshield are dominating the final averaged spectrum.

This study introduces “nonlinear space differencing”, which discretizes the space of bioshield region with the mesh size set of different from each other grids. First, we calculate the spatial distribution of neutron flux in the region of bioshield to obtain the function of neutron flux level against the depth of bioshield. Based on the radial flux distribution, the mesh size is decided in proportional with the magnitude of flux at the region of interest. In result, the spacing is fine in the inner region and coarse in the outer region, we call it “nonlinear space differencing”. A case study is performed to examine sensitivity of the number of grids to obtain any optimal spacing. Finally, comparison is discussed between the nonlinear differencing” and the conventional method of equidistant spacing (we call it “linear differencing”). We expect this study to give more effective and accurate solution to estimate radiological inventory for decommissioning program.

**Keywords:** pressurized water reactor, decommissioning, radiological inventory, space differencing, neutron energy spectrum, neutron flux distribution

**Acknowledgments:** This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. RS-2023-00251596).

# A preliminary study on evaluating radionuclide inventory in decommissioning program for Wolsong nuclear power unit 1 in Korea

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Wolsong unit 1, the 1st CANDU-type reactor in Korea, started commercial operation on April 22, 1983. The design life is 30 years, which was until November 2012. The Nuclear Safety and Security Commission approved 10-year extension on Feb. 27, 2015, allowing it to operate until November 2022. However, it was permanently shut down on Dec. 24, 2019 after 36-year operation, due to economic feasibility and other reasons. Currently, the dismantling process is in progress, and the Nuclear Safety and Security Commission is deliberating on the dismantling permission.

The evaluation of the radionuclide inventory is considered as the 1st step to decommission a permanently shut down nuclear power plant. The accuracy of estimating radionuclide concentrations is very important not only from the perspective of economy to classify waste grades according to radioactivity concentration but also from the viewpoint of ensuring worker safety.

This study discusses the methodology to calculate radionuclide inventory for decommissioning Wolsong unit 1. In the Bateman equation, which provides a solution of the radioactivity concentration, the effective nuclear cross-sectional area is weighted and averaged over the neutron energy spectrum at a certain location of interest. As a preliminary study, we consider a MCNP model for single fuel channel with the reflective boundary option of MCNP Code. First, the neutron energy spectrum is calculated to obtain one-group effective cross-sections in the region of pressure tube and calandria tube. Employing the obtained effective cross-sections, we solve Bateman equations to obtain the radionuclide concentration as the function of time during 36-year operation and 10-years cooling time. It is expected that the results obtained from this study would give useful data and information for making decommissioning plan for Wolsong unit 1.

**Keywords:** CANDU-type reactor, decommissioning/dismantling, radionuclide inventory, activation calculation

**Acknowledgments:** This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. RS-2023-00236918).

# Standards for radiation protection and detection instruments under development by various international organizations: IEC, IEEE and CENELEC

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The International Electrotechnical Commission (IEC) is the world's leading organization for preparing and publishing globally relevant international standards for all electric and electronic devices and systems. It brings together 86 countries, representing 98% of the world population and 96% of world energy generation. Nearly 20,000 experts collaborate on the global IEC platform. All IEC international standards are fully consensus-based and reflect the needs of key stakeholders from every participating nation. IEC standards serve as the basis for national standardization, references for drafting international tenders and contracts, and for conformity evaluation of instrumentation. Additionally, IEC standards are considered by CENELEC (European Committee for Electrotechnical Standardization) for adoption as European standards.

The Institute of Electrical and Electronics Engineers (IEEE) is a technical professional organization dedicated to advancing technology for the benefit of humanity, with over 400,000 members. The Standards Association Board of IEEE is engaged in developing international standards. Since 2020, the new IEEE Technical Committee 45 "Radiation and Nuclear Instrumentation and Systems" has been transferring relevant ANSI standards into IEEE standards and developing new ones.

Measuring neutron dose equivalent rates is challenging because no single instrument can cover the entire 9 orders of magnitude neutron energy range (thermal to 20 MeV). Quantifying performance requirements in a standard for such instruments presents unique challenges. The international standard IEC 61005, concerning portable neutron ambient dose equivalent (rate) meters, was developed by Sub-Committee 45B "Radiation Protection Instrumentation" of IEC. This standard is currently under revision and will be presented. The requirements for the following quantities will be discussed: constancy of the dose rate response, variation of the response due to neutron energy, variation of the response due to angle of incidence, overload, response time, temperature shock, protection against moisture and dust, drop, vibration and mechanical shock etc.

An example of the draft IEEE N42.61 standard under development, "Data Format for Real-Time Streaming from Radiation Detection Instruments," will also be discussed.

The criteria and compliance test methods in these standards result from an optimization and compromise among participating experts from many countries. These standards aim to achieve acceptable detection performance that reflects the positions of national regulatory agencies, scientific and technological progress, testing laboratories' capabilities, end users' needs, instrument production costs, and compliance testing procedures.

# Assessment of the total CBRN health effects is still a big problem

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Individual components of the CBRN (Chemical, Biological, Radiological and Nuclear) category of dangerous agents are characterised by some peculiar properties. This is why assessing the total impact of two or more components on the health caused by such exposures is practically impossible. Individual agents interact with human tissue and organs in very specific processes, and their results are difficult to put under a common denominator and express the total harm by one unit or parameter. Moreover, CBRN health effects at low exposures may result only in stochastic effects, while at exposure above a certain relatively much higher level, deterministic effects appear. The paper presents an overview of the current approach to quantifying risk due to the exposure to CBRN as a whole, where contributions from different individual components have to be considered.

# 2D echo in the diagnosis of IHD: Recent improvements, challenges, and prospects

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**Background/Aim.** Advanced radiodiagnostic methods, which include catheterization and computed tomography, can pinpoint ischemic heart disease (IHD). Cardiac catheterization has various flaws that compromise patient safety and diagnostic accuracy. Thus, employing two-dimensional echocardiography (2D echo) to overcome these difficulties is immensely advantageous to the patient. This research sought to examine recent developments in the prognostic and diagnostic utility of two-dimensional echocardiography (2D echo) in the diagnosis of ischemic heart disease (IHD).

**Methods.** This study included 100 patients with IHD who were referred by a cardiologist. They were assessed using an Acuson SC2000 Prime ultrasound machine from Siemens. The diagnosis was confirmed by conventional coronary angiography.

**Results.** Left ventricular (LV) end diastolic dimension > 50 mm, left ventricular ejection fraction (LVEF) ≥ 50%, aortic sclerosis, wall motion abnormalities (WMAs), mitral annular calcification, and left atrial enlargement (> 50 ml for males and > 45 ml for females) were all significant 2D echo findings in IHD patients ($P \leq 0.05$). 2D echo has 92% sensitivity, 33.33% specificity, and 90.29% accuracy in diagnosing IHD.

**Conclusions.** Our findings imply that 2D echo is crucial for IHD diagnosis, therapy, and prognosis. In addition to demonstrating 2D echo's sensitivity, specificity, and accuracy in diagnosing IHD, the study also demonstrated the accuracy of traditional invasive coronary angiography in each case.

# Radiation protection calculations in the design of the AB-BNCT facility for the PNC-PNRR-ANTHEM Project

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In the framework of the PNC-PNRR ANTHEM project, a new Accelerator-Based Boron Neutron Capture Therapy (AB-BNCT) research and clinical facility will be built in Caserta, Italy. The ANTHEM clinical facility neutron production will be based on a Radio Frequency Quadrupole proton accelerator coupled with a beryllium target. Both the accelerator and the target are designed and manufactured by the Italian National Institute of Nuclear Physics (INFN). This machine delivers 5 MeV protons with a 30 mA current in continuous wave, producing at the target a neutron flux of the order of $10^{14}$ neutrons per second.

The radiation protection aspects of the facilities have been studied for the design of the biological shield and to be able to guarantee operational safety for the clinical and technical staff and for the patients.

In particular, using the Monte Carlo transport codes PHITS and DCHAIN, we have calculated the dose-rate at different times after the accelerator shutdown. We have considered the neutron activation of the Beam Shaping Assembly (BSA) and the neutron activation of the walls in the treatment room. The obtained results allowed us to know the principal radioactive isotopes in the BSA and in the walls as a function of time. For each time, we have also calculated the ambient equivalent dose rate. Additionally, we have investigated the residual specific activity of air within the irradiation room, giving special attention to the neutron activation of Ar-40, that produces the beta-emitter Ar-41 with a half-life of approximately 109 minutes. In this case the specific concentration of the Ar-41 as a function of time was calculated considering also the recirculation of air.

The studies performed in this work, together with additional radiation protection studies carried out by our research group were pivotal in defining the design of the ANTHEM facility and will be fundamental for the management of the future patients after the BNCT treatment.

# Disinformation rumours spread about CBRN attacks and their consequences

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Disinformation related to chemical, biological, radiological, and nuclear (CBRN) threats can have severe and far-reaching consequences. This is especially critical in today's world, where information spreads rapidly with little regard for its accuracy or impact. Manipulated or false reports about a CBRN incident, such as a terrorist attack or a pandemic, can mislead governments and international organisations, hinder effective response efforts, waste resources, and incite panic among the public. Conspiracy theories and misinformation can heighten fear and anxiety, particularly if they suggest that a CBRN event is uncontrollable. They may even provoke social unrest if people wrongly believe that the event was deliberately orchestrated as part of a conspiracy. Furthermore, such disinformation can be exploited to radicalise individuals and recruit them for terrorist activities, as it fuels fear and promotes division among different groups. The paper presents an overlook of this topic with special emphasis on the consequences of disinformation concerning R and N components of the CBRN family.

# Comparison of INTERSPEC and FRAM for the analysis of uranium enrichment

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Gamma spectrometry is a valuable non-destructive method for the characterization of nuclear materials that are particularly used in the first 24 hours of criminal investigation if there is a material out of regulatory control (MORC) found. It is essential to develop methods and test capabilities in determining the isotopic ratio of uranium in nuclear material that can help estimate the risk and proper radiation protection measures at the radiological crime scene. Well-known gamma spectrometry equipment producers – Ortec and Canberra – have their software for spectra analysis, but they place limitations when the specific needs for the nuclear forensics analysis must be met. Different commercial software (FRAM, MGA++, and MGAU packages) that are especially dedicated to the fast analysis of gamma spectra of nuclear materials are available and very commonly used. They present very convenient and easy-to-use alternatives because the entire isotopic analysis of uranium and plutonium is reduced to just a few steps. FRAM software allows users to tailor the analysis to the specific requirements of a given measurement. This is achieved by a different selection or by creating a completely new set of parameters that defines the type of detector as well as the suitable energy region for analysis, then the shape (type) of the efficiency function, the selection of photopeaks used for energy, shape and efficiency calibrations as well as many other options within the software itself. On the other side, some laboratories do not have any of the mentioned commercial software for the analysis of gamma spectra of nuclear materials. This paper focuses on the potential use of InterSpec which is a native or web application to assist in the analysis of nuclear radiation spectra using the peak-based methodology. The set of different gamma spectra was used for testing the applicability of InterSpec in the isotopic ratio determination for uranium-containing samples and the optimal peak selection for the InterSpec was found. The obtained results from FRAM software and InterSpec show good agreement although with FRAM more precise values of isotopic ratios are determined. It can be concluded that InterSpec can be efficiently used for the rough estimation of enrichment and serve as a good screening tool for the initial characterization of the MORC.

# Root cause analysis of Kakavija border point radiation portal monitor failure in Albania

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The Republic of Albania is a non-nuclear country situated in the Balkan region. In Albania, radiation sources are mainly used in different applications including medicine, industry, agriculture, research and education. In Albania, radiation portal monitors (RPMs) are installed since 2005 in six border crossing points (BCP) of type Yantar 1-U and Yantar 2 U from ASPECT company. In Kakavija BCP, an RPM type Yantar-2U is installed. The RPM system is located at the entrance of the Albanian Border with Greece and covers one of the two incoming lanes.

Its main aim is to serve the purpose of preventing and deterring the illicit trafficking of radioactive or nuclear materials through Albania. This RPMs is operated by General Custom Directorate. The main issue in relation to illicit trafficking and smuggling in nuclear materials is to detect any possible illegal transits through Albanian territory and borders and to respond to them properly.

In the frame of the IAEA Coordinated Research Project (CRP) J02014 “Advancing Maintenance, Repair and Calibration of Radiation Detection Equipment” under the research contract No. 23325 titled “Analysis of Radiation Detection Equipment Failures: Causes and Sustainable Maintenance Plans”, Albania has made a root cause analysis of all the RPMs included in this CRP.

In this paper, we will discuss the root cause analysis done for Kakavija BCP RPM. Firstly, we defined the methodology which was followed to make the root cause analysis of RPM failure or malfunction. This methodology consisted of RPMs technical investigation, assessment of causes in case of failures or malfunctions and the recommendation of possible solutions. The importance of preventive maintenance, FLOs continuous training, cooperation between safety and security agencies/organizations, and tools to maintain, analyse and assess radiation portal monitors will be also covered.

# Alpha spectrometry of uranium and plutonium at short source-detector distances

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When measuring alpha spectra on a silicon detector with ion implantation, due to the small thickness of the source and the entrance window of the detector, the conversion electrons accompanying the alpha decay are also registered by the detector. The alpha spectrum is distorted by true coincidences between alpha particles and electrons. A possible solution to this problem would be measurements at a long distance from the detector, but in the case of low activity of the source or when measuring long-lived nuclides, in order to achieve the required statistical accuracy, measurements are carried out relatively close to the detector.

In the alpha spectrum of $^{238}$Pu, below the alpha line corresponding to the decay of $^{238}$Pu into the ground state of the daughter nucleus $^{234}$U, there are two more peaks of alpha particles with energies of 5357 and 5456 keV, respectively, from the decay into excited states of $^{234}$U. These excited states are instantaneously discharged by the emission of conversion electrons due to low energy gamma transitions. As a result, there is simultaneous emission of an alpha particle and a conversion electron, which can be simultaneously registered by a silicon detector. Therefore, in the experimental alpha spectrum, we will observe the summation of alpha lines with the spectrum of conversion electrons. This effect will increase with decreasing distance of the sample from the detector due to the increase in the efficiency of registration of both particles and significantly complicate the processing of alpha spectra, especially in cases where alpha spectra from different nuclides overlap, as in the measurement of $^{239}$Pu,$^{240}$Pu.

Several technical ways of combating this effect are proposed - applying a positive potential to the sample, using a magnetic field that blocks electrons from entering the detector. In this work, we propose another way of considering the summation of alpha and conversion electrons - by modelling the processes of nuclear decay and recording spectra using Geant4. This makes it possible to obtain energy model spectra that consider the summation of the energies of alpha particles with atomic electrons accompanying the internal conversion process.

For least-squares fitting, we used the theoretical spectrum in the form of a convolution of model spectra with a function that describes the shape of the monoenergetic alpha line. The proposed method of taking into account the effect of the summation of the energies of alpha particles and conversion electrons allows you to correctly describe the shape of the spectrum both at a distance of 49 mm and 1 mm from the detector.

The isotopic composition of the enriched uranium was measured by gamma-, mass-, and alpha-spectrometry. Determination of $^{232}$U content by alpha spectrometry is complicated by the fact that its activity is four orders of magnitude lower than that of $^{234}$U. Therefore, to increase registration efficiency, we performed measurements at a distance of 5 mm from the detector and used the alpha spectra processing method described above to obtain the uranium isotopic composition.

# 22NRM07 GuideRadPROS: Radiation protection dosimeter performance assessment – Aggregated calibration data in the Cs-137 reference radiation field

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One of the goals of the GuideRadPROS joint research project (JRP) is the harmonization and update of international standards for type testing of radiation protection dosimeters. This is to be achieved through analysis of the test methods and criteria of evaluation of dosimeters defined in different standards, and through analysis of the performance of radiation protection dosimeters used in different European countries. Within one of the activities under the WP3 of this JRP, most commonly used active radiation protection dosimeters used for area monitoring in the workplace and for individual monitoring of occupationally exposed workers have been identified.

Aggregated calibration data on several radiation protection dosimeter models have been collected from a total of six dosimetry calibration laboratories. The collected calibration data predominantly includes calibration at the radionuclide-based radiation qualities (termed as S-Cs and S-Co in the ISO 4037 standard). The calibrations are usually performed in these radiation fields at various dose rate and dose values. This data can be used to assess the dosimeter performance in terms of response non-linearity. Calibrations in the N-series radiation qualities are either not commonly requested by the end-users or not regularly provided by the calibration laboratories.

In this work, aggregated calibration data in terms of absolute dosimeter response have been presented. The collected calibration data is presented for S-Cs at the reference dose (rate). Inter-variation of dosimeter response within a dosimeter model of up to approximately 10 % can be observed. The cause of this variation can be addressed to the dosimeters being used in different environments, with different frequencies of use, as well as the differences between the data originating from several calibration laboratories. For some dosimeter models the conclusions on the behavior of dosimeter type under reference conditions cannot be clearly deducted due to the low sample size. The response of all the calibrated dosimeters is within ± 40 %.

The aggregated calibration data, along with the data on dosimeter performance from the literature, and the state-of-the-art manufacturer specifications will be used to identify the gaps in the data on radiation protection dosimeters. A measurement program is currently ongoing and being conducted under the scope of the JRP, to collect additional data on dosimeter performance including their energy and angular dependence of the response as well as their non-linearity.

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

# Management of health risks associated with occupational exposure to ionizing radiation and radon in the medical field

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**Ionizing radiation** is an everyday reality in the medical field, frequently used for the diagnosis, treatment and prophylaxis of many diseases, but occupational exposure of healthcare workers is a significant risk.

Radon emits alpha particles, which can directly damage lung cells once inhaled. Unlike other types of ionizing radiation in the medical field, radon exposure is continuous and difficult to detect without special equipment. Radon is associated with underground mines and old buildings, but it can also enter hospitals, clinics or laboratories.

The effects of occupational exposure to radon and ionizing radiation are of major concern as it can have long-term negative health effects, including the risk of oncological and non-oncological diseases.

**The aim of the study** is to assess the health status of occupationally exposed to ionizing radiation, with the development of measures to control the radiation health risk in the workplace.

**Research Methodology.** It is an observational, retrospective, analytic, cross-sectional, cohort and observational study comprising several stages, on the one hand it will consist in analyzing the health status of occupational exposures and on the other hand it will measure the level of occupational radioactive phonon levels. The health status analysis will include the study of clinical and paraclinical data from the personal medical records of medical occupational exposures working in fields such as radiology, nuclear medicine and radiotherapy. This will provide us with essential information about the health status of employees and the impact of radiation exposure on the body. The data on the gamma background level at the subjects' workplaces will provide us with essential information about the background radiation level and will contribute to the assessment of occupational exposure, identification of radiation sources, ensure workers' safety, establish protective measures and compliance with legal regulations.

**Results.** The specialists' health status will be assessed according to the results of medical examinations. In addition, it is proposed to carry out immunological analysis (lymphocyte immunophenotyping by flow cytometry method), at the same time radiation exposure records (individual dosimetry) will be investigated. This study will allow us to determine the impact of exposure on the health of medical personnel and to identify the factors influencing the level of exposure to radon and ionizing radiation.

**Conclusion.** Occupational exposure to radon and other ionizing radiation in the medical field is a reality, but the risks can be reduced through effective preventive measures. Radon is an additional source of radiation that requires constant monitoring and control strategies. Implementation of safety standards and education of healthcare workers are essential to protect the health of healthcare workers.

# Monitoring of indoor radon concentrations and implementing actions to prevent population exposure

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The population's exposure to natural radioactive sources is primarily due to radon ($^{222}Rn$), which constitutes over 50% of the total exposure. Radon is a radioactive gas, considered a toxic substance in the environment and poses a major health risk. In the Republic of Moldova, the radon problem remains relevant in the context of the dynamics of the incidence of tumors, especially lung cancer, thus affecting the sectors of the national economy and the health system.

To implement the requirements of the EUROATOM Directive 2013/59, the Republic of Moldova and Romania have been studying for many years the distribution of radon concentrations in buildings, the main environmental factors (water, soil) and the impact of natural ionizing radiation on human health in order to develop and improve preventive measures.

Among the achievements in the field of radon research we can mention: national radon survey, carried out under the aegis of the IAEA, within the technical cooperation project MOL9007. In this regard, the following was developed/established:

- National Program with the National Action Plan for Radon Exposure Control (NAPR);
- Radon reference level in homes and working places;
- Strategic directions, including the establishment of the regulatory framework and the responsibilities of the institutions involved in the implementation of the NAPR, and the harmonization of the regulatory framework with the existing legislation;
- Measurements of radon concentrations inside buildings and drawing up a radon map;
- Identification of workplaces inside buildings and other workplaces in areas with increased risk of exposure to ionizing radiation emitted by radon;
- Actions to prevent and control radon penetration into buildings to be built and remedial actions in existing buildings;
- Information, education, and communication strategy to raise awareness of the population and inform local decision-makers, employers and employees about the risks posed by radon;
- Reduction of lung cancer risks attributable to exposure to ionizing radiation emitted by radon in correlation with the risks for smokers and non-smokers;
- Training, education, and improvement of professional categories that could be affected by exposure to ionizing radiation emitted by radon and of those involved in the implementation of the PNAR.

The research activity is focused on collaboration with European countries, especially Romania. We are currently carrying out the second stage, implementation of the field sampling methodology for radiometric methods and radon measurements.

**Acknowledgments:** The research presented was carried out within the projects: "Monitoring of exposure to ionizing radiation of professionally exposed personnel and the public with the development of radiation protection measure", code 13.01.02 and „Increasing the digital data flow capacity between Romania and the Republic of Moldova regarding the monitoring of soil radioactivity and radon", PN-IV-P8-8.3-ROMD-2023-0241.

# Blind test measurement exercises for dosimetry system performance evaluation

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The Dosimetry Laboratory of the Greek Atomic Energy Commission (EEAE) conducts monthly individual dose monitoring for approximately 12,000 workers in Greece exposed to ionizing radiation, using whole-body, extremity, and lens of the eye Thermoluminescent Dosemeters (TLDs). The purpose of individual dosimetry is to assess the personal dose equivalent and to utilize these measurements for radiation protection. The personal dose equivalent $H_p(10)$ serves as a conservative estimate of the effective dose, which is the basis for regulatory dose limits.

This study presents and analyzes the results of blind test measurement exercises conducted at the Dosimetry Laboratory. These exercises are part of the regular performance evaluations prescribed in the applied quality management system in the framework of its accreditation according to the requirements of the EN ISO/IEC 17025 standard and other international and European standards to ensure the reliability and accuracy of the dosimetry system and services.

During these exercises, the EEAE' s Ionizing Radiation Calibration Laboratory irradiates TLDs under controlled conditions while keeping the actual doses unknown to the Dosimetry Laboratory personnel. The irradiated dosemeters are then integrated into routine procedures alongside occupational dosemeters and processed according to the laboratory's quality management protocols.

Measurement accuracy is evaluated using trumpet curves for illustrating the performance limits, as recommended by the international and European standards. The mean ratio of the measured to the true personal dose equivalent ($H_p(10)$ measured / $H_p(10)$ true), is 0.97, with a standard deviation of 0.13 across 290 measurements. The results confirm that all measurements remain within prescribed performance limits & approval criteria and comply with regulatory requirements.

**Keywords:** thermoluminescent dosemeter, personal dose equivalent $H_p(10)$, performance evaluation, trumpet curves

# Study on risk assessment for a graded approach to NORM regulation

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In Korea, under the *Act on Protective Action Guidelines Against Radiation in the Natural Environment*, enacted in 2011, Naturally Occurring Radioactive Materials (NORM) exceeding 1 Bq/g (Th or U and their progeny) are subject to registration. Additionally, when NORM residues are processed, disposed of, or recycled, they must be notified. The NORM industries include titanium dioxide ($TiO_2$) pigment production, phosphate industries, zircon and zirconia industries, water treatment, monazite processing, and potassium industries. As of the end of 2024, approximately 500 entities have been registered. While radiation exposure doses for workers in these industries have been confirmed to be below 1 mSv/y, regulation has been strengthened due to issues with consumer products containing NORM (e.g., “radon beds”), necessitating the implementation of an optimized regulatory approach. The ICRP recommends that a national-level list of NORM industries be established and that radiological risk assessments be conducted to determine the justification for radiation protection. The IAEA also emphasizes that the first step in establishing a regulatory process for the NORM management is to determine a list of industrial activities that need to be considered for regulatory control. Currently, NORM is regulated only based on radiation concentration and total annual radioactivity. However, a graded approach to regulation, proportional to the magnitude and likelihood of exposure, is required. This study analyzes industrial processes and evaluates the radiological characteristics and radiation exposure doses in various industrial activities to support this approach.

# Hg, Pb and Cd in mussels from Montenegrin coast: Human health risk assessment

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This study determined the concentrations of Hg, Cd, and Pb in mussels (*Mytilus galloprovincialis*) from three locations in Boka Kotorska Bay, Montenegrin coast, and assessed the potential human health risks associated with their consumption. Mussel samples, collected over a two-year period, were analyzed using ICP-OES and DMA. The calculated target hazard quotient (THQ) values for Hg, Pb, and Cd were all below 1, indicating no immediate health risks for the exposed population. However, when considering the mean concentrations over two years and the calculated maximum allowable mussel meal number, Pb and Cd were identified as limiting factors for mussel consumption. The results suggest that the maximum recommended weekly intake is 4.24 meals based on Pb and 7.48 meals based on Cd contents, with one meal consisting of 250g of mussels. Given the potential presence of additional toxic elements and their intake from other dietary sources, mussels should not be consumed too frequently.

**Keywords:** metals, *M. galloprovincialis*, human exposure, Montenegrin coast

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# Assessment of gamma dose rate and population exposure in Berat

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This study aims to establish the gamma dose rate and accumulated radiation dose of Berat and compare the exposure in inhabitants of the old town district within the protection of UNESCO since 2008 to those living in other parts of the city. For this purpose, we used the Backpack ATOMTEX device and made measurements at various points according to the International Atomic Energy Agency (IAEA, 2018) guidelines for environmental radiation monitoring. To calculate a per-year population dose estimation, one utilized the conversion coefficient for the dose to a gamma dose rate, advised according to suggestions of the IAEA (IAEA, 2014) as well as those of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000). Data were analyzed and processed via Kriging method interpolation to address the spatial distribution of values as well as via MATLAB processing for numbers. The largest gamma dose rate in the city was 0.134 μSv/h. Because 2/3 of people spend time indoors and 1/3 outdoors, the residents' annual dose would be around 704.3 μSv/year, which is lower than the European Union's 1000 μSv/year. Based on the data, it may be possible that the inhabitants of Berat's old town experience different amounts of radiation exposure than those residing elsewhere in the city. This study assists in comprehending the spatial distribution of natural radiation and assists in assessing radiological risk to the population based on international standards and practices for environmental monitoring of radiation.

# From dosemeter development to routine use – standards and uncertainties

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**The concept for dose limitation** in radiation protection consists of the protection quantities (doses in the human body, not measurable) and the operational quantities (for measurements) to (conservatively) estimate the protection quantities.

**Standardization ensures the quality of dose measurements.** For this,

- the International Electrotechnical Commission (**IEC**), committee IEC/TC45/SC45B on radiation protection instrumentation, issues standards on **performance requirements for type-tests** while
- the International Organization for Standardization (**ISO**), committee ISO/TC85/SC2 on radiological protection, issues, among others, standards on **reference radiation fields**.
- Regional standardization organizations are
  - the European Committee for Standardization (CEN) CEN/TC430 on nuclear energy, nuclear technologies, and radiological protection, adopting ISO standards, and
  - the European Electrotechnical Committee for Standardization (CENELEC) CLC/TC 45B on radiation protection instrumentation, adopting IEC standards; likewise
  - further regional organizations such as the GCC in the Gulf region, the SARSO in the South Asian region, and the ARSO in the African region, adopt ISO and/or IEC standards.

For photon **dosemeter type-tests** the narrow spectra (N-series) photon reference radiation fields described in ISO 4037 are used to **determine the dosemeters' (extreme) responses to (nearly) mono-energetic radiation**. (ISO 6980 describes beta-particle and ISO 8529 neutron reference radiation fields.) **Further influence quantities** such as angle of radiation incidence, dose and dose rate, ambient conditions (temperature etc.), electromagnetic immunity etc. are, e.g., dealt with by

- IEC 62387 for dosimetry systems with integrating passive detectors and
- IEC 61526 for active personal dosemeters.

The **ranges of influence quantities** that a dosemeter is tested for **must cover the ranges of the workplaces** the dosemeter will be used in. The **dosemeter** should be **calibrated at its reference energy** (if used at different workplaces) **or the mean energy of the foreseen workplace** (if used at only one workplace).

**The overall uncertainty of a dosemeter** is determined by combining the uncertainty contributions for the different influence quantities – deduced from the extreme values of the response values obtained in a previous type-test. The underlying procedure **is described in IEC TS 62461** which contains many examples. Its updated version as of 2025 also outlines the determination of the decision threshold and detection limit.

**The overall performance of dose measurements should be checked regularly** by comparison measurements **according to ISO 14146**, a standard on performance limits for individual monitoring services (IMS). This standard describes the so-called trumpet curves, i.e., the allowed response limits depending on the dose. Its updated version as of 2024 now covers comparison measurements from the European Radiation Dosimetry Group (EURADOS).

# Angular dependence of $H_p(3)$ – radial vs. polar rotation

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**Introduction.** With the International Commission on Radiological Protection (ICRP) lowering the annual dose limit for the lens of the eye to 20 mSv, precise monitoring of eye lens exposure has become essential. The personal dose equivalent at a depth of 3 mm, $H_p(3)$, is the measuring quantity for monitoring the lens dose. This quantity is, according to the International Commission on Radiation Units and Measurements (ICRU), defined at 3 mm depth in a rectangular cylinder (20 cm in diameter and 20 cm high) made of ICRU 4-element tissue. Conversion coefficients $h_{pK}(3)$ for photons from the basic quantity air kerma, $K_a$, to the quantity $H_p(3)$ are available for normal ($\alpha = 0°$) and oblique ($\alpha \neq 0°$) radiation incidence for radiation impinging from the left or right, i.e., when the cylinder is rotated about a vertical axis. However, this rotation direction does not adequately account for bottom-to-top radiation exposures which are common in real-world situations (such as radiation scattered by the patient reaching medical staff). Therefore, this study investigates how much the conventional quantity value (true value) changes when the ICRU 4-element cylinder is rotated about a horizontal axis compared to the common vertical rotation axis.

**Method.** Conversion coefficients $h_{pK}(3)$ were calculated for both vertical (normal) and horizontal rotation of the ICRU 4-element tissue cylinder for mono-energetic photons from 2 keV to 10 MeV. From the results, the ratio of the values for horizontal and vertical rotation were determined. For comparison, the corresponding values for the equivalent dose to the lens of the eye, $h_{lens}$, were calculated and their ratios compared to the corresponding ratios for the operational quantity $H_p(3)$. Corresponding ratios were determined for reference beta-particle radiation fields.

**Results.** The described ratios for photon radiation showed the following behavior:

- the larger the angle of radiation incidence $\alpha$ and the smaller the photon energy $E_{ph}$ the smaller the ratio $r_{Hp3} = h_{pK}(3;E_{ph};\alpha)_{horizontal} / h_{pK}(3;E_{ph};\alpha)_{vertical}$: for example, $r_{Hp3}$ falls below unity ($r_{Hp3} \leq 0.98$) for
  - $\alpha = 30°$ and $E_{ph} < 10$ keV and
  - $\alpha = 75°$ and $E_{ph} < 500$ keV;
- simultaneously, the ratio $r_{Hlens} = h_{lens}(E_{ph};\alpha)_{horizontal} / h_{lens}(E_{ph};\alpha)_{vertical}$ is significantly smaller than 0.98 for the same values of $\alpha$ and $E_{ph}$:
  - $r_{Hlens} \leq 0.88$ for $\alpha = 30°$ and $E_{ph} < 10$ keV and
  - $r_{Hlens} \leq 0.85$ for $\alpha = 75°$ and $E_{ph} < 500$ keV.

Similar results (with different actual numbers) were obtained for beta radiation.

**Conclusions.** For oblique radiation incidence ($\alpha \neq 0°$) the conventional quantity value (true value) of $H_p(3)$ is significantly smaller when rotation about the horizontal instead of vertical (normal) axis is performed. This effect is even much stronger for the dose to the lens of the eye, $H_{lens}$. These findings may serve ICRU to judge whether or not it should be considered for an updated definition of the operational quantity $H_p(3)$ – and, consequently, for type-testing of dosemeters.

# National review of diagnostic reference levels (DRL) for radiology and nuclear medicine

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Diagnostic reference levels represent sets of values of dose magnitudes in diagnostic and interventional radiology examinations/procedures and respectively values of activities administered in the case of radiopharmaceuticals used in diagnostic nuclear medicine procedures, established for typical groups of patients. They are used in the process of optimizing radiology and nuclear medicine practices.

The legislative framework is represented by the Ministry of Health Order no. 1245/2021 which establishes the diagnostic reference levels for adult patients, in the case of the most common radiology and nuclear medicine procedures, as well as the method of their application in current practice. At the same time, the MoH Order establishes the review every 3 years of the diagnostic reference levels for the most common diagnostic procedures in radiology and nuclear medicine. In order to fulfill this legal obligation, a methodology was developed for the national collection of dose amounts specific to each type of examination with ionizing radiation and their statistical processing in order to estimate nationally representative values for the dose amounts used in current practice.

The medical units of diagnostic radiology, interventional radiology and diagnostic nuclear medicine transmit to the National Institute of Public Health (NIPH) the records of individual exposure parameters, for 20 adult patients, respectively 10 pediatric patients from each specific age group, for each type of examination performed with each radiology or nuclear medicine equipment in the facility. The data recorded and reported for each patient are: age, gender, height, weight, information about the examined region and the type of examination, as well as data regarding dose amounts, namely the dose-area product DAP (for radiological imaging and fluoroscopy investigations performed with equipment equipped with a DAP-meter), the dose-scanned length product DLP (for computed tomography procedures), mean glandular dose MGD (for mammography and tomosynthesis) and the activity of the radioactive substance administered in the case of diagnostic nuclear medicine procedures.

At the same time, information is collected on the name and specifics of the medical unit reporting the data, as well as information on the type/model and year of manufacture for the radiological installations with which the medical examinations were performed, in order to ensure the representativeness of all types of medical units and equipment used.

Following the statistical processing by the NIPH of the data collected at national level during the period 2021-2023, the annual results obtained were analyzed compared to the diagnostic reference levels established by the MoH Order. The results obtained for conventional radiology and diagnostic nuclear medicine are generally slightly lower than the DRLs established in 2021, but for CT examinations, the results obtained are slightly higher, this being attributed to the lack of regulations on clinical audits and consequently the lack of interest in optimizing examination protocols for many of the CT equipment.

As a result of this study, new national DRLs are proposed both for the diagnostic radiology and nuclear medicine procedures mentioned in the MoH Order, as well as for other new types of diagnostic, radiology and nuclear medicine procedures. At the same time, the existing table was completed with DRLs for pediatric age groups, both for the procedures mentioned in the MoH Order, and for the new types of procedures introduced, given that the values established in 2021 referred only to adult patients.

# Assessment of excess lifetime cancer risk due to ingestion of radionuclides in some food spices

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In this study, the excess lifetime cancer risk was assessed due to the ingestion of radionuclides in food spices and the value obtained were compared with international reference values. Spices are found in special plants and have a different taste when added to food and have great benefits for our health. Spices are taken from the fruit of plants and trees, also from the bark, roots, seeds and they are used as recipes for food, and they play an important role in culinary art. Since all things on Earth contain radioactive elements, determination of the level of radioactivity in food is critical to controlling radiation which humans are directly or indirectly exposed to. Twenty of spice samples were collected in some markets in Tirana city, which may be produced in Albania or imported.

Gamma-ray spectrometry method with a high-resolution HPGe detector was used for the natural or artificial radionuclides detection and Genie 2000 for analysis of the measurements. The obtained results indicate that radionuclides of 40K, 226Ra and 232Th were detected in all spice samples, whereas the presence of artificial radionuclide of 137Cs was detected only in two of them. The average values of the activity concentration of 40K, 226Ra and 232Th were found to be 508.12 Bq kg-1, 12.84 Bq kg-1 and 5.98 Bq kg-1. The activity concentration in two samples for 137Cs is at a low level and these values are 0.53 Bq kg-1 and 0.41 Bq kg-1, while in all other samples are below MDA (Minimum Detection Activity). The average annual committed effective dose due to ingestion of these spices was found to be 8.12 μSv y-1. The average annual effective dose, due to ingestion the food spices was low compared to the average worldwide dose of 290 μSvy-1 from UNSCEAR 2000, and even lower than the recommended limit of 1 mSv y-1 for public exposure by WHO (World Health Organization) and ICRP (International Commission on Radiological Protection) for all age.

The range of excess lifetime cancer risk due to ingestion of radionuclide in food spices was found to be from 2.0×10-5 to 3.8×10-5 with average value 2.8×10-5 and the results obtained were compared with standards. The average value of excess lifetime cancer risk is lower than the world average value of 29×10-5 for the public. Therefore, these food spices can be used as a human diet with an acceptable risk and do not have any serious radiological effect. They are safe for consumption with low radiological risks.

**Keywords:** spices, HPGe detector, dose, cancer risk

# Sequestering polonium from copper surfaces for dark matter studies using activated carbon

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One theory to explain the missing mass in many cosmological models is dark matter. A favoured candidate for this material is Weakly Interactive Massive Particles (WIMPs). Unfortunately, their inherently rare interaction with baryonic matter makes their detection challenging. The NEWS-G collaboration has developed a WIMP detector that uses a 140 cm, 99.99 % pure copper sphere within archaeological lead and high-density polyethylene. The detector is located at the SNOLAB (Sudbury Neutrino Observatory Laboratory) facility in Sudbury, Ontario at a depth of 2 km. These measures are in place to minimise the contributions of cosmic events and background radioactivity. Actinide contamination represents a significant background contribution. Exposure to radon, particularly $^{222}$Rn, during sphere production and transportation may have caused contamination (as recoil of the nucleus during decay embeds radon daughters within the metal). Consideration of daughter radionuclides indicates that $^{210}$Pb and $^{210}$Po represent the most important background contributors. As a source of α-decay, reduction of $^{210}$Po is a higher priority and where this work concentrates its study.

The present work has focused on the etching of copper surfaces using aqueous hydrogen peroxide and acidic solutions. Also, this work used $^{209}$Po as a $^{210}$Po surrogate, as $^{209}$Po has a longer half-life of 124 years opposed to 138 days. Although, polonium has a favorable standard electrode potential, its vanishingly low concentration favours preferential re-reduction in the presence of copper metal. Although chelating resins investigated previously for this purpose, several factors drive the need to identify an adsorbent material to remove polonium from its solution-metal surface equilibrium. Not least amongst these are the difficulties of separating resin from solution for subsequent analysis. Activated Carbon (AC) has displayed a marked ability to adsorb polonium onto its surface. Replicate experiments have studied the circumstances of artificially contaminating copper surfaces, at $^{209}$Po activity levels of *ca.* 1 Bq·cm$^{-2}$. For application within the NEWS-G sphere, the $^{210}$Po levels are a factor of $10^5$ lower than our current experimental conditions, future studies will reduce $^{209}$Po contamination, to determine the relationship between activity and sequestration effectiveness.

Liquid scintillation analysis provides rapid and facile analyses of the metal surface, solution, and AC. It is evident that oxidative acidic etching liberates polonium from the copper surface and that careful use of AC provides > 80 % $^{209}$Po sequestration.

# Sorption of radio(toxic) metals onto biochars with and without activation via oxidation

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Radioactive contaminants found in liquid waste pose major risks to the environment and human health because they can pollute water, soil, and air. They can be found in liquid wastes from a variety of industries, including nuclear power stations, hospitals, mines, and laboratories, and can cause long-term health problems due to their toxicity and released radiation. As a result, it is critical to remove them from the environment using a variety of approaches, including biosorption.

In this study the sorption of U(VI), Th(IV), Ba(II), Co(II), Eu(III), Cs(I), I(I) and Tc(VII) onto biochars produced from winery waste after thermally modifications with and without activation via oxidation, was explored using a batch technique in aqueous solutions of different initial concentrations. The sorption capacity of the biosorbents was investigated under batch conditions at room temperature (20 ± 1 $^{o}$C) and dosage 1 g $L^{-1}$ in the concentration range 5–500 mg $L^{-1}$ at pH 3 for U(VI) and Th(IV), pH 4 for Eu(III) and Cs(I), pH 6 for Ba(II) and pH 8 for Co (II). For anionic species of I(I) and Tc(VII) the concentration range was 10-2500 mg $L^{-1}$ and the pH 3.

The investigation was performed with gamma-spectrometry using radioactive tracers as well as UV-photometric methods.

The overall objective of this study was first, to investigate whether sorbents based on agricultural wastes could be used for the removal of positive or negative charged species of radionuclides from low level radiation wastewater and second, to test the applicability of nuclear spectrometric techniques in sorption studies for determination of the metal concentration.

The results showed significant sorption capacity of the materials for the investigated metals demonstrating their effectivity and possible use in management of nuclear waste.

# New physics of radiation decay and cooperative laser electron-gamma-nuclear processes in diatomic and multiatomic molecules with radioactive atoms: New methods, effects and data

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In the modern molecular spectroscopy, a great interest attracts studying a new class of phenomena, connected with modelling the cooperative complex radiation processes in radioactive molecular systems as well as the cooperative laser-electron-g-nuclear processes in diatomic and multiatomic molecules. It includes calculation of the probabilities of the mixed gamma-optical transitions in molecules, intensities of the complicated g-transitions due to the changing of the molecular excited state population due to a laser field effect. The first qualitative estimates of the cooperative effects parameters have been earlier presented (e.g. [(1976). *JETP.*, 70, 794-804, *Nuclear Quantum Optics*, Preprint ISAN N-AS4. Troitsk, (2008). *Molec. Phys.*, 108, 1257-1260] and refs. therein).

We develop an advanced computational approach to quantitative treatment and computing the complex radiation processes characteristics for radioactive molecular systems as well as cooperative laser-electron-gamma-transition spectra (electron-vibrational-rotational satellites) of nucleus in diatomic and multiatomic molecules, based on density functional (one version) and model potential (second version) methods and energy approach [*Europ. Phys. J.*, T160, 195-208, *Series: Progress in Theoretical Chemistry and Physics,* 18, 525-541. Cham: Springer, *Series: Progress in Theoretical Chemistry and Physics,* 26, 231–252. Dordrecht: Springer]. Decay and excitation probability are linked with imaginary part of the "nuclei – molecular electron shells - laser field" system. New data on the electron-nuclear g-transition spectra of a nucleus in some molecules are presented, namely, for diatomics, 3-atomic $XY_2$ ($D_{\infty h}$), 5-atomic $XY_4$($T_d$), 7-atomic $XY_6$($O_h$) molecules (HI, HBr, $OsO_4$, $UF_6$, alkali dimers).

It is shown that studying cooperative electron-gamma-nuclear processes in the cryogenic Rydberg molecules (such as $^{133}$Cs nucleus; $E^{(0)}_g$=81 keB; $^{85}$Rb$^{133}$Cs and others) opens new horizons in spectroscopy of cryogenic Rydberg molecules and allows to discover the cooperative effects experimentally for the first time.

# Investigation of the proton induced reactions on the enriched tin $^{118}$Sn at the energies up to 18 MeV

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As nuclear technologies continue to advance, there is an increasing need for specialized computational codes that can model specific processes and help plan scientific experiments. These codes are also valuable for addressing practical issues such as reactor operation, spent fuel transportation, and fuel transmutation. Some of these codes include data from nuclear reaction libraries like TENDL (TALYS-based evaluated nuclear data library) [https://tendl.web.psi.ch/tendl_2023/tendl2023.html] or JENDL (Japanese Evaluated Nuclear Data Library) [https://wwwndc.jaea.go.jp/jendl/j5/j5.html] as input data. However, the true predictive accuracy of these models can only be confirmed through comparison with experimental data. Therefore, acquiring new experimental data is of paramount importance.

We measured the production cross-sections of residual radionuclides from proton-induced reactions on enriched tin-118 ($^{118}$Sn). The cross-sections for the reactions $^{118}$Sn(p,n)$^{118m}$Sb, $^{118}$Sn(p,2n)$^{117}$Sb, $^{118}$Sn(p,α)$^{115m}$In, and $^{118}$Sn(p,x)$^{117m}$Sn were measured up to an energy of 18 MeV using the stacked-foil activation technique. The measurements were performed at the CYCLON 18/18 cyclotron in Yerevan, Armenia.

We managed to find the only previously published data for the cross-section of the $^{118}$Sn(p.n)$^{118m}$Sb reaction for energies below 9 MeV [V.G. Batij, E.A. Skakun, Zeitschrift fuer Physik A, Hadrons and Nuclei, Vol.344, p.13 (1992)]. All other cross-sections are measured for the first time. Our results were compared with data from the TALYS 2021, TALYS 2023, and JENDL 5 libraries. The data for the $^{118}$Sn(p,2n)$^{117}$Sb reaction showed good agreement with all the libraries mentioned. However, for the other reactions, the data from different libraries varied significantly, and none of them showed good agreement with our experimental results.

It is well known that reactions involving the emission of composite particles, such as alpha particles or deuterons, are more challenging to describe theoretically compared to reactions that involve the emission of one or two nucleons. We have previously observed poor agreement between model-predicted cross-sections and experimental data for the reactions $^{120}$Sn(p,α)$^{117m,g}$In [G.H. Hovhannisyan et al., European Physical Journal A: Hadrons and Nuclei, Vol.59, p.161 (2023)]. Here, we observed the same behavior for the $^{118}$Sn(p,α)$^{115m}$In reaction.

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# Quality control of a Siemens ONCOR accelerator: Daily checks

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Quality control and quality assurance for units that produce ionizing radiation for radiotherapy, summarizes, archives and currently dates the performance of these units of irradiation by comparison to the parameters since the time of commissioning. Siemens ONCOR Impression is an advanced linear accelerator that can be used for routine clinical applications as well as for complex and advanced treatments such as stereotaxic radiosurgery. The linear accelerator enables the production of 2 clinical photon beams with energy 6MV and 7MV as well as beams of electrons with energies from 6 MeV to 18 MeV. Quality control of a Linear accelerator consists of dosimetric, mechanical and safety checks based on international standards and departmental decisions.

This work presents the daily dosimetric measurements of the flatten filter 6MV photonic beam with the Octavous 729 matrix detector. Data were collected over one year period and results obtained by daily measurements have shown that output of linac (dose), the uniformity and symmetry of the 6 MV photonic beam were within 2% to 3% comparing to reference values in compliance with recommendations of AAPM 142.

# Isoscapes analyses for identifying additional recharge sources of the Zagreb aquifer using stable isotopes of water

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Zagreb aquifer is the main source of potable water for the inhabitants of the City of Zagreb and Zagreb County. It presents strategic water reserves which are protected by the Republic of Croatia. In this research, focus is on the usage of stable isotopes of water for determining additional recharge source of the Zagreb aquifer. Stable isotopes of water ($\delta^2H$ and $\delta^{18}O$) were determined by laser absorption spectroscopy at the Laboratory for Spectroscopy, Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb. Study area is in the southern part of the Zagreb aquifer, in the influence area of the Velika Gorica well field. Groundwater, surface water and precipitation sampling was done in a monthly interval, from March 2021 to February 2022. Sava River was sampled in the western part, at the entrance of the Zagreb aquifer, precipitation was sampled in the Velika Gorica well field using Palmex rain sampler RS1, while groundwater was sampled from the 10 observation wells in the inflow area of the Velika Gorica well field. Sava River and groundwater isotopic composition were compared with the local meteoric water line (LMWL) of the Velika Gorica. All results fall on or near LMWL, where isotopic composition of eight observation wells was between those of the Sava River and precipitation, while two others were more negative. Additionally, based on the average yearly data, groundwater isoscapes were constructed using different interpolation methods, i.e. inverse distance weighting, kriging, natural neighbor and spline methods, which are all integrated in the spatial analyst tools of ArcMap 10.8.1. All methods resulted with maps which show difference in spatial isotopic composition while one generated with inverse distance weighting method probably gave the less realistic insight, especially when combining it with water table contour maps and modelling, which resulted with groundwater flow lines during low and high-water levels assuming a maximum pumping capacity of the Velika Gorica well field. It has to be emphasized that within the investigated time period, mostly dry period and low groundwater levels prevailed. Although difference in the groundwater isotopic composition was visible in this area for the first time, it suggests that it is necessary to continue monitoring and conduct more detailed isotopic investigation in the future research. In the end, results show that additional recharge source exists and that it can be tracked using isotope techniques.

# Spatial distribution and contamination assessment of heavy metal pollution of sediments in coastal areas of Montenegro

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The presence of toxic heavy metal pollutants in the aquatic ecosystem is mainly introduced through various natural and anthropogenic sources. Sediments in affected areas often have significantly higher levels of heavy metals from human activities, which can be toxic to aquatic life and enter the food chain, posing risks to human health. Major sources of pollution include industrial activities, agriculture, domestic waste, and rapid urbanization, all of which contribute to deteriorating water quality, eutrophication, flooding, and heavy metal contamination in sediments.

The Mediterranean Sea is characterized by a diverse geochemical composition of its sediments, with metal concentrations varying depending on the specific characteristics of the area and inputs from the surrounding coastal environment. The Montenegrin coast, located in the southern Adriatic Sea, is also significantly affected by anthropogenic factors and activities along the shore. Therefore, this study aimed to compare metal concentrations from three locations between the periods of 2014-2015 and 2019-2020, specifically for zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), chromium (Cr), cadmium (Cd), and mercury (Hg) in coastal sediments of Montenegro. The study also sought to assess the pollution levels using the geo-accumulation index, contamination factor, and pollution load index, as well as cluster analysis.

Since Montenegro has not established criteria for evaluating marine sediment quality, the assessment relies on the legal framework of the European Union and standards from developed countries like Canada, the Netherlands, and the UK. For comparison, the UNEP/MAP guide (UNEP(DEPI)/MED 439/15 - Pollution Assessment Criteria and Thresholds) and the OSPAR guide “The Convention for the Protection of the Marine Environment of the North-East Atlantic” (OSPAR) on contaminants and their biological effects were used. Based on the results and their comparison with BAC and ERL values, it is evident that the sediment content at the investigated sites exceeds the BAC value and/or both BAC and ERL values.

When examining the data across all four seasons, exceptions are observed at the location Kotor (for Cd) and Zanjice (for Cd, Cu, Ni, Hg, Pb, and Zn). The concentrations of Cr and Ni in the sediment exceed the ERL values at all locations. Additionally, the results of Pb, Zn, and Hg in the sediment surpass both the BAC and ERL values at Kotor and Orahovac.

Comparing the results obtained for selected heavy metals in 12 sediment samples, which were collected from the Montenegrin coast during the autumn period with a longer interval of years between samplings, it can be concluded that still anthropogenic influence and geographical location are probably the main factors contributing to the differences observed for these samples.

# Development of a multi-cell Polymer Electrolyte Membrane (PEM) system for tritium enrichment in environmental water analysis

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Tritium ($^3H$) is a cosmogenic isotope of hydrogen with a half-life of 12.32 years, making it an essential tracer of the water cycle, particularly valuable for groundwater recharge and vulnerability assessment. However, the low natural abundance of tritium and the analytical barriers pose significant challenges for detection at environmental levels. To overcome these limitations, this study presents the development and optimization of a 12-cell Polymer Electrolyte Membrane (PEM) electrolytic enrichment system, designed to enhance tritium concentration prior to Liquid Scintillation Counting (LSC) analysis.

Key methodological advancements include systematic optimization of electrolysis parameters, such as current, voltage, temperature control, and electrolysis duration, and Tritium Enrichment Factor (TEF) determination using the Deuterium Method (DM) improving enrichment reproducibility and reducing measurement uncertainty. Moreover, this study presents a long-term testing over a six-year period including blank assessments, inter-laboratory comparisons test samples for quality control and tritiated water standards for calibration purposes.

Results demonstrate significant improvements in tritium detection sensitivity, with the system effectively minimizing carry-over effects, simplifying operational procedures, and enhancing tritium separation efficiency with respect to commercially available PEM systems. The optimized PEM system presents a robust, reproducible, and scalable solution for tritium enrichment, offering improved accuracy and precision for low-level tritium measurements in environmental water samples.

# A new way to measure radio-sulfur in natural water samples

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The presented method aims at advancing the use of the short-lived cosmogenic radionuclide $^{35}S$ ("radio-sulfur", $t_{1/2}$ = 87.4 d) for the study of water transit time distributions in the different compartments of the hydrological cycle. Due to its very low natural abundance in precipitation (up to ~50mBq/L in Central Europe), pre-concentration of $^{35}SO_4^{2-}$ prior to Liquid Scintillation Counting (LSC) is necessary. The $SO_4^{2-}$ extraction procedure with an anion exchange resin has been adapted for application at the sampling spot, to address the logistical challenge of transporting and shipping large water volumes (20 liters per sample) to the laboratory. The retained sulfate ions are eluted in the laboratory, and the eluate is subsequently concentrated by evaporation and treated for the elimination of organic compounds. Once all organic compounds are removed and the sample is evaporated to pure $H_2SO_4$ + $H_2O$, the sample is mixed with a scintillation cocktail and analyzed using LSC. To reduce the sample volume necessary for the analysis, we aimed to optimize the entire procedure. Therefore, we separated the $SO_4^{2-}$ ions from other anions present in the sample by optimizing the sample treatment procedure. In particular, the removal of dissolved organic carbon (DOC) is critical, as DOC can add radio-carbon – a beta emitter in the same energy window as radio-sulfur - and can lead to color quenching. We further optimized LSC conditions for higher efficiency and lower background. This method was tested on various challenging natural water matrices, including samples from a wetland. Sulphate losses were monitored throughout the entire sample treatment using ion exchange chromatography. Significant losses were observed during the pre-concentration and sample transfer steps of $^{35}SO_4^{2-}$ s, but they did not exceed 15% of total sulphate load. Our optimized method achieved counting efficiencies exceeding 80% while maintaining a low background (ranging from 1 to 2 CPM depending on the LSC used), resulting in a detection limit of about 3mBq/L with 1500 minutes of counting. This work represents advancements in the utilization of radio-sulfur analysis, thereby expanding the suite of natural radionuclides to constrain water residence time distributions in terrestrial waters.

# Global carbon sequestration in marine sediments

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The annual rate of carbon sequestration within marine sediments remains largely unquantified in current scientific literature. This oversight is likely due to the prevailing view of sediments as material predominantly brought from land that is constantly in motion. However, a significant portion of marine sediments originates from in-situ primary biological production and chemical precipitation. In this process, sediments record the environmental conditions in which they were formed, acting as stable archives of past environmental conditions. These sediments can be geochronologically dated, measuring the decay of radioactive nuclides.

The present study investigates the hypothesis that a correlation exists between carbon sequestration in marine sediments and rising atmospheric CO2 concentration. Utilizing sediment cores from the Black and Adriatic Seas, we determined sedimentation rates via Pb-210, Cs-137 and Am-241 geochronology, comparing trends between these distinct marine environments. Both seas exhibited an approximate 1000% increase in sedimentation rates over the past century. Notably, the annual carbon flux into deposited sediments demonstrated a strong linear correlation with atmospheric CO2 influx. By extrapolating from the average carbon influx in the Adriatic and Black Seas, we estimated the global annual carbon sequestration within sediments (up to 200 m depth). Our findings suggest a significant role for marine sediments in carbon sequestration, accounting for nearly half of Earth's total annual carbon storage. This contrasts with the current consensus that terrestrial sequestration comprises half of the global carbon sink. Thus, the study offers a critical contribution to our understanding of the global carbon cycle, with implications for climate change mitigation strategies.

# Chemical composition and natural radioactivity of beach sands from the Adriatic Sea coastline, Albania

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The Adriatic coastline (Shëngjini Bay, Lalzi Bay, Durrës Bay and Spille Bay) is previously investigated for the activity concentration of natural radionuclides in sand samples by means of high-resolution gamma ray spectrometry technique. The highest concentrations of $^{40}K$, $^{226}Ra$ and $^{232}Th$ are found to be 458 Bq/kg, 67 Bq/kg and 91 Bq/kg, respectively. This study aims to investigate the dose rate and elemental composition of beach sands in order to better understanding of the behavior of radionuclides in the coastline of the Adriatic Sea in Albania. The same sand samples are characterized for the chemical composition by means of X-ray fluorescence spectrometry (XRF) together with some REEs (rare earth elements). A good correlation is found between natural radionuclide concentration and REEs in general giving a good indication on weathering conditions in the region. In particular, the highest concentration of REEs is measured for the same sample showing the highest concentration of natural radionuclides. Therefore, this area is investigated for the gamma dose rates by direct measurements using identiFINDER® 2, a handheld instrument. Results indicate layered deposits of showing relatively higher dose rates and confirming the presence of heavy minerals. However, it is required to obtain further information about geology and geochemistry of this area for investigating the mineralogy and origin of these deposits.

# Analysis of long-term measured $^{222}Rn$ and $CO_2$ flux from the soil in the context of using radon as a tracer for the estimation of greenhouse gas emissions

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Soil is a significant but often overlooked source of $CO_2$ emissions, contributing to atmospheric carbon mainly through root respiration and decomposition of organic matter. Accurate monitoring of soil-to-atmosphere $CO_2$ flux is important for understanding the global carbon cycle. It can also help in carbon sequestration projects and land management strategies aimed at reducing atmospheric $CO_2$ levels. The use of radon ($^{222}Rn$) as a tracer for soil $CO_2$ emissions provides an innovative approach to studying soil-atmosphere interactions. Radon shares similar transport properties with $CO_2$, allowing more precise tracking of gas movement and discrimination between different emission sources. The radon can be used in two different ways to estimate the $CO_2$ flux i.e., the "radon tracer method", which uses the concentrations of radon and $CO_2$ in the atmosphere, and the "radon calibrated method", which focuses on the concentrations of both gases in the soil.

This work presents the analysis of four years of continuous measurements of radon and $CO_2$ exhalation rates from soil to the atmosphere, along with their concentrations in soil and in the atmosphere. We focused on a single sampling area that eliminates the influence of factors such as soil type and properties (e.g., porosity, soil texture) and environmental changes, allowing for a more precise investigation of meteorological impacts on exhalation rates of these gases. In addition, we applied machine learning techniques to enhance the understanding of the interactions between meteorological variables and $CO_2$ and $^{222}Rn$ exhalation rates, to improve $CO_2$ emission predictions.

The main objectives of this study can be summarized as follows:

- investigating the relationship between radon and $CO_2$ concentrations in soil and atmosphere, as well as their exhalation rates,
- exploring the effect of meteorological parameters on the concentration and exhalation rate of radon and $CO_2$ through conventional regression analysis and different machine learning techniques,
- exploring the limits and conditions under which radon tracer method and radon calibrated method can be used effectively to estimate soil-to-atmosphere $CO_2$ emissions.

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# Simultaneous measurement and analysis of radon, air ion, and aerosol concentrations under varying air pollution and meteorological conditions

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Radon's radioactive decay is the primary natural source of small air ions in the near-ground layer of the atmosphere. The exhalation of radon from the soil is influenced by local meteorological conditions, while the reduction in small air ion concentrations is primarily associated with the concentration of aerosol pollutants in the air. The goal of this measurement campaign was to investigate the correlations between these factors across different meteorological conditions and pollution levels. To achieve this, measurements were conducted under distinct meteorological and air pollution conditions at two separate sites. Measurements in clean air conditions were carried out during the early autumn in a suburban area of Belgrade, while measurements in late autumn were conducted in the city center, where high levels of air pollution, low temperatures, and high humidity were present. Simultaneous measurements and correlation analyses were performed on radon concentration, air ions, particle size distribution, cumulative mass concentration (particulate matter, PM), relative humidity, pressure, and temperature. The results revealed substantially lower radon concentrations during late autumn, primarily attributable to the absence of nocturnal thermal inversions and the suppression of radon exhalation caused by elevated soil moisture content. Small air ion concentrations were notably lower, resulting from both reduced radon exhalation and high levels of air pollution, characterized by elevated aerosol concentrations, which is reflected in a high number of ultrafine particles. Additionally, a strong negative correlation was observed between air ion concentration and concentration of ultrafine and fine particles (20 to 650 nm). In contrast, radon concentrations exhibited a clear diurnal pattern during the summer, with nocturnal maxima and daytime minima, while radon levels remained consistently low during the winter.

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# Assessment of costal radiopollution via simulation experiment

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The contamination of coastal areas and beaches by radionuclides poses significant environmental and public health concerns, as these substances can persist in marine ecosystems, accumulate in sediments, and affect human populations through direct exposure or inhalation of beach sand. Numerical modelling of particle dispersion in the marine environment has proven to be an effective tool for tracing radionuclide transport and assessing their environmental impact across various aquatic environments. While the presence and behaviour of radionuclides in the open ocean have been widely studied, their accumulation and long-term effects in coastal areas remain less explored, highlighting the need for advanced modelling approaches to assess their transport, deposition, and associated risks in these vulnerable zones. Recent model simulations have been conducted to evaluate the dispersion of key radionuclides in the Eastern Mediterranean in the event of a hypothetical accident at the Akkuyu Nuclear Power Plant (NPP) in Turkey [doi.org/10.1016/j.pnucene.2021.103879, doi.org/10.1016/j.jenvrad.2022.106964], along with assessments of potential radiological impacts on human populations and marine organisms [doi.org/10.12681/hnpsanp.5097]. This study extends previous work by assessing the distribution and persistence of radionuclides in beach sands and evaluating the radiological exposure risks to affected coastal populations. The most impacted neighbouring coastal regions are identified based on oceanic dispersion processes and radionuclide interactions with sediments. Additionally, radiation doses received by representative inhabitants due to external and internal exposure are estimated. The assumptions and limitations of the adopted methodology, along with potential improvements for future assessments are also discussed.

# Pilot study of the thermal comfort perception in educational buildings

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Thermal comfort is an essential factor in ensuring a favorable learning environment in school buildings. This pilot study investigates the subjective perception of thermal comfort among students and teachers using a questionnaire survey. The study aims to identify problems with thermal comfort in different school premises and provide a basis for development a method for assessment and specific legislation for provision of thermal comfort in learning conditions. The questionnaire is applied to both students and teachers, taking into account their different activity (metabolic rate), perceptions and thermoregulation.

The study was conducted in a secondary specialized school, and for the purpose of the study, a questionnaire was developed to study the subjective perception of students and teachers of thermal comfort in school premises. The questionnaire includes questions related to the physical characteristics of the microclimate that can affect comfort and concentration during the learning process: temperature, humidity, air velocity. It includes both fixed-answer questions related to thermal sensation and open-ended questions that allow participants to propose specific solutions to improve existing conditions. The article presents data from a survey covering 100 students and 10 teachers.

The results of the study indicate the need to develop specific legislation for thermal comfort in educational buildings, taking into account both objective microclimatic conditions and the subjective perception of students and staff in school buildings.

# Implications of surface water-groundwater interactions in the Sperchios River basin using radioactive and stable isotope tracers

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The Sperchios River, which is located in Central Greece, is approximately 85 km long and flows from west to east through a flat plain area before discharging into the Maliakos Gulf. The Sperchios River Basin (SRB) has a mean altitude of ~640 m a.s.l. and a typical Mediterranean climate (Csa) with a mean annual temperature of ~17 $^{o}$C and a mean annual rainfall of ~800 mm. A large proportion of the southern and eastern part of the SRB is covered by karstic carbonate formations of Oiti Mountain, which host aquifers of high capacity, whereas the rest of the basin is occupied by igneous and metamorphic rocks, and clastic formations. In the current study, two sampling campaigns for $^{222}$Rn and stable isotopes ($^{18}$O and $^{2}$H of water) were performed in river and spring (some of them hydrothermal) waters of the SRB with the aim to identify areas where the river water interacts with the groundwater. The $^{222}$Rn values in the water samples ranged from 0.3 Bq/L to ~19.0 Bq/L, with the highest values detected in some of the spring waters and the river waters, particularly in the central part of the SRB. Our preliminary findings revealed the occurrence of a surface water-groundwater interaction zone near and downstream of Ypati settlement, as evidenced by the $^{222}$Rn values in the river water, which were similar to those of Mexiates springs located in the northern part of the Oiti Mountain. The $\delta^{18}$O and $\delta^{2}$H values in the river water samples of the SRB ranged from −8.7‰ to −8.0‰ and from -54.0‰ to −49.4‰, respectively. In the groundwater samples the $\delta^{18}$O and $\delta^{2}$H values ranged from −9.3‰ to −8.4‰ and from −57.3‰ to −52.4‰, respectively. Based on the linear relationship of water isotopes and altitude, the expected altitude of recharge of most river water samples was ~800 m a.s.l., whereas the spring waters originated from altitudes that exceed 1100 m a.s.l. To obtain further insights into possible seasonal variability of groundwater–surface water interaction, additional radon and stable water isotope measurements are recommended. The combined application of $^{222}$Rn and stable isotope tracers will help improve our understanding of the hydrological processes in the SRB, and thus, help the water managers and stakeholders for sustainable management of the water resources.

# New angle momentum and energy balance approach to the modelling of macroturbulent atmospheric dynamics: Spatial distribution of radionuclides in the global atmosphere

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We present the elements of a new advanced non-stationary theory of global mechanisms in atmospheric low-frequency processes, teleconnection effects to modelling global atmospheric behaviour, dispersion of radionuclides, assessing radioactivity impact of the Fukushima (Chernobyl) nuclear accidents on the environment. The approach is based on the energy, moment balance relationships for the global atmospheric low-frequency processes, atmospheric macroturbulence theory, link of tropospheric waveguides with atmospheric moisture circulation and, accordingly, with the shape of the atmospheric circulation over the position of the front sections of (atmospheric fronts as the main drives moisture) [Sensor Electr. and Microsyst. Techn. 2013, 10(1):22-28, Methods of computational mathematics and mathematical physics. P.1. TES: Odessa, 2015, Awrejcewicz J (Ed.) Perspectives in Dynamical Systems III: Control and Stability. Series: Springer Proceedings in Mathematics & Statistics. 2021, 364:Ch.16, Awrejcewicz J, Kazmierczak M, Olejnik P and Mrozowski J (eds.) Dynamical Systems Applications. Politechniki Łódzkiej: Łódz, 2013, T2:145-152, Theory. J. of Atmos. and Solar-Terrestrial Phys. 2010, 72:498-508]. Atmospheric moisture cycle is linked with such typical low-frequency process as the angular momentum balance; the latter accounts violation of the atmosphere rotating balance with the Earth, which may be under developing meridional processes with the implementation of the mass transfer of air and steam between the tropical latitudes (with a large linear velocity) and slowly rotating air masses of the polar latitudes (a process of slow teleconnection). The approach is realized and implemented into the new microsystem technology “GeoMath-RadEnv” and focused on the testing and prediction of the air mass (particles) flows in the global atmospheric picture, determination of the new predictors for long-term and very long-forecasts of low-frequency atmospheric processes. PC experiments demonstrated the effectiveness of the approach in applying to modeling the balance of angular momentum, the transfer of atmospheric masses (moisture flow) with respect to the genesis of tropospheric waveguides, the continuity of atmospheric circulation forms (telecommunication, front-genesis). The application of the method to the modeling of global atmospheric behavior, the scattering of radionuclides after accidents at the nuclear power plant in Fukushima (Chernobyl) demonstrates its effectiveness, which is confirmed by the physically reasonable agreement between the predicted and measured spatial distribution of radionuclides in the atmosphere, the direction and dynamics of the flows of air masses (particles).

# Temporal trends in the beryllium-7 activity concentrations in Serbia, Croatia, and Slovenia: 1991–2022

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Beryllium-7, a cosmogenic radionuclide with a half-life of 53.28 days, can be used as a tracer of atmospheric transport as it travels attached to aerosols from the point of its production in the upper layers of the atmosphere to the surface. Beryllium-7 is a gamma emitter, and its activity concentration can be inexpensively measured using standard gamma spectrometry. Hence, it is closely followed in many national radioactivity monitoring programs. In our paper, records from the Ground Air Radioactivity Monitoring (GRAMON) database are used to investigate temporal trends of this radionuclide's activity concentration.

Specifically, the national air radioactivity monitoring programs of Serbia, Croatia, and Slovenia, all of which are contributors to the GRAMON database, offer the beryllium-7 time series since 1991. Four sampling sites are chosen: Belgrade (44.88333 °N; 20.583333 °E; 95 m a.s.l.) in Serbia; Zagreb (45.835361 °N; 15.982972 °E; 166 m a.s.l.) in Croatia; Krško, a town in the vicinity of the Krško Nuclear Power Plant (45.950414 °N; 15.512261 °E; 204 m a.s.l.), and Ljubljana (46.042356 °N; 14.487494 °E; 292 m a.s.l.) in Slovenia. Between 1991 and 2022, there are 384 mean monthly values of the beryllium-7 activity concentrations per site (with 22 missing values for Belgrade, and 6 for Ljubljana).

Temporal trends are calculated as best-fit straight lines using the least-squares method. In addition to looking into the 1991–2022 period (32 years), we also calculate the trends over a shorter period of the latter 12 years, i.e. 2011–2022.

The trends over 1991–2022 show an increase in the beryllium-7 activity concentration in all the sites, except Zagreb: 28 %/decade in Belgrade, -13.2 %/decade in Zagreb, 1.7 %/decade in Krško, and 12.4 %/decade in Ljubljana.

The trends over 2011–2022 imply that this latter period differs from the overall period of 32 years. The trend in Krško still shows the least value (-2.8 %/decade) but is negative, indicating a slight decrease in the beryllium-7 activity concentration in recent years. In contrast, in Zagreb, the trend, negative over 1991–2022, is now positive (30 %/decade). In Ljubljana, the trends over the two periods are practically the same (12.4 %/decade vs 12.6 %/decade), while in Belgrade, the positive trend is even stronger in recent years (28 %/decade vs 33 %/decade).

Our results bring out questions that might be fully answered only in a study that concurrently investigates the temporal trends of the meteorological parameters. One of the questions could focus on the Zagreb, Krško, and Ljubljana sites that are within 100 km, and yet, their trends, both long- and short-term, are notably different.

# Iron content, particle mass, $^{210}$Pb and magnetic properties of urban aerosols' samples in Helsinki (1962-2005)

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Finnish Meteorological Institute has collected aerosol samples for over six decades to monitor airborne radioactivity. Archived aerosol samples allow retrospective analysis of air pollutants. In this study, 608 weekly aerosol samples (1962-2005) from Helsinki's downtown (Kaisaniemi) were analyzed for elemental composition, including bulk iron (Fe) using XRF analysis, and their magnetic susceptibility was measured and normalized to 1000 m$^3$ of air. Total suspended particulate (TSP) was measured from 11000 daily aerosol samples. Additionally, selected samples underwent remanent magnetization and scanning electron microscopy (SEM) analysis.

Both Fe concentrations (μg/m$^3$) and magnetic susceptibility exhibit a slight downward trend from 1962 to 2005. Their correlation is only qualitative, as magnetic particles contribute variably (10-70%) to bulk Fe content. Magnetite, the dominant magnetic mineral, shows concentration variations relative to total Fe over time. Remanent magnetization analysis indicates the presence of maghemite and hematite, with hematite concentrations increasing during winter months. SEM analyses confirm anthropogenic iron oxide particles, mainly magnetite and maghemite, while hematite originates from natural sources. Average annual TSP decreased from 55 μg/m$^3$ in 1974 to 17 μg/m$^3$ in 2004.

The long-lived radioactive isotope $^{210}$Pb was also analyzed as a tracer. Seasonal variations reveal lower $^{210}$Pb concentrations (μBq/m$^3$) during summer due to enhanced vertical mixing in the troposphere and diffusion processes. Conversely, winter conditions, characterized by a lower tropopause and stable atmospheric stratification, lead to higher $^{210}$Pb levels in the lower troposphere. Air masses from southeastern Europe contribute significantly to $^{210}$Pb levels, particularly in winter when long-range transport dominates.

Trace element analysis shows seasonal variability in Fe and other elements (Si, Ti, K, Ca, Zn, Pb, etc.). Fe concentrations peak in winter due to emissions from energy production and reduced atmospheric mixing. In contrast, higher Fe concentrations in summer result from soil-derived dust resuspension under dry conditions. PMF analysis attributes 76% of Fe mass to the dust factor, reinforcing its mixed anthropogenic and natural sources.

Results highlight the interplay between urban emissions, long-range transport, and seasonal atmospheric dynamics in shaping Fe and $^{210}$Pb distributions in Helsinki's air over four decades.

# Analysis of the beryllium-7 activity concentration dynamics in the atmospheric environment after the Fukushima Daiichi NPP emergency: Chaos-geometric and artificial intelligence modelling

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We present the results of an analysis, modelling temporal dynamics of the beryllium-7 (caesium-137) activation concentration in the atmospheric environment time series in Austria after the Fukushima Daiichi Nuclear Power Plants emergency accident. As method of studying, we use the complex of different methods and algorithms, which are based on an advanced non-linear analysis technique and chaos & dynamical systems theory methods (Correlation integral approach, average mutual information, surrogate data, false nearest neighbours algorithms, the Lyapunov's exponents and Kolmogorov entropy analysis, nonlinear prediction models, etc.) as well as neural networks and artificial intelligence simulations (in versions [Modeling an ecological state of environment with accouting radiactive contamination and radionuclides transfer. Odessa: TES, 2019, Mathematical and Numerical Aspects of Dynamical Systems Analysis' (with J. Awrejcewicz, M. Kaźmierczak and J. Mrozowski). ARSA Publishing, Lodz, 2017, Vol.2. P.205-214, Awrejcewicz J, Kazmierczak M, Olejnik P and Mrozowski J (eds.) Dynamical Systems Applications. Politechniki Łódz, 2013, T2:145-152, Awrejcewicz J. (ed) Perspectives in Dynamical Systems II: Mathematical and Numerical Approaches. Series: Springer Proc. in Math. & Statistics, 2021, vol 363. P.79-88 (Springer), Theory of optical neural networks and artificial intelligence. Odessa: ONPU, 2025]).

As the input data we use the data on the long-term time series and activity size distribution of beryllium-7 in the atmospheric environment time series and activity size distribution of iodine-131 in Austria after the Fukushima NPP. The cosmogenic radionuclide Be-7 is formed through spallation reactions with decreasing production rates with atmospheric depth and about two thirds of the Be-7 production takes place in the stratosphere and one third in the troposphere (mainly in the upper troposphere) [5]. Due to stratosphere- to- troposphere exchange the Be-7 is also present in the near-to-ground atmosphere. The time series of Be-7 and Cs-137 over a period of 24 years are reanalysed too. As various factors govern the Be-7 activity concentration in the near-to-ground atmosphere they are highly episodic and vary strongly. The Be-7 results are given per day of the year from the high-altitude station at Sonnblick (3106 m) for a period of 15 years [Radioprotect.-2011.-Vol.46(6).-P.S7–10].

The advanced data on the topological and dynamical invariants, namely, the correlation, embedding, Kaplan-Yorke dimensions, the Lyapunov's exponents, Kolmogorov entropy etc are presented. An availability of the chaos elements in the corresponding Be-7 time series is found. Nevertheless, this fact is not evidence of the universal availability of the deterministic chaos in any radionuclide concentration time series.

# Demonstration exercises to study sediment dynamics at the shoreline applying geo-referenced low-resolution underwater gamma-ray spectrometers

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Radioactivity analysis is mainly performed by the lab-based method to map natural radionuclides for sediment dynamics in industrial coastal areas as well as in areas that are affected from the extreme meteorological events. A lot of effort has been made the last years to improve technology for environmental monitoring, safety assessment and rapid response to protect humans from natural and artificial disasters. In this work an in-situ method will be presented for rapid mapping of radioactivity and subsequent site characterization of the study area in environments close to the coast. The idea of the proposed work is to present demonstration exercises using the underwater low-resolution gamma-ray spectrometer named KATERINA II. The detection system may be integrated in any mobile platform for continuous operation (backpack and/or trolley mode). The measured data are deduced after the end of the experiment using an algorithm that analyses the gamma-ray spectra according to the total counting rate for each time lag. The quantification method is performed using the EGS4nrc simulation code taking into account the measurement geometry and the characteristics of the sand. The demonstration exercises are performed at beach sand areas at coastal regions in Greece. Furthermore, a recent study will be presented in the water inlet of the WWTP of Corinth-Loutraki (Greece) to examine potential tracers for future activity to study sediment dynamics at the discharged coastal area of the plant.

# Measurement of $^{36}Cl$ activity in graphite from the thermal column of the 2nd unit of ChNPP

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It should be noted that according to various estimates and for different time intervals after the shutdown of the RBMK units, the percentage of graphite masonry and graphite channel elements in the total volume of radioactive reactor waste can vary up to 80%. Therefore, for the safe disposal of these blocks, it is important to determine the activities of nuclides in graphite, the decay of which is not accompanied by gamma-radiation and at the same time they are harmful to humans and the environment. One of these radionuclides is $^{36}Cl$. This radioisotope is formed in the structural elements of the reactor from the stable nuclide of $^{35}Cl$. The half-life of $^{36}Cl$ is 301,000 years, the decay is accompanied by β-radiation with a end-point energy of 710 keV.

Based on the above, the purpose of this work is to develop a methodology for determining of the $^{36}Cl$ activity, by comparing the activity of long-lived radionuclide that emits γ-rays and is present in irradiated structural materials simultaneously with $^{35}Cl$. This reference radionuclide is $^{60}Co$, which has a half-live of 5.27 years.

To create the methods, the two samples of graphite and the chlorine sample were irradiated by bremsstrahlung end-point energy of 18 MeV at the M-30 accelerator of the Institute of Electron Physics of National Academy of Sciences of Ukraine (Uzhhorod). The induced activity was measured by γ-spectrometers based on HPGe-detectors.

Duration of work of the 2nd unit of ChNPP was about 13 years. One graphite sample had considerable mass and was irradiated with a low neutron flux. It was used to determine the $^{35}Cl$ content in graphite by the relative method using a chlorine sample of known mass, which was irradiated by bremsstrahlung together with him. Another graphite sample had lesser mass and was irradiated with an intense neutron flux and in it the $^{60}Co$ activity was identified. However, after irradiation by bremsstrahlung, $^{58}Co$ was not identified in either graphite sample. Therefore, the amount of cobalt impurity in graphite was obtained using the passport data and the experimental cross sections of the $^{59}Co(\gamma,n)^{58}Co$ reaction.

From these data, it was determined that the activity of $^{36}Cl$ in the graphite from the thermal column of the 2nd unit of ChNPP is approximately 1020±200 Bq/g.

The maximum permissible concentration (MPC) of the radionuclides is usually in the range of 1-10 Bq/g. As can be seen, a significant excess of the MPC for $^{36}Cl$ in reactor graphite requires special attention during the control of radioactive materials.

# Microplastic detection and characterization in different matrixes by computed tomography

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X-ray microtomography (microCT) is an emerging tool for investigating microplastic (MP) contamination in soil. Its non-destructive nature enables repeated analyses on the same samples, while its automated measurements of size and shape minimize manual errors. Notably, microCT's ability to analyze internal structures proves advantageous in studying MPs embedded in soil matrices. This study explores the potential of microCT for evaluating MPs in soil by simulating laboratory conditions where plastic fragments were mixed with sandy and humiferous soil samples.

Plastic fragments were sourced from commercial product packaging (PET, PEHD, PS, and PP), and soil samples were collected from environmentally relevant locations in Brazil. MicroCT imaging was performed with a Phoenix V|tome|300 M system, generating high-resolution 3D models and quantitative data. The study highlights challenges in differentiating MPs from porous spaces due to similar gray-level intensities, which were addressed using advanced segmentation and morphological filters.

All MP fragments were successfully detected across both soil types, with sandy matrices exhibiting lower error rates compared to humiferous soils. The data revealed key morphological features, such as surface area, volume, and anisotropic diffusion, facilitating shape-based MP classification. Additionally, differences in gray levels between materials indicated microCT's potential for identifying MP composition within complex matrices. These findings demonstrate that microCT is a powerful method for characterizing MPs, offering both morphological and compositional insights, even in heterogeneous soil environments.

# Impact of natural and anthropogenic sources on the composition of atmospheric particulate matter: Analysis by X-ray microfluorescence and scanning electron microscopy

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Atmospheric particulate matter (PM) is one of the main components of air pollution, with its composition influenced by various emission sources, including industrial activities, vehicular emissions, soil resuspension, marine aerosols, and biogenic material such as pollen. Prolonged exposure to PM is associated with a wide range of adverse effects on human health. In addition to its health effects, PM can interfere with vegetation growth and soil chemical composition, impacting ecosystems and altering natural processes.

In this study, the chemical and morphological composition of PM collected in the metropolitan region of Rio de Janeiro, Brazil, was investigated. Samples were collected under different environmental conditions and analyzed using X-Ray Microfluorescence (micro-XRF) to determine elemental composition and Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS) to characterize the morphology of the particulates. The results revealed distinct elemental signatures associated with each emission source, allowing differentiation between chemical elements typical of anthropogenic emissions and those enriched with marine salts and minerals of terrestrial origin. Additionally, biologically derived particles, such as pollen, exhibited specific morphological characteristics. The integration of these techniques proved effective in distinguishing the contributions of different sources to atmospheric PM.

The findings provide valuable insights for air quality management and the development of strategies to mitigate the impacts of pollution on human health and the environment.

# The prospects for the development of Small Modular Reactors (SMRs)

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The twenty-first century brings about a growing demand for higher energy production, coupled with the urgent need to protect the environment, which has already suffered significant damage. In response to this challenge, several countries, including the Republic of Serbia, are considering nuclear energy as a key component of their energy mix. Utilizing nuclear energy for electricity generation offers several advantages, including stable production and supply, low greenhouse gas emissions, and high safety standards. Several countries, including the Republic of Serbia, are considering turning to nuclear energy as a staple in the energy mix. The use of nuclear energy for the production of electricity is positive in terms of production and supply stability, low greenhouse gas emissions, as well as high safety.

In contrast to the benefits of nuclear energy, there are significant drawbacks, such as the high cost of constructing and operating traditional nuclear power plants, the challenges associated with treating and disposing of radioactive waste, and the potential for large-scale accidents, which contribute to public fear. To address these issues, the development of small modular reactors (SMRs) has started. SMRs have lower costs compared to conventional reactors, and their potential for serial production can further reduce expenses by shortening both construction and licensing times. Additionally, because SMRs are more compact, they require reduced number of components necessary for transporting steam, such as pipes and pumps.

Serial production enables the repetition of knowledge for operational work, especially since there will be multiple reactors of the same type. In addition to their economic development potential, Small Modular Reactors (SMRs) have significant opportunities for applications beyond electricity generation. For instance, they can be utilized in hydrogen production, which might be essential for various industries such as chemical manufacturing, metal processing, and as fuel for vehicles.

There is also the potential to use Small Modular Reactors (SMRs) for applications such as process heating, district heating, thermal desalination, and reverse osmosis in the production of drinking water or for wastewater treatment. Although they are still in development, SMRs have the capacity to be widely adopted in the future, not only for power generation but also across various industries. This paper provides an overview of the benefits of SMRs as a promising new technology.

# Resonance radiation processes in laser photoionization radioactive isotopes separation systems and devices and quantum modelling and artificial intelligence and neural network computing optimal separation schemes

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The use of laser photoionization or photodissociation schemes in the isotope separation methods has a number of chemical, physical and technological advantages in comparison with the known classical methods (such as electromagnetic separation, gas diffusion, or the use of centrifuges or distillation etc. The advantages include significantly lower energy consumption, higher selectivity of the elementary separation act, and a smaller number of separation stages. If the wavelength of monochromatic radiation irradiating an isotopic mixture of some elements coincides with the absorption line of one of the isotopes, then only the atoms of this isotope absorb the radiation and naturally pass into an excited state. Excited atoms are then separated from unexcited ones by photochemical and quantum-physical methods such as photoionization, photodissociation, or photolysis. The first successful laboratory implementations of the laser isotope separation method, involving classical two-step schemes for selective photoionization of atoms or photodissociation of molecules, were carried out back in the 70s-80s of the last century [Sov. Phys. Usp. 20(3) (1977) 209]. However, the two-stage laser photoionization schemes originally used in the pioneering work turned out to be rather ineffective and suboptimal, mostly because of high energy consumption, low selectivity, and low values of the main parameters of the separation process such as energy efficiency, selectivity, and ionization yield. Various approaches for the improvement of the laser isotope separation method have been proposed over the past years.

The aim of this work is to provide highlighting how green chemistry principles are being incorporated into radiochemistry, by presenting a selective review of latest novel trends and conceptions in modern theoretical radiochemistry and their interfaces with green chemistry. We try to consider and provide further development of the most promising approaches for the processing and transmutation of radioactive elements at industrial level, after processing spent nuclear fuel. The use of gamma neutron transmutation methods, as well as methods involving selective laser separation of heavy radioactive elements (isotopes) to enable greener handling of radioactive materials, is one of the foundations of green radiochemistry. For example, one of the last processes in radiochemical technologies entails the regeneration of spent uranium. The problem can be radically solved by the gamma-neutron transmutation method, which complements the traditional fission process by other electro-, photo-, and neutron-physical methods, to realize a sort of circular route by which the most dangerous products of the fission process become sources of neutrons for reproducing the power generating potential of uranium, and only stable isotopes and low-activity radionuclides reach the environment. Furthermore, the use of laser isotope separation (for example, separation of the $^{90}$Sr, $^{137}$Cs, and $^{129}$I isotopes from the corresponding stable fragments Sr, Cs, and I) raises the efficiency of transmutation processes and reduces the energy spent on them. All these outcomes are in full agreement with the principles of green chemistry. The need to calculate the optimal conditions for the implementation of the described processes stimulates the determination of both energy and radiative and spectroscopic characteristics of different isotopes in a nuclear fuel, and in a variety of physical conditions, including in the presence of external electromagnetic fields. The computational methods of quantum chemical modelling are further applied for a better understanding of the processes involved. New quantum models integrating computational chemical and dynamical approaches are here presented in detail, considering the most optimal conditions for the realization of transmutation cycles, including laser photochemical separation of radioactive isotopes. Special interest attracts the first using new quantum processes modelling package as well as an artificial intelligence and neural network computing for construction of the optimal schemes of laser photoionization radioactive isotopes separation.

# Structural, vibrational and magnetic characterization of nanostructured $BaFe_{12}O_{19}$ synthesized by sonochemistry

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M-type hexaferrites have versatile applications as permanent magnets, high-density recording media, in devices such as sensors or antennas or for microwave absorption and stealth technology, and many others. The suitability of a given magnetic material for specific applications is determined primarily by the requirements set by those applications. Tailoring hexaferrites with required magnetic properties for specific applications includes implementation of different synthesis techniques to control the grain size and morphology of the produced material, the variations of the stoichiometry of the precursors and ion substitutions in the reference composition as well as the experimental conditions.

Herein, we report the effects of magnetic ordering on the temperature evolution of the Raman modes in nanocrystalline $BaFe_{12}O_{19}$, a topic less explored compared to bulk and thin-films. The precursors were synthesized by the ultrasonic co-precipitation method. It is a novel method based on ultrasonic treatment of an aqueous solution containing salts of the desired metals and NaOH as a precipitation agent, which yields the preparation of nanosized homogeneous particles of iron oxyhydroxides and barium hydroxide. The fine powders obtained at optimized ultrasonic power and solution pH were subjected to heat treatment in a furnace for 4 hours at 800°C, 850°C, 900°C and 930°C. The ongoing processes of synthesis add the advantages of inexpensive precursors and homogenous molecular mixing to the resulting nano-sized powder of controlled particle size and high product purity compared to other alternative procedures. Indeed, Rietveld refined X-ray diffraction (XRD) patterns and transmission electron microscopy (TEM) studies of morphology confirmed the phase purity and nanocrystalline nature of the resulting powders of $BaFe_{12}O_{19}$. The particles had irregular shapes ranging from spherical to hexagonal platelet. Lowering the calcination temperature from 930 °C to 800 °C resulted in a decrease in the average particle size from 90 nm to 25 nm. SQUID characterization of magnetic properties yielded rather high saturation magnetization $M_s$ reaching up to 61.24 emu/g and coercivity $H_c$ ranging from 44 Oe to 103 Oe. Powders consisting of particles with 25 nm size showed an anomaly of the magnetic behavior around 150K. To get a closer insight, for a powder sample from the same batch we measured the temperature-dependent (80–300K) Raman scattering evolution using 830 nm excitation. The Raman spectroscopy results confirmed this anomaly, which can be most likely attributed to spin-phonon coupling mechanism in $BaFe_{12}O_{19}$. To the best of our knowledge, such spin-phonon interactions at temperatures as high as 150 K for $BaFe_{12}O_{19}$ nanocrystalline material are reported for the first time, as this interaction can significantly affect the magnetoelectric and multiferroic properties.

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# A new and straightforward method for thermal quality control of radiation shielding materials based on photoacoustic thermoelastic response

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**Introduction.** Radiation shielding materials are various mixtures of elements that serve to block or keep radiation dose as low as reasonably achievable. It was found that thermal properties are one of the factors that influence the design, selection, and use of shielding for radioactive material, so the development of methods for their thermal quality control is gaining more and more importance. In this article, we will present a new and straightforward method for the thermal quality control of shielding materials, based on their thermoelastic photoacoustic response in the modulation frequencies domain from 20 Hz to 20 kHz.

**Methods and Materials.** In our experiment, we used an open-cell transmission setup to analyze the total photoacoustic signal of radiation shielding materials (aluminium and high-density polyethylene) with thicknesses $l$ ranging from 10 to 1000 microns. Our objective was to determine the position of the maximum temperature difference $\Delta Tmax$ between the illuminated and non-illuminated sides of the sample within the specified frequency range. This $\Delta Tmax$ position also represents the cut-off frequency position $f_c$ of the sample's thermoelastic response - a constitutive component of the total photoacoustic signal. By plotting the dependencies of $\Delta Tmax = f(l)$ and $f_c = f(l)$ on a log-log scale, we can establish linear relationships that allow us to calculate the sample's thermal conductivity $k$ and thermal diffusivity $D_T$. By comparing potential deviations from the reference curves, we can deduce the thermal quality of the investigated materials and identify any alterations from the required properties due to manufacturing defects.

**Conclusion.** This presentation aims to demonstrate that the proposed new and straightforward methodology for assessing the thermal quality control of radiation shielding materials, based on the thermoelastic photoacoustic response, holds significant promise for heat flow analysis. This method allows for calculating thermal transport parameters in aluminium and high-density polyethylene. These properties are essential for the advanced materials development assigned for radiation shielding and their non-destructive thermal analysis.

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# Utilization of the thermoluminescence method to analyze radiation dosimetric characteristics of wide bandgap semiconductor gallium nitride (GaN) produced by MOCVD

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The radiation dosimetric Characteristics of the wide-bandgap semiconductor gallium nitride (GaN) were investigated using the thermoluminescence (TL) method. A $^{90}Sr$-$^{90}Y$ β-beta radiation source irradiated GaN wafer (dimensions: 4 × 4 × 0.35 $mm^3$, weight: 25 mg) at varying doses. This wafer was prepared by the metal-organic chemical vapor deposition (MOCVD) technique and was obtained from the Tyndall National Institute, Ireland.

This method consists of four experiments. In dose response, the wafer was irradiated with doses ranging from 12Gy to 18.4kGy and read out at a heating rate of 1°C/s from room temperature to 400°C. The resulting TL glow curve exhibited a primary peak at 210°C during all radiation doses, while an additional peak appeared at 2.3Gy, located around 150°C. The area under the TL glow curve showed two distinct regions of linear increase, suggesting the contribution of two separate trap populations before reaching the saturation dose. To examine the effect of heating rate, the wafer was exposed to 36Gy and TL glow curves measured at five heating rates (1, 2, 3, 4, and 5°C/s). A small peak emerged around 80°C at 2, 3, 4, and 5°C/s. However, the location of these peaks shifted to a deeper trap area centered around 234°C and 98°C at 5°C/s. In the reproducibility experiment, the sample was irradiated with 36Gy and read out eight times using a TLD reader at 1°C/s. The TL signals demonstrated good stability over multiple measurements. Finally, for dosimeter calibration, the sample was exposed to 36Gy and then faded for varying periods, ranging from 10 minutes to 480 hours, before being read out in the TLD reader at 1°C/s. The results show high dosimetric stability, highlighting the material has promising long-term dosimetry applications.

# The study of black pigments used by Albanian post-Byzantine painters Jani and Vasili from the XVIII century

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The study of black pigments used in Orthodox church frescoes in southern Albania was conducted using Raman spectroscopy, micro-FTIR spectroscopy, and X-ray fluorescence. These frescoes, painted by the atelier of Jani and his son Vasili from Qestorati, represent artistic expressions that have been preserved since the 18th century. The frescoes belong to *The Church of the Monastery of Saint Michael* in Nivan, near Gjirokastra (1779), and *The Church of Saint Nikolla* in Dhrovjan village, Saranda district (1796).

The techniques used by painters of the post-Byzantine period have been traced through specific research. Over the years, artists have experimented with modern materials and their combinations.

The black pigments used by Jani and Vasili's atelier consist of light elements based on carbon structures, as investigated through Raman and micro-FTIR spectroscopy. Their molecular composition corresponds to a graphite structure. Measurements with EDXRF were performed to detect any traces of heavy elements.

**Keywords:** Raman spectroscopy, X-ray fluorescence, micro-FTIR, post-Byzantine, frescoes

# A Python based data analysis of Raman spectra: Application to pigment analysis

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This study presents a comprehensive data analysis workflow for comparing pigment spectra using Python and its specialized libraries. The versatility of Python enables seamless spectra processing, supporting various file formats and structures. Key preprocessing steps, including noise reduction, smoothing, background and baseline correction, and peak detection, are efficiently executed through Python's robust computational tools. Additionally, the workflow incorporates Raman Spectroscopy techniques, leveraging second derivative analysis to enhance the identification of both visible and hidden spectral peaks. This improves the accuracy of organic component identification and spectra processing for pigment classification in frescos and ceramics. The approach is further strengthened by the integration of extensive Raman Spectroscopy datasets available in open-access databases, facilitating precise spectral comparisons.

**Keywords**: Raman spectroscopy, Python, data analysis, spectra processing, pigments

# Reduction of a set of thermoelastic photoacoustic parameters used for shielding material characterization

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**Introduction.** The frequency domain photoacoustic characterization of solids has traditionally relied on multiparameter fitting to extract investigated samples' thermal, optical, and mechanical properties. While this method has proven effective, it also has its drawbacks. Therefore, a growing focus is on finding alternative, simpler sound processing methods with fewer parameters. Our recent research has demonstrated that analogue electrical circuits can be useful for the straightforward study of photoacoustic systems and processes. Using this analogy, one can represent the thermoelastic photoacoustic response with just one parameter instead of the large number in traditional photoacoustic theory. Even though the analogy is approximative, this approach retains the original behaviour of the thermoelastic response.

**Methods and Materials.** The method used in this study is based on electroacoustic analogies of thermal systems, where heat is transferred and stored, and can be described using *RC* circuits of various complexity. It is based on the similarity between the thermoelastic response of the illuminated material (lead, iron, aluminium, high-density polyethylene) and the response of the low-frequency *RC* filter in the frequency domain. We discovered that the filter we mentioned is defined by a single parameter, the cut-off frequency, and found a similar point in the thermoelastic response. Using the analytical form of the thermoelastic component equation, we linked the cut-off frequency to the sample's thermal and mechanical properties. This allowed us to create referent curves using data from existing literature to characterize various materials intended for radiation protection.

**Conclusion.** With this presentation, we want to show that the proposed reduction of a set of thermoelastic photoacoustic parameters is nothing but the transformation from a multi- to one-parameter analysis retaining some meaningful properties of the original data, ideally close to its original one. By reducing the number of parameters and discretizing thermal systems, where heat is transferred and stored through various physical processes, it has been demonstrated that all thermal processes can be represented using *RC* circuits of varying complexity It was found that reducing parameters is essential in establishing an efficient thermal characterization method, knowing that thermal properties are an important factor influencing the design, selection, and use of shielding for radioactive material.

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# The substrate effect on optical, structural and electrical properties of sol-gel derived $TiO_2$ films

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The intensive research and rapid growth in the transparent electronics industry has increased the need for transparent photovoltaic cells (TPVs) and transparent self-powered devices. TPVs could act as an invisible power source for mobiles, buildings, and vehicles. Titanium dioxide ($TiO_2$), as an inorganic material, is widely used in p-n heterojunction devices due to its n-type semiconductor properties. $TiO_2$ has high oxidation properties, wide band gap, high transparency, chemical and structural stability. It is well studied material due to its low cost, applicability to large surfaces and the use of many fabrication methods makes it very convenient for experimental studies.

$TiO_2$ thin films in anatase, rutile or mixed crystal modifications are investigated for application in environment sensors, energy storage, solar cells, electrochromic devices, control-manipulation of biomolecules, photocatalysts, cosmetics, paints, wastewater treatment, capacitors etc.

This work presents the sol-gel spin coating deposition of $TiO_2$ thin films on glass, silicon and ITO substrates. The effect of the number of layers on the optical and vibrational properties was studied. $TiO_2$ films, obtained on ITO substrates were highly transparent in the visible spectral range (over 80 %) reaching the transmittance of bare substrate. Optical band gap values are determined and discussed. The FESEM study manifested smooth surface without film cracking for the sol-gel films, deposited on ITO substrates depite the number of layers (1, 3 or 5 layers). X-Ray diffraction was applied for revealing the substrate effect on the film crystallization. Workfunction is determined as a function of the annealing temperatures and substrate types (Si wafers and ITO).

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# The effect of nitrogen doping in sol-gel ZnO thin films on their optical, electrical and structural properties

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Zinc oxide (ZnO) is one of the most investigated metal oxides, which is environmentally friendly, easily accessible, convenient, cost-effective. ZnO is a direct band gap semiconductor, possessing wide band gap, high exciton binding energy (60 meV), the possibility of low-temperature growth and good transparency in the visible spectral range. These properties make ZnO an excellent material for application in optoelectronic devices, gas sensors, light-emitting diodes, flexible or wearable UV light sensors, spintronic devices, biomedical applications, and surfaces.

The properties of ZnO thin films can be modified by adding metallic elements such as Mg, In, Ga, Al, Li as well as non-metallic dopants such as F, N. Nitrogen has a similar radius and electrical structure to oxygen, and this makes N a promising candidate to produce p-type conductivity in ZnO. Other advantages of ZnO:N films are high transmittance and low resistivity values.

In this work, we report sol-gel method for depositing ZnO and ZnO:N films on silicon wafers and glass substrates. X-ray diffraction and FTIR spectroscopy were applied for revealing the film structure. The effect of the film thickness (number of layers) and the annealing temperatures (300-500$^{o}$C) on the optical transmittance and reflectance is studied. It was found that the optical band gap decreased with increasing the film thickness and the annealing temperature. Nitrogen dopant reflects on the optical and structural properties.

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# Optical, plasmonic and structural properties of sol-gel $TiO_2$:Ag thin films

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$TiO_2$ is a key mulifunctional material considering its excellent electronic and optical properties, high chemical and thermal stability, nontoxicity and low cost. Due to these features, $TiO_2$ is widely investigated due to the potential applications in the fields of environment and energy, gas sensors, photochromic and electrochromic devices, ceramic membrane etc. $TiO_2$:Ag nanocomposites are recently studied due to their enhanced photocatalysis, as solar selective absorber, as photoanode in dye-sensitized solar cell, and for sensitive surface-enhanced Raman scattering (SERS) sensor. The deposition methods and technological conditions play an important role in the properties of the resulted thin film. The sol-gel synthesis has advantages such as homogeneity of the thin films, low cost, reliability, reproducibility, control of film thickness, and relative easiness.

$TiO_2$ and $TiO_2$:Ag films were deposited by the sol–gel spin coating method on quartz and silicon substrates. The aim of the study is to investigate the influence of the Ag amount, UV radiation and thermal annealing on the vibrational and optical properties of Ag nanoparticles (NPs) incorporated in $TiO_2$ films. The optical behavior of UV treated $TiO_2$:Ag films with different number of layers (ranging from one to five layers) with and without additional thermal treatments was investigated. It had been observed that the increasing the layer number, the transmittance was lowering and respectively the absorption in visible spectral region was enhanced. The determination of optical band gap ($E_g$) of thin films is of great importance in the materials science. In the case of $TiO_2$, smaller $E_g$ allows more efficient absorption of solar energy and on the other side the wider optical band gap is beneficial for applications as dielectric in electronic devices or as optical coatings and waveguides. The Ag presence significantly influenced the optical band gap values as $TiO_2$:Ag films possess significantly lower values than those of pure $TiO_2$. Silver incorporation induces the decreasing of band gap energy.

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# Optical, electrical and structural properties of NiO thin films derived by sol-gel method

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Nickel oxide films gain significant scientific interest due to its superior chemical stability, its notable optical, electrical, magnetic, and electrochemical characteristics. The stoichiometric NiO (with a precise 1:1 ratio of nickel to oxygen) is resistive, but obtaining the stoichiometric thin films is challenging. Deviations from the ideal stoichiometry results in the generation of oxygen vacancies or nickel interstitials, which can influence the film electrical, optical and magnetic properties. NiO is one of the very few p-type metal oxides as the structural point defects like interstitial oxygen and nickel vacancies cause the p-type conductivity. NiO exhibits a low electron affinity of 1.46 to 1.85 eV, a wide band gap energy (3.6–4.0 eV), high chemical stability and good transparency (>60 %). NiO films received a lot of attention for applications in gas sensors, electrochromic devices, UV photo-detectors, hole transport layer in perovskite solar cells and many optoelectronic devices. One interesting application of NiO films is in transparent solar cells (TPV). The transparent photovoltaic cell is a solar cell, which works by absorbing UV light (which is harmful) to generate electric power while passing the visible range light.

The properties and respectively the applications of NiO films are affected by the deposition techniques and the main precursor employed during the process. There are various methods available for NiO film deposition: pulsed-laser deposition (PLD), magnetron sputtering, thermal or electron beam evaporation, spray pyrolysis, chemical vapor deposition etc. Among these methods, the sol-gel approach is versatile, efficient, cost-effective (relative low processing temperature, low-cost equipment), which allows the control of the homogeneity, the microstructure and the thickness. Sol-gel NiO thin films were obtained by spin coating on Si, glass and ITO substrates. The impact of the film thickness (different number of layers), annealing temperatures (200, 300, 400 and 500°C) and the type of substrates on the morphology, optical transmittance and vibrational properties were investigated. The work function (WF) of the samples was also determined. The obtained results revealed high transparency (75-83% NiO film on ITO substrate), WF values up to 5.25 eV, smooth morphology. Based on the research it can be concluded that the quality of sol-gel NiO films is comparable to that of the films prepared by more complicated and expensive techniques and these films are suitable for integrating in TPV devices.

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# Efficient radionuclide capture using thermally processed materials

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Generating electricity using fission nuclear reactors is a potential method to reduce carbon dioxide emissions. Additionally, nuclear reactors are regarded as reliable production systems. However, apart from the high costs associated with building and maintaining nuclear power plants, the treatment of liquid radioactive waste poses a significant challenge. There is extensive research on the concentration of radionuclides, such as unstable isotopes of copper, lead, nickel, strontium, cesium, etc. from liquid phases onto solid matrices. While commercial ion-exchange resins are commonly used as solid matrices, any material that can bind these isotopes—which are primarily found in ionic form in liquid waste—can be utilized. Materials with notable sorption properties often include those that have been subjected to thermal treatment. For instance, the heat treatment of materials high in carbon can produce either ash or biochar, depending on the conditions of the process. Biochar, in particular, is known for its large specific surface area, which is essential for their effectiveness as sorbents. In addition to the transformation of organic matter due to high temperatures, the thermal treatment of inorganic materials also enhances their sorption properties. Research has shown that changes in structure positively impact the sorption capacity of minerals like bentonite, as well as waste inorganic materials such as red mud. This paper summarizes previous research on the sorption performance of thermally treated materials that can be used in the treatment of liquid radioactive waste.

# Radiation induced two-dimensional transition metal dichalcogenides lattice rejuvenation

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Our study of laser irradiation of two-dimensional transition metal dichalcogenides (2D TMDC) samples reveals several stages of alternation of their optical and electronic properties. Upon controllable light irradiation with carefully selected laser power, 2D $MoS_2$ quality improves towards more pristine crystalline structure. This is manifested with increasing A exciton weight in the photoluminescence (PL) spectrum. For multilayered TMDC samples, laser irradiation results in photoinduced etching, down to the single layer thickness, as confirmed by measured separation between $E_{2g}$ and $A_{1g}$ Raman peaks. For all original sample thickness – monolayer or multilayer – PL enhancement is observed, for $SiO_2$ and $Al_2O_3$ substrates. This suggests the internal mechanism which is reliant on the material itself rather than an interaction with the substrate.

# Radiation modification of As-S network glass formers in nanoconfined geometry

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The phenomenology of radiation-structural modification in covalent glass-formers such as vitreous arsenosulphides (As-S) is critically reexamined with respect to intrinsic free volume determining their compactness. The configuration-enthalpy model evolving combination of free energy configuration-coordinate and thermodynamic (enthalpy) / (entropy) / (free volume) diagrams is developed to adequately describe phenomenology of optical responses in radiation-structural metastability of these arsenosulphide glasses activated under prolonged physical ageing and/or high-energy irradiation. Destruction of covalent chemical bonds under irradiation is accompanied by structural relaxation of these glasses towards novel metastable state, this process being referred to as radiation-induced physical ageing. When such relaxation occurs via direct transformation of hoteronuclear (As-S) bonds into homonuclear ones (such as As-As and S-S, as in stoichiometric arsenic trisulphide glass, $As_2S_3$), an additional free volume appears resulting in red shift of optical absorption edge. Assuming that quasi-tetrahedral (QT) units based on double-bonds (such as $S{=}AsS_{3/2}$) forming coordination disordering in binary As-S network is stabilized due to free volume disappearing (in nanoconfined geometry resulting from intrinsic pressure), an opposite blue shift is expected in optical absorption edge in these glasses. This analysis critically resolves speculations with QT units as principal blocks forming topological self-organized phases in chalcogenide networks.

# Studies on bronze artifacts from the Bârlad Plateau using XRF and CT methods

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The main purpose of the present study was to determine the elemental composition of certain artifacts using X-ray fluorescence spectrometry (XRF), as well as to assess the quality of casting by examining the pieces with the help of computed tomography (CT), which provided technological insights. The studied artifacts originate from a deposit consisting of five Heleşteni-type sickles, a Krasnyj Majak-type spearhead, a knife fragment, and a Krasnyj Majak-type sword fragment. These artifacts represent prestige objects—symbols of social status and power—as well as tools and weapons. Their identification helps determine their composition, provenance, manufacturing technology, and authenticity. The Bronze Age is characterized by metal casting technology, with metal objects subsequently being transformed into weapons. Issues related to bronze metallurgy during this period emerged with the discovery of isolated finds and hoards. The analysis of bronze objects must consider four key aspects: bronze metallurgy, the circulation of bronze objects, their typology, and their cultural and chronological context. Some bronze objects are composed solely of copper, while others consist of two elements, but most commonly, multiple components are present, as evidenced by the results obtained through the XRF method. Preliminary physicochemical analysis of these bronze artifacts indicates that the alloys contain high concentrations of copper, along with other elements such as lead, antimony, and arsenic. Imaging techniques provide the only means to visualize the interior of objects without causing any damage, thus preserving their integrity. These techniques offer valuable information regarding the object's density, material thickness, inclusions, and voids, which may be aesthetic features or casting defects, depending on each case. In the reconstructed images, the objects appear in different tones, ranging from bright white and light gray to very dark gray, depending on the density of the materials. By using X-ray fluorescence and computed tomography, important information was obtained regarding the alloy composition, dimensions, and appearance of the artifacts, their state of preservation, and the methods by which they were assembled.

# Technologies of warfare: The XRF analysis of arrowheads found in the Scythian necropolis from Celic-Dere (Romania)

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The paper focuses on the compositional analysis, using X-ray fluorescence, of more than 70 arrowheads found during older archaeological excavations in the necropolis from Celic-Dere, Tulcea County, Romania. Based on the characteristics of the funerary structures, which were present as burial mounds covering inhumation graves, and the typology of the grave goods, the necropolis was identified as belonging to a Scythian community, living in the area from the end of the 7$^{th}$ century BC until the beginning of the 5$^{th}$ century BC. From the large number of Scythian-type arrowheads found in the graves, 78 items were selected during this phase of research, taking into consideration their association in graves and their typological details. All of them proved to be made of tin bronze, with various other trace elements. It should be mentioned that the arrowheads still preserve their patina, which could not be removed for the purposes of compositional analysis, situation influencing the percentage of tin identified on the surface layer. The use of a high-quality copper alloy is discussed in connection with the intended use of these items as weapons, sources and technological solutions. Also, the variations in the trace elements, leading to compositional clusters, is analysed against the typological variations identified in this batch, in an attempt to determine if there are any trends or reflections of technological choices.

# Luminescence of $Eu^{3+}$ doped $Na_3Sc_2(PO_4)_3$ and $Na_{3.6}Y_{1.8}(PO_4)_3$ phosphates under high energy irradiation

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Compounds containing rare earth elements have found applications in many technologies, from medicine and telecommunications to solid-state lighting and displays. Among the trivalent lanthanides, $Eu^{3+}$ is well known for its strong emission in the red spectral region and is also a luminescent probe for material structure studies. Phosphates, with their structural features, high chemical and thermal stability over a wide temperature range, are a suitable host type and good candidates for solid-state lighting. Recently, $Na_{3.6}Lu_{1.8-x}(PO_4)_3$ doped with $Eu^{3+}$ has been shown to improve the thermal stability of europium emission due to the increase in level population with temperature rise [N. Krutyak, D. Spassky, D.V. Deyneko et al. Dalton Trans., 2022, 51, 11840]. Here we present the results of the study of the luminescence properties of Eu-doped $Na_{3.6}Y_{1.8-x}(PO_4)_3$ and $Na_3Sc_2(PO_4)_3$ under high energy irradiation.

$Na_{3.6}Y_{1.8-x}(PO_4)_3$ and $Na_3Sc_2(PO_4)_3$ phosphates doped with 0.7 and 0.01 mol% $Eu^{3+}$, respectively, were synthesised in the reduction atmosphere by a high temperature solid state method. Powder X-ray diffraction study revealed that the obtained compounds were single phase with a NASICON-type structure. Luminescence studies in the energy range 2.5 - 9 eV were carried out using laboratory setups. The studies at higher excitation energies up to 40 eV were performed at the photoluminescence endstation of the FinEstBeAMS beamline of the MAX IV synchrotron radiation facility. Luminescence spectra and emission decay curves were also recorded at the laboratory pulsed cathodoluminescence setup.

Energy transfer processes from the host to the dopant have been studied in a wide energy range and the origin of the emission bands has been determined. Intrinsic luminescence, represented by a broad band at 260 nm and related to self-trapped excitons with a 3d Sc electron component, is detected only for the $Na_3Sc_2(PO_4)_3:Eu^{3+}$ compound. Emission bands in the range 320-550 nm detected for both phosphates were attributed to defects in the crystal structure. The behaviour of an intense dopant emission as a set of characteristic peaks in the 550-750 nm region associated with intraconfigurational transitions in $Eu^{3+}$ ion has been studied for $Na_{3.6}Y_{1.8-x}(PO_4)_3$ and $Na_3Sc_2(PO_4)_3$ phosphates. The influence of temperature on the luminescence properties, in particular on the energy transfer between host and dopant, has also been analysed.

# The application of machine learning techniques to data from solid-state nuclear track detector CR-39

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The study presents an application of classification-based machine learning techniques to a dataset comprising the radiation dose measurements with solid-state nuclear track detectors of Poly(Allyl Diglycol Carbonate) type. The detectors were irradiated with alpha particles and fast neutrons in various experimental configurations making the final dataset complex and suitable for machine learning methods. The most suitable experiment is chosen as a stepping stone, and the proposed evaluation method is tested. The detectors are analysed with the commercially available TASLImage system and the final performance in dose determination is compared to the machine learning efforts. Moreover, the uncertainty quantification algorithm is applied to better judge the future applicability of the new evaluation method.

# Solar irradiation prediction for energy-efficient urban planning using machine learning

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Demands for accurate prediction of renewable and efficient energy consumption are increasing. The primary aim of this study is to emphasize the cost-effectiveness and environmental benefits of solar energy in urban planning. The study evaluates the performance of different machine learning methods for solar irradiation prediction in regions with high solar energy potential in Serbia and/or India. The analysis is based on hydro-meteorological data collected in a long period. The study compares the performance of Long Short-Term Memory (LSTM), Gated Recurrent Unit (GRU), XGBoost, Bagging, Random Forest (RF), Regression Neural Network (RNN), Support Vector Machines (SVM), and Artificial Neural Networks (ANN). The hydro-meteorological variables used include temperature, relative humidity, precipitation, and wind speed, while the target variable is solar irradiation. Performance evaluations were conducted using Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). The results of solar irradiation prediction indicate the superiority of deep learning-based approaches.

**Keywords:** solar irradiation, machine learning, energy-efficient planning, prediction

# Radiation pre-sowing seed treatment as a method of plant protection and growth stimulation

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Important problems in the agronomic sector include managing the adverse effects of climate change, loss of soil fertility and species diversity, and the spread of crop pests. The use of physical methods such as radiation treatment can reduce the chemical load on plants and soil and prompt seeds to germinate.

In the presented study, wheat seeds were irradiated with two types of ionizing radiation: low-energy accelerated electrons and X-rays at doses of 5-30 Gy. A two-year field experiment showed that treatment with X-rays at doses of 5-15 Gy in both years of the study increased the number of stems in plants. Consequently, the biomass of the above-ground part of plants and the amount of yield obtained increased. The maximum yield increase amounted to 48.3 %.

In case of accelerated electrons application in the first-year irradiation at doses of 5-15 and 30 Gy was more beneficial for plant growth and yield. In the second year, treatment at doses of 5 and 15 Gy significantly decreased observed parameters. The maximum yield increase for this type of radiation was 37.5 %.

Phytopathogenic analysis showed infection of plants by root rot and septoriosis. Radiation treatment failed to prevent the spread of root rot among plants, however, in the second year of the study there was noted a decrease in the incidence of septoriosis in wheat ears up to its complete suppression when seeds were irradiated at doses of 20 and 25 Gy.

The obtained results indicate the effectiveness of pre-sowing radiation treatment as a method of increasing wheat productivity and partially as a method of plant protection. At the same time, it should be taken into account that plant growth and morbidity depend on many factors, including weather and soil conditions. Nevertheless, the inclusion of radiation technologies in the list of used techniques is potentially a way to improve the quality and quantity of the agronomic sector's products with less environmental impact.

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# First images with plastic scintillator and radioisotope neutron source

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D-D neutron generators have a big potential to become versatile tool for neutron imaging. They provide a stable and monoenergetic source of fast neutrons able to penetrate the large objects. Sensitivity of fast neutrons to light nucleus that can be used creates the basis for fast neutron radiography. Another advantage of a neutron generator is its portability. With this in mind, we decided to build a device capable of acquiring images under laboratory conditions. This paper is aimed to present the first results where the reliability of our design is tested. The construction of an imaging device is based on plastic scintillator as a medium to convert the stream of fast neutrons into light photons and a high-resolution astro-camera for capturing their projection to the image. The whole apparatus is constructed in a straight line and the experiments were carried out with radioisotope neutron source. The purpose of this study is to determine the capabilities of the device and to gain experience with the imaging properties of the plastic scintillator. This will lead to the main goal of our research, which is to use the D-D neutron generator with our developed device for fast neutron defectoscopy of large industrial components. In this paper the principal construction and operation management of the developed device for neutron defectoscopy is presented. The first images obtained using combination of polyethylene and several slits or gaps are also presented. The results of these experiments provide enough knowledge about the functionality of the device for future use with the D-D neutron generator and fast neutron imaging.

# Proposal of the first design of the collimator of fast neutrons generated through the DD108 neutron generator at STU

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The Center of Nuclear Technology and Applications (CENTA) operates the newest laboratory of the Slovak University of Technology in Bratislava (STU), The Laboratory of Neutron Applications. The laboratory has a long-term research objective of developing an irradiation facility for imaging of large industrial components using fast neutrons. For this purpose, a DD-type neutron generator with an emission rate of 1E8 n/s has been purchased and is currently licensed. One of the most important parts of neutron imaging will be the availability of a fast neutron collimator that could deliver the desired portion of neutrons of required energies to the irradiation subject. The collimator will be installed right at the Laboratory of Neutron Applications. In this paper, we investigate the first design of this collimator, which was proposed and evaluated using the Mini Labyrinth experiment of STU. The paper consists of experimental results as well as simulation results achieved using the state-of-the-art SCALE6 system.

# Resonance phenomena and radiation in heavy few-electron multicharged ions collisions

**Alexander Glushkov**

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An existence of a narrow e+ line in the positron spectra obtained from heavy nuclei (ions) collisions near the Coulomb barrier. The consistent quantitative theory of these phenomena is of a great interest. In our paper a consistent unified operator perturbation theory formalism and relativistic energy approach and QED perturbation theory formalism are used for studying the electron-positron pair production processes in the heavy and superheavy few-electron multicharged ions collisions as well as the different radiation processes. The resonance phenomena in the nuclear system leads to structurization of the positron spectrum produced. The positron spectrum narrow peaks as a spectrum of the resonance states of compound super heavy nucleus are treated. To calculate the electron-positron pair production cross-section the advanced versions of the combined relativistic operator perturbation theory (ROPT) and relativistic energy approach, based on the S-matrix Gell-Mann and Low formalism. The nuclear and electron subsystems are considered as two parts of the complicated system, interacting with each other through the model potential. The nuclear system dynamics is treated within the Dirac equation with an effective potential. All the spontaneous decay or the new particle (particles) production processes are excluded in the $0^{th}$ order. We take into account for the corrections of the perturbation theory, which are corresponding to an effective attraction between the nuclear fragments because of the bounding action of electrons. The imaginary part of energy is given by the sum of square of the matrix element of effective one-electron operator effective electron-nuclear interaction on the initial and final state functions for the nuclear and electron subsystems, divided by the standard energy denominator (summation is over discrete and integration over continuum parts of spectra, all possible final states of the electron-nuclear system including the states of the negative continuum); The calculation (on the basis of the Superatom-ISAN PC complex) results for cross-sections at different collision energies (non-resonant energies and resonant ones) for the colliding multicharged ions $^{209}Po^{73+}$-$Po^{81+}$ and $^{238}U^{82+}$-$^{238}U^{90+}$ are listed. Calculation with the different (two-pocket, one-porker) nuclear potential is carried out. It is led to principally the same physical picture for cited potentials, however there is some difference, connected with an appearance of new peaks. An additional electron potential has shifted the scattering states resonances in comparison with collision states ones on the values of order 0.8-1.1 MeV. In result the additional irregularities in the positron spectra are produced due to these interactions.

# Cooperative laser electron-gamma-nuclear spectroscopy of complex atomic and ionic systems: Radiation processes and "shake-Up", NEET Effects

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A new class of problems has been arisen and connected with modelling the cooperative laser-electron-nuclear phenomena such as the radiation and collision processes, electron shell shake-up and NEET or NEEC (nuclear excitation by electron transition or capture) effects in heavy neutral atomic/nuclear systems [JETP. 93, 396 (1987), Preprint ISAN N-AS4, ISAN, Moscow-Troitsk, 1992, *Europ. Phys. J.* T160, 195 (2008), *Molec.Phys*. 108, 1257 (2008), *Phys.Rev.A*. 75, 022509 (2007)]. Though the shake-up effects in the neutral atoms (molecules) are quite weak (because of the weak coupling of the electron and nuclear degrees of freedom), the possibilities of their realization significantly change in a case of the multicharged ions (MCI). This opens new perspectives of obtaining and study of complex radiation and collision decay processes for different radiation applications, etc.

We present consistent, relativistic computational approach to calculation of the probabilities of the different cooperative radiative, laser electron-gamma-nuclear processes in the in heavy neutral atomic/nuclear systems as well as MCI (including the characteristics of the electron satellites in gamma-spectra of nuclei of the multicharged ions and the resonant NEET (NEEC) effects in heavy nuclei of MCI). The theory is based on the relativistic energy approach (S-matrix formalism of Gell-Mann and Low) and relativistic many-body perturbation theory [*Europ. Phys. J.* T160, 195 (2008), *Molec.Phys*. 108, 1257 (2008), *Progress in Theoretical Chemistry and Physics* (Springer) 26, 217 (2013), *Int. J. Quant.Chem*. 109, 3330(2009), *Progress in Theoretical Chemistry and Physics* (Springer) 29, 54 (2015)]. Within the energy approach, decay and excitation probability (of the electron shell shake-up process or etc.) is linked with the imaginary part of energy of the excited state for the "electron shell-nucleus-photon" system.

We present the advanced data about intensities of the electron satellites in gamma-spectra of nuclei in the neutral (low lying transitions) and O-and F-like MCI for isotopes which demonstrate an existence of a new effect of the giant increasing (up 3 orders) electron satellites intensities (electron shell shake-up probabilities) at transition from the neutral atoms to the corresponding MCI. We develop an advanced energy approach to the NEET (NEEC) process in the heavy MCI and list values of NEET probabilities in the nuclei of the O-and F-like MCI. The data listed demonstrate an effect of the significant changing the corresponding NEET probabilities under transition from the neutral atomic/nuclear systems to the corresponding MCI. The possible applications of the obtained data in different radiation applications are considered.

# Cooperative laser beta-nuclear spectroscopy, bound-state beta decay and the chemical environment effect: Relativistic computing

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Many attempts have been made to influence on the nuclear decay rate by varying the temperature, pressure, chemical environments, or by applying strong electromagnetic fields. The situation is completely different in hot stellar plasmas where the ions are partially or fully ionized. In this case it can be expected that the rates of nuclear beta decay and electron capture, as well as internal conversion, are strongly affected in comparison to those of neutral atoms [*Nucl.Phys.A*. 1997.V.626.P.187; *Phys. Rev. Lett*. 1992. V.69. P.2164; *Phys. Lett.B*. 2003.V.573.P.80]. This is of a great interest for understanding the astrophysical nucleosynthesis. In our paper the relativistic many-body perturbation theory is used to calculate b decay parameters for a number of b-transitions. The relativistic calculation method is based on the optimized Dirac-Kohn-Sham formalism with taking into account the nuclear, radiative and exchange-correlation effects [*Phys. Lett.A*. 1992. V.170. P.33; *Nucl.Phys.A*. 2004. V.734 S. P.21; *J.Phys. CS*. 2006. V.35. P.420; Series: Progress in Theor.Chem. and Phys., (Berlin, Springer). 2009. V.20. P.125.]. We studied the electronic rearrangement induced by nuclear transmutation in b-decay $^{6}$He-$^{6}$Li, the b-decay parameters for a number of transitions: $^{33}$P-$^{33}$S, $^{35}$S-$^{35}$Cl, $^{63}$Ni-$^{63}$Cu, $^{241}$Pu-$^{241}$Am etc. and show that the theoretical values agree quite well with some available experimental data. This is connected with account of a few factors (changing ò limits in the Fermi function integral; energy corrections for different chemical substances as well as the possibility of the bound or other decay channels). We also studied the chemical environment effect on parameters of the different beta transitions, in particular, $^{63}$Ni$^{(0)}$-$^{63}$Cu$^{(+1)}$, Ni$^{(+2)}$-Cu$^{(+3)}$, $^{241}$Pu$^{(0)}$-$^{241}$Am$^{(+1)}$, Pu$^{(+2)}$-Am$^{(+3)}$. The correct treatment of the chemical environment effect is shown to modify b-decay parameters. The half-life period for decay of the tritium atom (ion) has been estimated with taking into account the bound b-decay channel correction and some accompanying effects (population of bound states of $^{3}$He, population of the continuum states with exchanging the orbital electron by electron, the charge screening effect due to orbital electrons etc.). The estimated values of $T_{1/2}$ for the tritium b-decay and free triton decay are: $(T_{1/2})_a$=12.26 years (correction due to the electron-atomic effects $(\Delta T_{1/2}/T_{1/2})_a$=0.82%) for the tritium atom and $(T_{1/2})_t$ =12.36 years for the triton decay. These data are in physically reasonable agreement with experimental data. We firstly present the value $T_{1/2}$ in a case of the b-decay in the halogen-containing molecular tritium ($^{3}$HCl): $(T_{1/2})_m$=12.28 years ($^{3}$HCl); the correction due to the chemical bond effect is $(DT_{1/2})_{am}$=0.024 (i.e. 0.20%). The estimates for a ratio $l_b/l_c$ of bound-state (b) and continuum- state (c) b-decay rates for the bare $^{207}$Tl$^{81+}$ ions and isomeric states of fully ionized $^{144m}$Tb etc. are given. The similar effects are also studied for $^{187}$*Re*. The effects considered are responsible for creation of elements in the space and astrophysical plasma. Besides, an approach proposed can be useful for development of new nuclear models, search of the new cooperative effects on the boundary of atomic and nuclear physics, diagnostics of the hydrogen-containing compounds by means of exchange of the hydrogen atoms by tritium, studying properties of energy releasing in the tritium (DT, TT) plasmas.

# Evaluation of the electronic personal dosimeter's response to cell phone radiofrequency interference

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Currently, members of the Canadian Armed Forces (CAF) and Defence Research and Development Canada (DRDC) staff involved in radiological training employ the use of active personal dosimetry that includes the Mirion Technologies brand SOR/RF electronic personal dosimeter (EPD). The SOR/RF EPD has been shown to be a satisfactory active dosimetry monitoring tool with a rugged design for military usage. It is still thought to be susceptible to certain radio frequencies (RF), such as those emitted by mobile phones. This susceptibility has been well noted in the literature for other EPD models and technologies; the RF interference from mobile phones has been shown to affect the radiation dose provided by the EPD significantly. Whether this effect would be observed on the current EPD worn by the CAF and DRDC personnel is questionable. The SOR/RF EPD was previously evaluated by DRDC Ottawa in 2014, and although it was noted to meet S-106 dosimetry standards, RF testing was not conducted at the time but recommended for future testing. Since then, while the EPD has not been updated, modern cell phones and similar communication devices have become increasingly more sophisticated, utilizing multiple RF antennas. Given that personnel have been observed to carry/use these devices within the vicinity of the EPD, the question of RF influence on these EPDs is raised. Since the EPD is relied upon as an active, real-time radiation dosimeter, accuracy is of importance as scenario decision-making and radiation exposure times depend on the EPD's reading. In this work, two different EPDs, the SOR/RF and ALADOS (ALArming DOSimeter ALADOS by Automess), were tested. Their dose to various radiation source energies within the vicinity of a mobile phone's RF was evaluated to determine whether the EPD's dose reading is significantly affected. Experimental measurements show that EPD's readings seem to be affected by the proximity of the RF emitted by the modern 5G mobile phone and, thus, could negatively impact the decisions associated with the use of EPD for active radiation dosimetry. The presentation will provide insight into whether a recommendation should be made that personnel avoid carrying and/or using a cell phone or similar radio device in the presence or proximity of an EPD.

# A pilot study of ultraviolet emission and personnel exposure from tanning bed in cosmetic studio

**Hristina Petkova, Mihaela Ivanova, Tsvetelina Shalamanova**

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In 2010, besides the numerous proven harmful effects of ultraviolet (UV) radiation, the use of tanning devices for cosmetic purposes was recognized as carcinogenic to humans and included in the list of carcinogens as Group 1 by IARC. Considering the widespread use of solaria by young people, often under the age of 18, measuring and assessing UV from such equipment is extremely important to minimize the health risk both to clients and to UV exposure consultants.

The paper presents a pilot study of UV radiation emitted by solariums in cosmetic studios. The study is conducted to evaluate the performance characteristics of a tanning bed, according to EN 60335-2-27, and to assess possible UV exposure to the personnel. Two measurement methods are applied: spectral and non-selective measurement for determining effective irradiance. The methodology encompasses three key components based on the received data of measurements: (1) categorization of the tanning bed according to its radiation spectral distribution, (2) evaluation of effective UV irradiance, and (3) exposure assessment and calculation of maximum permissible exposure duration to minimize the risk of UV-induced skin and eye damage during inadvertent exposure (according to Directive 2006/25/EC).

Nevertheless, UV exposures are into the framework of Directive 2006/25/EC, this pilot study is a model for developing methods for measurement and assessment of UV radiation, to address immediate safety concerns and also to provide a scientifically robust framework for future research and legislation in the operation of tanning facilities and safety protocol development. The acquired data enable the basis for future formulation of targeted recommendations for enhancing safety measures, including routine monitoring of UV radiation, ensuring appropriate personal protective equipment (PPE) for staff, and educating both personnel and clients about the risks of UV exposure.

# Exposure assessment of low-frequency electric and magnetic fields generated by high-voltage power lines: Simulation and on-site measurements

**Tsvetelina Shalamanova[1], Mihaela Ivanova[1], Petya Ivanova[1], Hristina Petkova[1], Radoslav Simionov[2], Michel Israel[1,3]**

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High-voltage power lines generate low-frequency (LF) electric and magnetic fields (EMFs), which have raised health concerns in recent years. This study investigates EMF levels around high-voltage power lines using both computer simulations and field measurements. Field distributions were studied at various distances from the central conductor under different loads and conductor configurations. Numerical simulations were performed using the NARDA EFC-400EP tool, and selected field measurements were performed for validation. The results were compared with international limit values like Council Recommendation and International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. A similar approach has been used in previous studies to assess LF EMF levels from high-voltage power lines (Belkhiri & Yousfi, 2022; Iatcheva et al., 2018, Bürgi et al., 2017).

The measurement results justify the theoretical calculation made by the means of the simulation software.

Both simulated and measured values were found to be well below Council Recommendation and ICNIRP exposure limits.

This study not only validates the accuracy of simulation models with real measurements, but also contributes to a better understanding of LF EMF exposure. These findings support the development of regulatory and engineering strategies aimed at minimizing potential health risks associated with high-voltage transmission lines. The results are very important for assessing the exposure of the population living in the vicinity of power lines.

# Comparison of proton and X-rays irradiation effects on laboratory, probiotic and baker yeast strains

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There are several yeast probiotic strains. In recent years, interest in probiotics has been growing. It is due to the need to search drugs with a physiological effect, which recover a violation of the human intestinal microbiota, immune mechanisms or reduce the incidence of side effects when used different antibiotics, immunosuppressants, chemotherapeutic drugs and in aggressive environments as like at space stations. The effect of probiotic use on the microflora of astronauts is being studied. In addition, yeast is widely used in the food industry in the manufacture of bakery and lactobacilli fermented milk products. Some companies are developing starters for baking bread, as well as technologies for the production of fermented milk products with probiotic during long-term space flights and in space stations. Besides these, yeast is a standard model for studying the molecular mechanisms of a eukaryotic cell. All this makes yeast an indispensable object for studying the impact of stress conditions during space flight.

In our work, we compared the viability and genetic stability of several types of yeast strains. Currently, the most studied is the probiotic yeast strain *Saccharomyces boulardii*, which is used as a medical drug that improves the human microbiota. For our work, we isolated this strain from the drug Enterol® (Biocodex). The baker's yeast strain was isolated from the special Belgian preparation Cosm-O-tentic® Mission to Mars (Puratos). Laboratory strains *Saccharomyces cerevisiae* based on the reference strain S288c were used as a control. In assay, we research genetic and physiological characteristics probiotic and baker's strains before and after proton and X-rays irradiation and compared them with characteristics of laboratories strains.

Irradiation of cell cultures were performed with unmodified 170 MeV proton beams at the clinical proton beam facility with LET 0.54 keV/μm, 0.6 Gy/min. The dedicated cabinet X-ray irradiator designed CellRad+ with Al filter 0.5 mm (130 kV, 5 mA, dose rate ~5 Gy/min) was also used.

Isolates from commercial preparations show some differences, particularly in relation to ploidy, nucleotide sequences, antibiotic and metal resistance, which are important characteristics for a microorganism to be used as medicine. It was shown that survival and mutagenesis of yeast strains were different and corresponded in part by their ploidy: sensitive of diploid strain isolated from Enterol was highest and corresponded with radiosensitivity analogous laboratory strain. The baker's strain Puratos turned out to be much more radiosensitive and less viable. The frequency of mutations was low. Apoptosis, change in cell growth rate and antibiotic sensitivity were also studied.

# Generation and study of a novel DNA base lesion derived from thymidine

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In aerobic organisms, radiation leads to oxidative stress when the balance between Reactive Oxygen or Nitrogen Species (ROS/RNS) production and antioxidant defenses is severely disrupted. This imbalance may lead to DNA damage through the oxidation of nucleobases and sugar moieties in nucleotides. The main DNA base alteration repair mechanisms include Base Excision Repair (BER) and Nucleotide Excision Repair (NER), which may operate simultaneously on the same lesion [doi.org/10.1002/ejoc.200500581]. Within our laboratory, research has been focused on the role of these mechanisms in cell function, with studies, utilizing synthetic nucleotides with oxidized bases, linked to the sugar through stable BER-resistant glycosidic bonds, that allow the study of NER processes [doi.org/10.1093/nar/gkad256, doi.org/10.1039/C8OB00378E].

During the synthesis of BER-resistant derivatives of 5-hydroxy-5-methylhydantoin (HydT), a DNA lesion derived from thymidine oxidation, we observed the formation of a previously unreported lesion derivative which we have termed AnhydroHydantoin (AnHydT). This lesion results from an unexpected dehydration of HydT, leading to the formation of a methylene hydantoin. AnHydT displays an enhanced reactivity as a Michael acceptor. Details will be provided on the isolation, characterization, stability, and reactivity studies on both the carbacyclic and the natural 2-deoxyribo-form of this novel AnHydT lesion.

# Polarity effects on the UV-induced electronic relaxation in DNA dinucleotides

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Ultraviolet (UV) radiation, when absorbed by DNA, initiates photophysical and photochemical processes that can lead to carcinogenic mutations and cell damage. Understanding the earliest electronic relaxation pathways is crucial for deciphering DNA photostability mechanisms. In this study, we investigate the ultrafast dynamics of two dinucleotide pairs, 5'-XG-3' and 5'-GX-3' (X = thymine or adenine, G = guanine), to examine the role of charge transfer (CT) states in DNA photophysics.

Using femtosecond transient absorption spectroscopy with a temporal resolution of 30 fs, we track the excited-state dynamics from 20 fs to 45 ps. Complementary quantum chemistry calculations aid in interpreting the experimental data. In all studied systems, we observe the ultrafast population of a variety of excited state minima via energy and charge transfer processes. The majority of these excited species recombine within mere picoseconds, consistent with photoprotective mechanisms that prevent long-lived excitation. The exception is the CT state ($G^+ \rightarrow X^-$), which forms within 90–130 fs and becomes the predominant species at longer timescales. The properties of these CT states strongly depend on the dinucleotide polarity: when X is positioned at the 3' end relative to guanine, which has the lowest oxidation potential, the CT state exhibits a longer lifetime and higher quantum yield. These findings build upon recent studies on DNA photophysics (e.g., Petropoulos *et al.*, *J. Phys. Chem. Lett.*, 2023, *14*, 10219; Petropoulos *et al.*, *Chem. Sci.*, 2024, *15*, 12098) and provide new insights into the influence of DNA sequence polarity on excited-state charge transfer, shedding light on the early events governing DNA photostability and potential photodamage pathways.

# “molecularDNA” – a Geant4-DNA example application for simulation of radiation-induced DNA damage

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There is a large interest and effort in the scientific community worldwide to develop accurate models and validate radiobiological measurements of DNA damage in cells induced by hadronic particles. There have been several Monte Carlo Track Structure software codes (MCTS) developed for these purposes, making use of a bottom-up approach, starting from an early-DNA scale event to the macroscopic radiobiological endpoints such as cell survival, single and double DNA breaks, DNA repair, and other late effects. The Geant4-DNA extension (https://geant4-dna.org/) of the Geant4 (GEometry ANd Tracking) toolkit represents the first open-source and general-purpose MCTS code. Geant4-DNA delivers the framework for simulating the physical interaction of radiation with DNA molecules and the chemical stages of the water radiolysis responsible for producing oxidative radical species. It also provides validated geometrical models of cell nuclei with a complete DNA genome implemented. The geometries of cell nuclei are, by default, seeded from a fractal packing using the “fractalDNA” model, where the DNA chain is represented with a continuous Hilbert curve made of straight and turned chromatin sections, including nucleosomes. More recently, a new model of cell nuclei named the “complexDNA” has been created, incorporating all 23 chromosome pairs of a human cell. The chromosomal model showed minimal discrepancies in DNA damage yield compared to the default human cell model and demonstrated approximately three times reduction in computation time to obtain equivalent results. The geometric models are interfaced with the direct and indirect stages of DNA damage induction, and the full chain application, named “molecularDNA”, has been released as an advanced example of the Geant4-DNA toolkit in December 2022 (https://moleculardna.org). The “molecularDNA” application is user-friendly and can be utilized following simple macro commands. The first Monte Carlo study of two cancer cells, the lung carcinoma HTB-177 and the breast adenocarcinoma MCF-7, irradiated with a clinical helium ion beam using “molecularDNA” and its comparison to experimental data was published in 2023, showing good predictability of the Geant4-DNA example application. An overview of the “molecularDNA” application, with its design, purpose, and features, will be presented in this talk, as well as a demonstration of its predictability compared to experimental data of cancer cells irradiated with helium ions. The new computational technique to create complex chromosomal DNA geometries will also be detailed.

# Evaluation of low-dose-induced DSBs after minimally invasive vertebroplasty

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**Objective.** Symptomatic vertebral fractures are common among the population and are associated with pain and obstruction of free movement of the individual. Vertebroplasty is a minimally invasive, fluoroscopically guided medical procedure widely used to treat these vertebral fractures. It involves the percutaneous injection of bone cement, typically polymethyl methacrylate (PMMA), into the fractured vertebra to provide stabilization, alleviate pain, and restore structural integrity. However, fluoroscopy for real-time image guidance exposes patients to low-dose ionizing radiation. The cumulative exposure in such procedures raises concerns about potential long-term health risks. According to the Linear No-Threshold (LNT) model, even low radiation doses may increase the risk of malignancies over time.

**Aim.** This study aimed to assess the extent of DNA damage by quantifying DNA double-strand breaks (DSBs) in peripheral blood mononuclear cells following low-dose irradiation in patients undergoing vertebroplasty.

**Methods.** Blood samples were collected from patients before and after the medical procedure. DNA damage was detected in lymphocytes using immunofluorescent microscopy, assessing the co-localization of γ-H2AX and 53BP1 DNA damage repair proteins as markers of DSBs. All doses received by the patients during fluoroscopy time were in the low and very low dose range (≤100mGy).

**Results.** In the investigated group of 67 patients a statistically significant increase in DSBs frequency was observed after vertebroplasty compared to baseline levels before the medical procedure ($p < 0.0001$). However, this increase was not statistically correlated with cumulative air kerma dose received during the procedure.

**Conclusion.** Our findings indicate a significant rise in DNA damage of patients following vertebroplasty, despite the low radiation doses received by the patient. The missing correlation with dose is probable indicator of individual radiosensitivity. Misrepaired DSBs can lead to stable chromosomal aberrations, a key factor in genomic instability and potential long-term health risks. These results highlight the need for further investigation into radiation-induced DNA damage in fluoroscopically guided interventions.

**Keywords:** vertebroplasty, fluoroscopy, osteoporosis, ionizing radiation, low doses, genomic instability, DNA double-strand breaks, γ-H2AX/53BP1 foci

# Investigating the impact of COX-2 and LOX-5 inhibition on cancer cells irradiated with conventional and hadronic beams

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Despite recent advancements in the management of cancer, there is still a large necessity to identify more effective strategies while minimizing undesirable side effects. A promising option is to use hadronic particle beams applied combined with drugs that increase sensitivity to radiation therapy. Moreover, the improved modeling of irradiation-induced DNA damage with Monte Carlo Track Structure (MCTS) codes results from validation with experimentally obtained data. These MCTS codes also provide possibilities for dose determination in treatment planning. The abnormal activation of the cyclooxygenase-2 (COX-2) and/or prostaglandin E2 (PGE2) pathway is commonly observed in various tumor types. This points to the anti-inflammation therapy as a promising cancer treatment option. The activation of the COX-2 pathway decreases the response of tumor cells to radiation therapy while enhancing radiation-induced unwanted late effects in healthy cells. In this regard, COX-2 inhibitors, a structurally diverse class of compounds, can be useful. Also, the increased activity of the 5-LOX signaling pathway in cells exposed to COX-2 inhibitors suggests that dual COX-2 and 5-LOX inhibitors could be the most optimal. In this work, several newly synthesized COX-2 and dual COX-2 and 5-LOX inhibitors were tested on selected cancer cell lines. Based on the results of their cytotoxicity, the most potent inhibitors were selected for combined treatment with radiation. Irradiation with increasing doses of γ-rays was performed at the Laboratory for Molecular Biology and Endocrinology of the Vinča Institute of Nuclear Sciences. Clonogenic assay was done using BxPC-3 (ATCC CRL-1687, pancreatic adenocarcinoma) and HT-29 (ATCC HTB-38, colorectal cancer) cell lines. The obtained survival data was used both for the evaluation of the sensitivity of cells to conventional irradiation and for an investigation of the radiosensitizing potential of tested compounds. The cell geometries were added to the online library of Geant4-DNA, which is openly available to users. To further extend the investigation to irradiation-induced effects on selected cancer models, low-energy protons (≅5 MeV) and alpha-particles (≅ 7.5 MeV) will be used to reproduce the LET values that occur at the mid-SOBP of clinical proton and $^{12}C$ beams (i.e. around 7 and 75 keV/um, respectively) and will be performed at the 3-MV TANDEM accelerator of the University of Caserta, in Italy. The obtained results will show if the combination of COX-2 and dual COX-2 and 5-LOX inhibitors with radiation of different types has the potential to improve tumor control and whether it can be introduced into clinical routine.

# Fractal and multifractal analysis of various tissue samples from beagle dogs irradiated with $^{60}$Co

**Jelena Matković[1], Jelena Trajković[2], Aleksandra Nenadović[3], Tatjana Paunesku[4], Gayle E. Woloschak[4], Andjelija Ž. Ilić[2]**

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There is a notable increase in use of computational image analysis and data classification, due to the continuous increase of computational power, as well as availability of computers over the past two to three decades. This method is auspicious for improved diagnostic precision and subtle feature detection, which makes it particularly interesting in medicine. It makes possible to precisely identify and measure changes and patterns in medical images (Oprić et al., 2020; Joseph and Pournami, 2021; Lopes and Betrouni, 2009).

Through data patterns and correlations, the method also provides new insights into the mechanisms and progression of the disease while saving a significant amount of time and handling large amounts of data.

Large radiobiology megastudies led to the creation of archives of paraffin-embedded tissues accompanied by extensive datasets with gross pathology and histopathology information (B. Haley et al., 2011).

After a pilot study that we performed on kidney tissue of beagle dogs which gave promising results, we decided to subject more of these archival tissue specimens to fractal and multifractal analysis in order to study structural changes in various tissues due to exposure to external beam exposure to $^{60}$Co gamma rays. Here we performed multifractal analysis (Karperien et al., 2016; Torre et al., 2020) on hematoxylin-stained image components, in order to evaluate the complexity of a spatial distribution of cell nuclei, their sizes and shapes. Eosin-stained component underwent the distribution of the local fractal dimension analysis (Oprić et al., 2020). Similarly with our finding from the pilot analyses of several kidney samples – differences in radiation exposure could be associated with differences in tissue organization.

# Study of apoptosis factors and adipokines in ischemic heart disease developing on background of metabolic syndrome

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**Relevance.** Due to the limitation of physical activity in modern times, changes in lifestyle, the high caloric content of food products, and the continuously increasing impact of emotional stress factors, cardiovascular diseases have been rapidly increasing among the global population. Ischemic heart disease, which develops on the background of metabolic syndrome and is considered a significant pathology, is the leading cause of human mortality worldwide. Apoptosis factors and adipokines play a crucial role in the development of cardiovascular diseases.

**Objective.** The aim of this research is to study adiponectin, lipocalin-2, resistin as an adipokines factors, apoptosis-inducing factor (AIF) as one of the main markers of apoptosis, and nitric oxide (NO) as an indicator of oxidative stress during ischemic heart disease on the background of abdominal obesity.

**Materials and Methods.** The study included patients who were referred to the Teaching Surgery and Teaching Therapeutic Clinics of Azerbaijan Medical University. Laboratory analyses were conducted at the Department of Biochemistry of Azerbaijan Medical University using the "Mindray BA-88A" device.

A total of 120 individuals participated in the study. These 120 individuals were classified into three groups:

1. Control group consisting of 20 healthy individuals;
2. Group consisting of 55 individuals with ischemic heart disease and abdominal obesity;
3. Group consisting of 45 individuals with ischemic heart disease only.

The levels of adipokines and apoptosis indicators in the blood serum of healthy individuals and those with ischemic heart disease were determined using enzyme-linked immunosorbent assay (ELISA) methods.

**Results:** In the control group of 20 healthy individuals, the mean concentrations of adiponectin, lipocalin-2, resistin, AIF, and NO were 232.14 pg/ml, 199.63 ng/ml, 30.84 ng/ml, 0.98 ng/ml, and 11.5 mmol/l, respectively. In the group of 55 individuals with ischemic heart disease and abdominal obesity, the results showed that adiponectin was 145.84 pg/ml, lipocalin-2 173.49 ng/ml, resistin 29.41 ng/ml, AIF 3.1 ng/ml, and NO 23.8 mmol/l. In the group of 45 individuals with ischemic heart disease only, the levels of adiponectin, lipocalin-2, resistin, AIF, and NO were 141.34 pg/ml, 129.15 ng/ml, 23.96 ng/ml, 2.87 ng/ml, and 21.5 mmol/l, respectively.

The results show that, compared to the control group, the levels of adiponectin, lipocalin-2, and resistin were significantly lower in the group with ischemic heart disease only (39.11%, 35.3%, 22.3%). Comparative analysis indicates that, compared to the control group, the levels of AIF and NO were significantly higher in the group with ischemic heart disease and abdominal obesity (68.4%, 51.7%).

An increase in apoptosis factors is observed during ischemic heart disease developing on the background of metabolic syndrome, which indicates intensified oxidative stress and a more pronounced apoptosis process.

**Conclusion.** To increase the effectiveness of combating ischemic heart disease developing on the background of metabolic syndrome, it is necessary to monitor the regulation of apoptosis factors and adipokine levels.

# In-vitro cell function assays with and without the application of radioactive nuclides

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Cell assays used in-vitro for tumor cell functional evaluation or ex-vivo investigations from patients are essential in immunological studies in oncology as well as for studies of effects of certain drugs on tumor cells. In the past, the majority of these assays were based on the use of short-lived radioactive nuclides. Radioactive labels can be used in a variety of ways. Some of these radionuclides were bound to the cell membrane, such as radioactive $^{51}Cr$, in the study of cytotoxicity. Contrary to the others, such as 3H-thymidine, after incorporation into the nucleus, were used to determine cell proliferation. This research after detail analyses has been shown a significant correlation between diverse assays that use of radioactive nuclides with other new assay based on monitoring metabolism and target cells or with applied modern assays for apoptosis and necrosis investigations through very sophisticated devices such as flow cytometers. It has been shown that there is a significant correlation between various tests during stimulation of tumor cells in-vitro. However, it must always be taken into account that each assay has its own specificities and shows changes in individual parts of the cells, whether it is apoptosis, necrosis, proliferation or intracellular metabolism investigated. It must always be clearly indicated to which part of the cell the data obtained using individual tests refer and it must always be taken into account what are the limitations of the applied test.

# Cardio-protected radiology department in real life

**Nikita Berezin[1], Mikhail Cherkashin[1], Berezina Natalia[1], Aleksey Nikolaev[1], Sergey Kozlov[1], Albina Gokoeva[1], Tatiana Bolshakova[1], Sergey Aleksandrov[1], Danila Berezin[2,1], Andrey Samanov[1], Iuliia Kim[3]**

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**Purpose.** The purpose is to discuss our experience with implemented in real life outpatient cardiac arrest responding system in radiology department.

**Methods.** Since 2019, we've gradually implemented the «cardio-protected hospital» program: 250-beds oncology hospital with surgery, pediatric oncology, radiology etc; 75000 patient-visits per year; 15 automatic external defibrillators - AEDs in public access areas; 543 healthcare providers and non-medical staff were trained at least for Basic Life Support. Also 11 BLS instructors were educated and certified, internal emergency communication system was established and connected with Code teams (well-equipped ALS providers mainly from ICU department).

**Results.** During 5 years we have identified 8 outpatient (in fact, out of hospital) cardiac arrests (6 - return of spontaneous circulation - ROSC, 2 passed away). Most cases occurred in radiology department (5 from 8). In all cases first responders were non-Code team BLS providers (radiologists, radiographers, nurses and physicians). 1 case of AED deployment before Code team arrived (non-shockable rhythm, CPR, epinephrine, monitor applying by Code Team, ALS algorithm, after 2 rhythm analysis - VF, 2 shocks, ROSC). In 3 cases 4 - 8 minutes of CPR, Code team arrived, VF, ROSC after 1st or 2nd shock. 2 cases of ROSC during CPR before AED applied (grey zone, but we decide to recognise it as cardiac arrest). In most cases in critical stressful circumstances first responders has timely recognised arrest, call for a help and start CPR, but AED arrived quickly only in 1 case of 8.

**Conclusion.** Cardio-protected hospital concept is working in real life. All hospital staff covering by BLS trainings and regular recertification are the key points for system effectiveness. AEDs (if possible) should be placed with time-to-reach of no more than 2-3 minutes.

# Basic life support implementation program in out-patient oncology department

**Nikita Berezin[1], Mikhail Cherkashin[1], Berezina Natalia[1], Aleksey Nikolaev[1], Iuliia Kim[2], Danila Berezin[3,1], Tatiana Bolshakova[1], Sergey Aleksandrov[1]**

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**Purpose.** The purpose is to discuss the process of Basic Life Support implementation in radiation oncology department.

**Methods.** Sudden cardiac arrest (SCA) is one of the most common causes of death nowadays. Despite significant advances in the prevention and treatment of heart and vascular disease over the past decades, mortality rate from SCA remains high.

Outpatient units, according to the daily number of visits, in the majority are actually public places and availability of AEDs and well trained in resuscitation staff increases the level of safety. According to the results of large studies in Denmark and USA it is economically reasonable to place AEDs in areas where one cardiac arrest can be expected over a period of 2-5 years. With a high degree of probability, we can assume that medical organisations also fall into this category.

Since 2018, in our hospital (oncology hospital for 250 beds, proton therapy center for 60 beds, two outpatient facilities, more than 80 detached outpatient CT/MRI cabinets) we've been implementing the program of AED availability in public access areas. Every outpatient setting, including CT and MRI departments, was equipped with AED (totally 15). Educational roadmap for all departments was developed based on European Resuscitation Council Basic Life Support (BLS) program.

Training is provided in strict accordance with the training materials and clinical recommendations of European Resuscitation Council (ERC) by certified instructors. It is recommended to repeat the education annually to maintain skills and qualifications.

**Results.** In 2019-2025, 590 employees were educated and certificated as BLS providers. At the same time, after first step education, more than 30 doctors finished advanced life support (ALS) course.

The simulation center development continues because the global goal is to train all employees without exception.

Second key point is the development of technical infrastructure for affordable AED. In seven years, 15 AEDs were installed in our sites at the intersection of the main routes for stuff and patients.

One of the most important requirements of ERC is annual BLS recertification, because skills not used constantly in routine practice, may be lost. In general, the vast majority of researchers recognize that learning should be constant and repetitive.

Undoubtedly, continuous training and regular recertification require significant resources, but only in this way it is possible to develop and maintain the skills of cardiopulmonary resuscitation using an automatic external defibrillator at the proper level.

**Conclusion.** Implementation of AEDs availability in public access areas in outpatient departments is the good example of patient's and public safety culture. Educational and infrastructural processes aren't complicated and with adequate resources allocation (instructors, simulation equipment, AEDs etc.) can be realized in good standing.

# Hybrid visualization for solid tumor biopsies in pediatric oncology

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**Purpose.** The purpose is to discuss the role of different imaging modalities deployment for biopsy planning, preforming and safety assessment in pediatric oncology.

**Methods and Background.** In adult patients, most part of biopsies usually performed under local anesthesia with free-hand core needle technique and US or CT navigation. In pediatric oncology process mostly is complicated because we need general anesthesia. Due to possible safety issues preferable way is to provide pediatric biopsies in operating room, but usually visualization in OR restricted with ultrasound and/or C-arm. In such circumstances it is important to strongly plan intervention and support it intraoperative by simultaneously deployment of multimodal imaging.

**Results.** In our hospital standard algorithm for pediatric solid tumors (chest, abdomen etc.) biopsies in operating room was implemented. Zero step - diagnostic imaging by CT/MRI. First step - prebiopsy imaging and mapping by C-arm and ultrasound. Second - intraoperative roentgenoscopy for needle navigation by bone landmarks and US support for tumor visualization. We usually use free-hand step-by-step biopsy technique with coaxial needle and imaging control after each step. Third - control look in early postbiopsy period to ensure safety and to identify potential complications (pneumothorax, haemothorax, organs injury etc).

**Conclusion.** Preoperative planning by multimodal imaging and intraoperative deployment of simultaneous hybrid visualization (usually X-ray and ultrasound) allows to perform even transthoracic core needle biopsies with high accuracy without life-threatening complications.

# Anesthesia for proton therapy in pediatric oncology depratment

**Mikhail Cherkashin, Aleksey Nikolaev,
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**Purpose.** The purpose is to discuss anesthesia management for proton beam therapy in pediatric oncology.

**Methods and Background.** During last 3 years, in our hospital 876 children with CNS and body tumors received proton therapy. In 360 cases radiation treatment delivered with anesthesia. Mean fractions number was 34 (anesthesia number - 34 for 1 patient). Mean age - 6 years (6 months - 17 years). 76% of patients has CNS tumors, 9% lymphomas, 15% - soft tissue and other body tumors. 5 children with stem tumors have sevofluran anesthesia with mechanical ventilation, other has propofol with nasal oxygenation. In all patients, ports or PICCs were used. For treatment time optimization, revolver-style anesthesia was implemented: 1st team waking up children after treatment, 2nd team provided anesthesia during treatment and in parallel, 3rd team started with sedation in anesthesia room, then all teams moving for new patients.

**Results or Findings.** Mean anesthesia number - 23 (20-32) per day. In 2 stem tumors patients during propofol anesthesia desaturation revealed and mechanical ventilation started. In 24 children, radiation treatment was interrupted due to radiation-induced hydrocephalus, patients transferred to neurosurgery department for ventriculoperitoneal shunting and started again with radiotherapy. In 56 patients (15.5%), due to tumor decreasing and strong clinical psychologist support, on 15-20 fractions, we were able to refuse anesthesia and children continued proton therapy without sedation.

**Conclusion.** Implementation of pediatric anesthesia during proton therapy characterized by strong infrastructure creation (anesthesia rooms, awakening wards, patient trolleys with oxygen, monitoring and ventilator etc). For optimal treatment room time management, it's critical to implement revolver-style patient anesthesia clinical way.

# Comparative analysis on the impact of age on occurrence of oral pathologies – pregeriatric age versus geriatric age

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**Background.** Despite the fact that saliva production decreases significantly as a result of the physiological aging process, aging that occurs as a result of increasing age and the individual's inclusion in the geriatric age is accompanied by the appearance of systemic pathologies for which the geriatric patient is forced to be treated with medications that, as a side effect of systemic use, also have a reduction in saliva production. The aim of this study involves analyzing the data collected from the clinical examination of geriatric patients versus data collected from pre-geriatric patients, to find out if and how age affects the appearance of these oral pathologies. The aim of this study is to analyze how age of patient affects the appearance of soft tissue and hard tissue lesions in oral cavity, analyzing the results of these pathologies, results that are expressed in the number of remaining natural teeth in the oral cavity, in number of endodontically treated teeth, in presence or not of total partial dentures or fixed dentures.

**Methods.** A total of 61 patients: 26 of geriatric age and 35 of pre-geriatric age, were evaluated during oral examination for the presence of oral soft tissue and hard tissue pathologies, also expressed by the number of remaining natural teeth in the oral cavity, in number of endodontically treated teeth, in presence or not of total partial dentures or fixed dentures. Oral cavities were examined in order to evaluate previous dental treatments. Photography of oral pathologies were also performed.

**Results.** Regardless of pre-geriatric and geriatric age, endodontic treatment occurs in almost 70% of cases and their absence in 30% of cases included in the study. Endodontic treatments with the aim of preserving the natural tooth has the highest value in pre-geriatric patients, expressed in the value of about 50% of the number of patients included with 1 or more endodontic treatments in the same oral cavity. For geriatric age, 2% of patients are classified in category with the largest number of teeth in the oral cavity, 26-32 teeth, for non-geriatric age, patients with 0-15 teeth in oral cavity are about 10%. The combination of these figures indicates an increasing trend in population that will pass to total edentulism in geriatric age. The presence of removable prostheses for pre-geriatric age in the amount of 7%, as opposed to geriatric age where this value is 18%. It is clear that the pre-geriatric age tends towards fixed prosthetics, while the geriatric age tends towards removable prosthetics. The tendency for prosthetics for both the pre-geriatric and geriatric ages appears in the ratio 1:1.

**Conclusions.** The combination of figures on the minimum number of natural teeth in the oral cavity in the pre-geriatric age and on the maximum number of natural teeth in the oral cavity in the geriatric age shows an increasing trend in the population that will go into total edentulism in the geriatric age; a tendency that appears from the pregeriatric age. Patients of the pre-geriatric age present with more teeth treated endodontically compared to patients of the geriatric age.

**Keywords:** natural teeth, dental prosthetics, geriatric, oral hygiene, pre-geriatric, oral health

# Endodontic retreatments: Clinical opportunities and challenges

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**Background.** Apical periodontitis, including persistent periodontitis, is thought to limit intra-radicular infection. The apical periodontitis itself is the frontline of the battle between bacteria that have accidentally or unintentionally entered this area and the host of the affected individual. Continuing this logic, it can be thought that the granuloma may be the place where these types of bacteria are deposited, sometimes not responding to the normal course of endodontic treatments and indicating surgical endodontic treatment rather than endodontic re-treatment according to the normal intervention protocol. In fact, the bacterial flora of persistent periapical periodontitis may even be resistant to endodontic treatment. Technological advances in endodontic dental materials and equipment and tools for endodontic treatments have led to a major evolution in endodontic canal therapy. The clinical outcome of a successful root canal therapy has been the preservation of the tooth that was the subject of endodontic treatment in the dental arch, thereby removing the need for extraction as a sign of infectious pathology that spreads from the tooth pulp to the periapical tissues.

**Methods.** The study was carried out in a total of 60 patients: 23 patients were female and the rest 37 patients were male. The patients included in the study are divided according to the number, type of tooth, or group of teeth indicated for endodontic re-treatment as a result of the confirmed presence of persistent apical periodontitis. The aim of this study is to analyze how different factors affect the possibilities of achieving successful initial endodontic treatment and to find the clinical reasons for not achieving this goal, which leads the patient to endodontic re-treatment.

**Results**. Gender not only, does not affect the frequency of persistent apical periodontitis pathology but also the distribution in the oral cavity of this pathology assessed by the positioning in the oral cavity of the affected tooth. In the inclusion of patients in this study based on the inclusion criteria, this uniformity of the sample of patients taken for radiological assessment of the above-mentioned pathology is clearly expressed in table 4 where the distribution of affected teeth is 50% in the maxilla and 50% in the mandible, where both according to gender and according to the arches where the teeth affected by persistent apical periodontitis pathology are included, the ratio 1:1 is clearly visible. The highest number of teeth initially treated endodontically and then presented with persistent apical periodontitis is presented under the category of molars in the value of about 52% of all teeth evaluated for this study. This value is followed by premolars at a value of about 32% and then by incisors at a value of 16%. The distribution of the affected teeth is 50% in the maxilla and 50% in the mandible, where both according to the gender of the patient and according to the arches where the teeth affected by the pathology of persistent apical periodontitis are included, the ratio is clearly 1:1.

**Conclusions.** Endodontic re-treatments as a reason for clinical application have in fewer cases the pain and in more frequent cases the security of having an endodontically healthy tooth for fixed prosthetic replacements. The clinical challenges of endodontic re-treatments are mainly oriented around the application of the correct steps of the routine protocol of endodontic treatments.

**Keywords:** endodontic re-treatment, apical periodontitis, clinical success, periapical radiograph

# Mechanisms of radiation hormesis in cancer patients

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While medicine has made significant strides in detecting, treating and curing cancer, the inability to vanquish the disease is leading growing number of patients to seek out alternative treatments.

Low-dose radiation in Radon spa is effective for advanced cancer patients. Many cancer patients who have been given over by doctors gather from all over Japan to Radon spa—one final hope. Radiation hormesis is considered. Recently, the remarkable progress on radiation hormesis has given clear evidences.

Several famous Rn spas in the world are: Tamagawa Rn spa (Miyagi, Japan); Misasa Rn spa (Shimane, Japan); Bad Gastein (Austria), Jáchymov (Czech Republic), Radon Health Mine (Montana, USA).

Mechanisms of radiation hormesis are: Activation of immunity by stimulating Langerhans cells; improvement of the function of hypopituitary and adrenal gland; irradiation of cells and removal of active oxygen by α-emitters; inhibition of active oxygen by SOD, Glutathione peroxidase, Catalase; inhibition of cancer growth by activation of p53 gene; repair of DNA injury leading to apoptosis; activation of NK cells.

In conclusion: Low-dose irradiation is not only harmless but beneficial in advanced cancer patients; evidence of clinical improvement is increasing; mechanisms of radiation hormesis have been turned out by remarkable medical progress.

# The identification of elemental and molecular changes in cerebellar structures following high-calorie diet-induced obesity – studies using multimodal spectroscopic imaging

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Obesity is currently a global epidemic problem. Due to the complex biological mechanisms involved in the development of this disorder, the pathogenesis of obesity as well as its complications is not fully understood. Whilst the hypothalamus and the mesolimbic system are widely recognized as being pivotal in the regulation of food intake, the cerebellum has also been demonstrated to play a significant role in this process. The role of the cerebellum in the regulation of food intake is primarily associated with its control of chewing and swallowing. However, it has also been hypothesized that this part of the brain is responsible for the homeostatic, reward-related and affective aspects of food consumption. Furthermore, imaging studies in obese patients have revealed substantial morphological and neurodegenerative alterations in the cerebellar structures, which have yet to be elucidated. Considering the elemental and molecular abnormalities in brain structures responsible for appetite regulation previously identified in obese rats (doi.org/10.1016/j.saa.2023.122478) as well as reports of morphological changes in the cerebellum in obese patients (doi.org/10.1155/2021/6613385), the objective of our studies was to determine which chemical elements and biological macromolecules are involved in neurodegenerative mechanisms within the cerebellum in obesity.

In the experiment we used male Wistar rats with high-calorie diet-induced obesity and their lean counterparts. Thin sections from the rat cerebellum underwent multimodal spectroscopic imaging using X-ray fluorescence microanalysis (μ-XRF) and Fourier transform infrared microspectroscopy (μ-FTIR). In order to identify potential alterations within the cerebellum structures with regard to elements that are responsible for nerve impulse conduction (Na, Mg, Cl, K, Ca) and those with structural functions (P, S), a scanning X-ray fluorescence microanalyzer, M4 Tornado Plus (Bruker), was utilized. Concurrently, in the same tissue samples, we investigated alterations in lipid and protein structures, as well as the levels of phosphate functional groups, utilizing a Continuum IR microscope coupled to a Nicolet 8700 FTIR spectrometer (Thermo Scientific). To assess biochemical changes in cerebellum structures induced by a high-calorie diet, statistical and chemometric analyses were employed.

Multimodal imaging of rat cerebellar sections provided insight into the distribution of selected chemical elements, as well as biological macromolecules, in cerebellar structures to be studied with micrometer spatial resolution in obese and lean counterparts. The use of advanced data mining methods allowed for the identification of differences in biochemical composition that appear in rat cerebellar structures as a result of a high-calorie diet-induced obesity. The detailed outcomes of this study will be presented.

# Prevalence of emphysema in patients undergoing lung cancer screening using low-dose CT

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Chronic obstructive pulmonary disease (COPD) and lung cancer are leading causes of death globally, that share common risk factors such as age and smoking exposure.

**Aim.** The aim is to determine the prevalence of emphysema in high-risk population that underwent LDCT screening for lung cancer.

**Methods.** A secondary analysis of Lung Cancer Screening Database of Secretariat for Health Care of Autonomous Province of Vojvodina, Serbia between 1 December 2023 and 31 November 2024.

Persons aged 50-74 years, with a smoking history of ≥30 pack-years/or ≥20 pack-years with additional risks (COPD, prior pneumonia, other malignancy, family history of lung cancer or exposure to environmental carcinogens) were offered LDCT.

**Results.** Of total 1 288 participants, mean age 62.1±6.7 years, 535 male (41.5%), 386 (30.0%) had emphysema. Majority of patients with emphysema (301/386, 78.0%) had no prior history of chronic lung diseases. Compared to patients without emphysema, patients with emphysema reported more dyspnea (140/386, 36.3% vs. 276/902, 30.6%, p=0.046), chronic cough (117/386, 30.3% vs. 209/902, 23.17% p=0.007), purulent sputum expectoration (70/386, 18.1% vs. 95/902, 10.53%, p<0.001) and weight loss (45/386, 11.7% vs. 63/902, 7.0%, p=0.005). Patients with emphysema had longer exposure to smoking (pack/years, 43.8±18.8 vs. 39.3±18.1, p<0.001) and higher prevalence of solid or semisolid lung nodules (141/386, 36.5% vs. 278/902 30.8%, p=0.04). Radiation doses were maximally below the mean values of radiation doses when applying the standard and amounts: CTDIvol 0.77mGy, DLP 30.98mGy/cm, average 0.42mSv.

# Examining the proficiency of computed tomography radiographers in addressing severe contrast media reactions: A cross-sectional study

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**Background/Aim.** Using intravenous contrast material (IVCM) in computed tomography (CT) scans improves the quality of images by increasing detail and accuracy, which is critical for detecting complicated medical problems. While IVCM offers significant advantages, it also bears the risk of uncommon but possibly fatal adverse events. The purpose of this research was to assess CT radiographers' skill and preparation in addressing serious adverse responses to IVCM. Furthermore, the study aims to investigate how characteristics such as professional experience, training, and practice location influence CT radiographers' ability to manage such incidents.

**Methods.** This cross-sectional study evaluated CT radiographers' knowledge and preparation in addressing severe IVCM responses. Following ethical permission from the Institutional Review Board (IRB), an electronic survey was piloted with 15 radiographers for validation prior to distribution. Participants were practicing CT radiographers who were recruited by snowball sampling using social media and professional networks. The research looked at knowledge variances depending on experience, training, and practice context. Despite the aim of 300 participants, 241 replies were received, offering valuable insights into radiographers' abilities in contrast reaction control.

**Results.** We used several measures to test CT radiographers' knowledge and competence in addressing severe IVCM responses, resulting in a 97.2% response rate. The total knowledge measure showed high reliability, with a Cronbach's alpha value of 0.854. The average knowledge score was 25.02 out of 40. Participants demonstrated appropriate knowledge in a variety of areas, with the majority (93.4%) being aware of preventive precautions for IVCM usage. However, only 22.0% of individuals demonstrated consistent understanding in all five tested knowledge areas.

**Conclusions.** This research illustrates the necessity of continuing professional development and systematic training, especially based on international standards, in enhancing CT radiographers' awareness of how to handle adverse responses to contrast media. Senior specialists and those with overseas training display outstanding knowledge.

# Quantification of metals in human bone using *in vivo* X-ray fluorescence

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Lead is a well-documented toxin in the human body, associated with neurodegenerative diseases like Alzheimer's and multiple sclerosis, as well as psychological changes and reduced IQ in children. In modern society, people are continually exposed to this harmful element through the environment, food, water, and workplace hazards. Likewise, exposure to other metals—such as tungsten, lanthanum, gadolinium, and strontium—has increased despite their limited presence in the past. Tungsten's widespread use in electronics, industry, and military applications has become a common part of daily life. Research has also explored its medical potential, including sodium tungstate for diabetes treatment and tungsten nanoparticles for enhancing radiation therapy. Lanthanum and gadolinium accumulate in the bones of those exposed, particularly individuals taking lanthanum carbonate orally or receiving gadolinium-based MRI contrast injections. However, not all metal exposure leads to health issues; for instance, strontium supplements have been suggested to support bone health and prevent osteoporosis. As interest in the health effects of various metals grows, numerous epidemiological studies are examining their impact on workers and the general population, including children.

X-ray fluorescence is the emission of characteristic (or fluorescent) X-rays from a metal excited by high-energy gamma rays or X-rays. The *in vivo* X-ray fluorescence-based measurement of metals accumulated in bone was introduced for bone lead quantification over forty years ago but remains an underutilized diagnostic tool. Detection based on the K-series of the metal of interest (K-XRF) has traditionally been performed using radioisotope-induced methods ($^{125}$I, $^{59}$Co or $^{109}$Cd) with either a liquid nitrogen-cooled Si(Li) or HPGE detection system. More recently, portable X-ray fluorescence spectrometers were introduced, providing a more economical, portable and convenient way to conduct *in vivo* XRF quantification of metals in bone and nails. However, this method relies on detecting L-series characteristic X-rays (L-XRF) using the X-ray tube sources.

Metals are primarily stored in the bones, where they can remain for years. *In vivo*, bone X-ray fluorescence is a noninvasive and painless diagnostic tool that provides information about metal exposure over time, unlike blood levels. This presentation will provide an overview of the diagnostic tool based on *in vivo* X-ray fluorescence bone measurements and its potential role in supporting the diagnosis and monitoring of metal stored in human bone concerning metal-induced toxicity and neurotoxicity, occupational or population exposure, which is still widely not under-investigated.

# On the response of alanine dosimeter to ultra-high dose rate electron beam

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**Introduction.** The development of ultra-high dose rate (UHDR) platform machines and extensive studies on radiobiological effects have demonstrated a reduction in normal tissue toxicity via FLASH radiotherapy [Favaudon et.al., Sci. Trans. Med., 2014. 6(245)]. In particular very high-energy electrons (VHEE) with energies ranging from 50 to 250 MeV have gained increasing interest in/to be employed as radiation sources for FLASH radiotherapy due to their ability to penetrate deeply-seated targets [Bohlen et. al., Med. Phys., 2021. 48(7)]. The delivery of high doses within sub-seconds (>40 Gy/s), pose significant dosimetric challenges. Conventional detectors suffer from saturation and ion recombination, leading to substantial errors and uncertainties in measurements. Alanine dosimeters can potentially be well suited for such UHDR beams. They are composed of organic crystalline amino acids. The mechanism of energy absorption & storage in alanine crystals is similar to its absorption in tissue. Stable free radicals generated in irradiated alanine have unpaired electron which can be measured using electron paramagnetic resonance (EPR) spectrometers [Bradshaw et. al., Rad. Res., 1962. 17(1)]. The amplitude of the measured signal is correlated to the energy deposition i.e. dose. Alanine dosimeter is used as a secondary standard dosimeter in radiotherapy by several national metrology laboratories. Alanine is weakly energy dependent within the therapeutic energy range (6-25 MeV) [Anton et. al., Phys. Med. Biol., 2013. 58(10)]. Its dose rate independence makes alanine a potential dosimeter for UHDR dosimetry [Bourgouin et. al., Phys. Med. Biol., 2022. 67(20)]. However, the response of alanine to very high energy electrons has not been reported which is the chief aim of this research.

**Materials and Methods.** Alanine pellets (Harwell Dosimeters Ltd.), calibrated with Co-60 gamma-ray, were irradiated using 100 MeV electron beams from the Pulsed Energetic Electrons for Research (PEER) end station, located in the Linac tunnel that serves as the injector for the Australian Synchrotron. The Linac can deliver electron pulses with pulse dose rates up to $10^7$ Gy/s. Six different dose per pulse (DPP) from 6 – 28 Gy per pulse (in a single pulse of 200 ns time) were delivered to alanine pellets, with three pallets for each dose. The EPR spectra of irradiated alanine pallets were measure using Bruker EPR spectrometer. The amplitudes of the spectra were converted to absorbed dose to water using a calibration curve for alanine dosimeter irradiated with Co-60 gamma ray. The relative response of alanine dosimeter was determined by the ratio of dose measured by alanine dosimeter based on Co-60 calibration to nominal dose delivered. Charge delivered in each pulse is measured with in-flange Bergoz FCT sampled with a 14-bit ADC that is calibrated against a Faraday Cup [Cayley et. al., Front. Phys. 12, (2024)] at the start of each experiment. The expected peak nominal dose is calculated from the integrated pulse charge. The beam size and position stability were measured under the same conditions with EBT-XD.

**Results.** The absorbed dose measurement of the alanine dosimeter irradiated with a 100 MeV VHEE beam is 16% lower compared to the nominal dose as measured by Faraday cup. The relative response of alanine dosimeter for 100 MeV electron beam was 0.84. This result demonstrates the significant energy dependence of alanine dosimeter when exposed to a 100 MeV VHEE.

# Examining lesion visibility of thick compressed breasts under different ionizing radiation exposure conditions by using a mammographic mathematical phantom

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**Introduction.** Mammography is an X-ray imaging application used for breast diagnosis. Its high importance is denoted by the routinely mammographic examinations suggested for women above a certain age. In the era of digital mammography various dedicated detector designs have been considered for possible use in a mammographic system. Despite, the detector characteristics the image of thick or dense breasts is a challenge since the amount of radiation transmitted through the breast and incident at the detector surface is a function of the ionizing radiation energy and exposure. In addition, possible breast lesions may be visible or not depending upon their size and composition. In general, a large size and high atomic number lesion has higher visibility than a small size and low atomic number one. The imaging performance of mammographic systems is tested through physical phantoms as well as with mathematical or software phantoms.

**Materials and Methods.** A simple mathematical breast phantom was designed. It was comprised from breast tissue as a background material and areas corresponding to a) blood for low atomic number material and b) Ca for a high atomic number material. The phantom dimensions were 1000x1000 pixels, while the lesions were constructed as squares ranging from 2x2 pixels up to 50x50 pixels and lines with sizes from 2 pixels up to 35 pixels. The phantom was assumed compressed. The thicknesses considered were 5.2 cm and 6 cm for the phantom. For the Ca the thicknesses ranged from 0.0008 cm up to 0.01 cm and for the blood lesions from 0.08 cm up to 0.5 cm. The phantom was mathematically irradiated with 22 keV and 28 keV X-ray photons for different photon fluences. The phantom mathematical image was assumed to impinge at a Dexela mammographic detector. The image transfer characteristics of the detector were obtained from literature.

**Results.** A Point Spread Function leading to a Modulation Transfer Function differed 1.67% from the experimental was derived. In the produced 22 keV images for the 6 cm breast the 0.003 cm thickness, 10x10 pixel Ca rectangular lesion could be observed. The 20x20 pixel blood lesion of 0.2 cm thickness was also visible. The corresponding 28 keV X-rays could visualize lesions of smaller dimensions. The increase of photon fluence improved the derived image due to the decrease of the image noise levels. The irradiation conditions used in the case of 5.2 cm thickness resulted in less noisy images due to the higher number of photons impinging on the detector surface.

**Conclusion.** A mathematical phantom was designed which can be used to assess mammographic imaging capabilities of thick breasts.

# A mechanistic model for assessing spinal cord complications after ion irradiation

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The current hadrontherapy treatment-plans are based on constraints related on physical quantities and on the optimization of the distribution of absorbed dose within the patient. However, incorporating biologically related models of Normal Tissue Complication Probability (NTCP) would help further minimizing adverse tissue reactions, and would allow achieving a more patient-specific strategy. The aim of this study is to develop a mechanistic approach to directly predict clinical outcomes, specifically the NTCP for late tissue reactions following ion irradiation [Casali et al., Phys. Med. Biol. 69 245012, 2024].

A dataset on the tolerance of the rat spinal cord is considered, providing NTCP experimental data following irradiation by photons, protons, helium and carbon ions, under different fractionation schemes, for several LET (Linear Energy Transfer) values. The considered mechanistic NTCP model is the Critical Element Model, which is based on the concept of Functional SubUnits (FSUs) and the serial architecture of the organ [Withers et al., Int. J. Rad. Oncol. Biol. Phys., 14:751-759, 1988]. The photon data are fit by the Critical Element Model, with four free parameters; this allows fixing the two parameters that only depend on the tissue features. The other two parameters, depending on radiation quality, are the α and β parameters of the Linear-Quadratic cell survival model. They are predicted, for ion irradiation, by applying the BIANCA biophysical model [Casali et al., Phys. Med. Biol. 69 245012, 2024], coupled with the GEANT4 transport code: an interface between BIANCA and GEANT4 was developed to obtain the α and β values for mixed fields. Thus, the irradiation conditions of the experimental SOBP (Spread Out Bragg Peak) are reproduced with GEANT4 (in collaboration with the GEANT4-INFN project).

Since all model parameters for ion irradiation are set a priori, the obtained NTCP simulation outcomes are pure predictions. Therefore, the predicted NTCP curves for ion irradiation are tested against the ion experimental data, by performing a statistical analysis. The model shows a good predictive power, as assessed by a Chi-Square test. Indeed, the model passes a significance test at 5% for most of the datasets. This study represents a first step towards a novel approach, based directly on the prediction of clinical outcomes, to improve treatment plan optimization and evaluation in hadrotherapy, allowing for more effective and personalized therapies. To this aim, the approach needs to be extended to other endpoints and to be applied to patients' data.

# Quantification and analysis of out-of-field dose in radiotherapy for 6 MV and 18 MV beams

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Accurate estimation of out-of-field doses in radiotherapy is essential for minimizing healthy tissue exposure and optimizing radioprotection, particularly in pediatric patients. This study aims to quantify and compare out-of-field doses for 6 MV and 18 MV photon beams using Monte Carlo (MC) simulations via GATE, Treatment Planning System (TPS) calculations, and Optically Stimulated Luminescence Dosimetry (OSL). Experiments were conducted on PMMA and pediatric phantoms to evaluate the impact of anatomical characteristics on dose distribution. Dose measurements were performed at 10, 15, 20, 25, and 30 cm from the beam axis for a 10 × 10 cm² field using the three methods. For the pediatric phantom, dose assessments focused on six critical organs using OSLDs (nanoDots™) and TPS under 3D-CRT and VMAT techniques. For the PMMA phantom, MC estimated higher out-of-field doses than OSL and TPS, particularly near the irradiation field. At 10 cm for 6 MV, the absolute dose differences were 0.20 Gy (MC vs. OSL, 21.98%) and 0.309 Gy (MC vs. TPS, 33.96%), persisting at 30 cm (MC vs. OSL: 23.08%; MC vs. TPS: +30.77%). For 18 MV, TPS and OSL showed strong agreement (differences <10%), but MC remained significantly higher (31.31% vs. OSL and 42.86% vs. TPS at 30 cm). For the pediatric phantom, OSL doses were consistently higher than TPS across all organs. In 3D-CRT, differences between OSL and TPS were 26.22% (right lung), 29.81% (left lung), 25.57% (left kidney), and 16.62% (right kidney). In VMAT, discrepancies ranged from 7.34% (esophagus) to 24.96% (right lung). Significant discrepancies in out-of-field dose estimation among MC, TPS, and OSL highlight the limitations of TPS in peripheral dose assessment. Experimental validation remains essential, particularly in pediatric radiotherapy, to refine dose calculation algorithms, enhance treatment planning, and improve radioprotection strategies.

# Method for range calculation based on empirical models in radiotherapy or proton therapy in liquid water and DNA bases in hemodialysis patients with kidney cancer

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In patients with kidney cancer or hemodialysis, direct ionization and excitation of biomolecular electrons of DNA or by indirect chemical reaction of free radical products with DNA bases usually lead to quite significant biological damage that can lead to death.

In this work, we first narrowed down an extensive study by trying to focus on the choice between radiotherapy and proton therapy. The first calculation results clearly show the difference in interaction between the beams of energetic photons or ionic protons and the softest tissues of the kidney containing water, representing more than 80%. The results agree to serve as a basis for an estimate of the Bragg peak in matter biological H2O + DNA. In recent years, much more interest has been devoted to studying the interaction of charged particles with biological molecules. This will help us better understand the physical and chemical steps of the actions of radiation on matter. We developed a semi-empirical Rudd-based model for proton ionization processes, and before electron excitation and capture processes based on the results obtained with the water target. and stopping the cross-section in the DNA bases. We performed a calculation for the incident energy of the proton ranging from 1keV to 100MeV. The results were a good comparison with experimental data, theoretical results and data from the GEANT4DNA simulation. Secondly, a follow-up of hemodialysis patients; protein albumin, body mass index (BMI) are parameters to be monitored more closely.

According to the results observed, a significant trend emerges: as the energy of the photons increases, the absorbed radiation dose increases. This increase is observed both in the right kidney, identified as the tumor organ, and in the left kidney and bladder, identified as organs at risk. This direct relationship between the energy of the photons and the dose of radiation deposited sheds light on the fundamental physical characteristics of photons as massless electromagnetic particles with an energy proportional to their frequency. When high-energy photons interact with biological matter, they have more potential to transfer their energy and induce cellular damage. Thus, this observation highlights the crucial importance of taking into account the physical properties of photons when planning radiotherapy treatments, in order to maximize effectiveness while minimizing adverse effects on surrounding healthy tissues. For electrons, at energies of 2 MeV and 6 MeV, their energy is insufficient to penetrate deep into biological tissues. Therefore, the dose deposited in the target organs, such as the right kidney (tumor organ) as well as the left kidney and bladder (organs at risk), remains negligible at these energies. However, at 10 MeV, there is an increase in the dose deposited in the right kidney, although this dose remains very low, resulting in the absence of a dose deposited in the organs at risk. This observation underlines the increased sensitivity of the right kidney to irradiation by electrons at higher energies. The physical characteristics of electrons include their low mass compared to other particles such as protons and neutrons, as well as their negative electric charge. Because of their charge, electrons interact strongly with surrounding atoms and molecules, causing collisions and disruptions to chemical bonds. This leads to the release of energy in the form of radiation, which can induce cellular damage when delivered with enough energy. Thus, the increase in electron energy leads to an increase in their ability to penetrate tissues and deliver a dose of radiation, which explains the concomitant increase in the deposited dose observed in the right kidney as well as in organs at risk. For protons, at an energy of 70 MeV, their energy is insufficient to penetrate deep into the tissues of the right kidney, and therefore, no dose is deposited there. However, at 110 MeV, the energy of the protons is optimal to reach the center of the right kidney and deposit the maximum dose at that precise location. Above 110 MeV, the protons extend beyond the center of the right kidney, reducing the dose deposited in this region.

# Methods for dose, LET and energy measurements in laser accelerated particle beams

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One of the many applications of the ELI-NP laser accelerated particle beams is the medical biophysics and radiotherapy. One of the problems confronting the experiments envisaged for such applications is the measurement of dose and energy.

The laser accelerated beams will be delivered in very short pulses and very high doses per pulse which are ideal for studying the effects of flash radiotherapy, for instance, but on the other hand the beam characteristics make the dose and energy measurements rather difficult.

We have already shown that a new detector concept, the QUADRO (QUad Array Detector for RecOmbination factor measurements) can be successfully used for dose measurements taking into account the saturation effects at high dose rates. Furthermore, the development into QUADDRIL (QUad Array Detector for Dose, RecmbInation and LET measurement) can be used for determining both dose and LET in such high dose rate environments, but the energy measurement is still necessary. Such measurement can be done successfully with radiochromic films placed axially into the beam, such as to record the PDD curve of the beam. The problem with such an experimental set-up is the errors due to the misalignment. These errors were assessed in a standard therapy electron beam, by varying the gantry angle for a stack of EBT3 Gafchromic(TM) films and observing the variations in the results of energy measurements.

The paper presents the initial stages of development of the QUADDRIL detector as well as the results of the assessment of the energy measurement errors due to the angle misalignment in the beam.

# IAEA activities in support of accelerator-based research and applications with socio-economic impact and the IAEA Ion-Beam Facility project

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Due to their unique analytical and irradiation capabilities, ion beam accelerators play a major role in solving problems of modern society related to environmental pollution and monitoring, climate change, water and air quality, forensics, cultural heritage, agriculture, development of advanced materials for energy production via fission or fusion, and many other fields. Moreover, particle beams delivered from almost 20.000 accelerators worldwide are used for industrial applications and high-tech services resulting in business revenues in the billion-dollar scale, which clearly demonstrates the decisive contribution of particle accelerators to the increase of competitiveness of economies worldwide and the welfare of modern society in general. For all these reasons, accelerator-based applications are among the thematic areas, where the International Atomic Energy Agency (IAEA) supports its member states in strengthening their capacity to adopt and benefit from the use of accelerators. In this context, the IAEA Physics Section implements various activities in support of accelerator-based research and applications that focus on

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

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

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

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

# Meta-analysis of risks and benefits in immunotherapy treatment of metastatic melanoma

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Immune Checkpoint Inhibitors (ICI) have significantly improved survival outcomes for patients with metastatic melanoma and various other malignancies. Patients receiving ICI therapy have achieved a median overall survival (OS) of 20 to 72 months with mono- or combination immunotherapy, compared to just 4 to 12 months with chemotherapy. However, despite these promising results, ICI therapy carries a high risk of severe immune-related adverse events (irAEs), where the immune system mistakenly attacks healthy tissues. These side effects, which include pneumonitis, colitis, thyroiditis, pancreatitis, and others, can significantly reduce a patient's quality of life.

Our study includes a literature review based on 13 scientific papers and various clinical studies, encompassing a total of 6 296 patients. These patients were treated with either monotherapy or combination immunotherapy. The primary objective is to compare the therapeutic outcomes and safety profiles of these two treatment approaches. Since the data were collected from multiple clinical studies, meta-analysis techniques were used for statistical processing. The tested null hypotheses evaluated whether there were significant differences in risks (the appearance of irAEs) and benefits between monotherapy and a combination of immunotherapy treatments. In meta-analysis, the combined confidence interval (CI) integrates data from multiple studies to calculate a single (aggregate) confidence interval for the proportion. Combined confidence intervals were calculated for both treatment types (mono compared to combination therapy), and conclusions were drawn accordingly for risks and benefits. To quantify treatment benefits, we applied the RECIST criteria, categorizing responses as complete response (CR), partial response (PR), and stable disease (SD). Adverse effects monitored included pneumonitis, colitis, diarrhea, hyperthyroidism, and hypothyroidism. For each of these risks and benefits, the effects of monotherapy and combination therapy were compared through the formation of a unified 95% confidence interval based on results from multiple clinical studies.

Our analysis has shown a statistically significant difference in the profile of immune-related adverse events (therapeutic risks) and the therapeutic benefits when comparing monotherapy with a combination of immunotherapy treatment. The results indicate that combination therapy provides significantly greater benefits in treatment; however, this approach is also associated with a higher incidence of adverse effects.

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# Incident learning systems in radiation therapy

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Incident learning systems (ILS) have emerged as a cornerstone for improving patient safety and clinical quality in radiation therapy, an area where precise treatment delivery is critical. This abstract presents a detailed examination of the evolving structure and implementation of ILS in radiation oncology, with a focus on how these systems help prevent errors, optimize treatment processes, and ensure continuous learning within clinical teams. The presentation will cover the following key areas:

1. Design and Structure of Incident Learning Systems: A review of the fundamental components of an effective ILS, including standardized reporting protocols, categorization of incidents, and the role of multidisciplinary teams in reviewing and addressing reported events. We will discuss how an optimized ILS integrates seamlessly with existing quality assurance (QA) processes and regulatory frameworks, such as AAPM's TG-100 and other international guidelines, ensuring both compliance and quality improvements.

2. Building a Non-Punitive Reporting Culture: A critical factor for the success of an ILS is fostering a non-punitive culture that encourages staff to report errors and near-misses without fear of retribution. The abstract will explore methods to build this culture, emphasizing the importance of leadership, training, and ongoing education in ensuring openness and transparency. This section will draw on successful models from high-reliability industries, such as aviation and nuclear power, to demonstrate how these lessons can be applied in radiation therapy settings.

3. Advancements in Data Analytics and Automation: With the rise of big data and artificial intelligence (AI), the field of incident learning is undergoing rapid transformation. This abstract will highlight recent technological advancements that have enhanced incident detection, data analysis, and trend identification. Automation tools can streamline the reporting process and help in identifying recurring patterns of errors, while AI algorithms can predict potential incidents before they occur, thereby contributing to proactive safety interventions.

4. Case Studies and Metrics for Success: Real-world case studies from leading radiation therapy centers will be presented, showcasing how the implementation of well-structured incident learning systems has led to measurable improvements in patient outcomes, workflow efficiency, and safety. We will also discuss key performance indicators (KPIs) and metrics that departments can use to assess the effectiveness of their ILS, such as incident reporting rates, resolution times, and post-incident review actions.

5. Future Directions and Challenges: Finally, the abstract will address the future of incident learning in radiation therapy, including emerging challenges such as managing increasingly complex treatment modalities, ensuring interoperability between systems, and addressing staff workload concerns. We will also explore how ILS can evolve to support personalized treatment plans and adaptive therapy techniques through continuous learning and feedback loops.

In conclusion, this presentation will provide a comprehensive guide to designing, implementing, and optimizing incident learning systems in radiation therapy. Attendees will gain practical insights into building a culture of safety, leveraging data and technology for incident prevention, and driving continuous improvement in clinical care. The ultimate goal is to support radiation oncology departments in their efforts to deliver the highest standards of patient care while minimizing the risk of errors.

**Keywords:** incident learning system, radiation therapy, patient safety, non-punitive culture, artificial intelligence, quality assurance, data analytics, continuous improvement

# Production of the $^{124}$Sb isotope via proton-induced reactions on enriched $^{124}$Sn

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Isotope $^{124}$Sb can be used for medical applications, particularly in low-dose rate intravascular brachytherapy (IVBT), due to its favorable nuclear characteristics, such as high-energy β-particles (1-2 MeV and more) and low-energy γ-rays (20–300 keV). Studies have shown that it can be successfully used to prevent recurrent restenosis of blood vessels, which accrue after invasive angioplasty [E.K. Elmaghraby, et al., Appl. Rad. Isotopes 67, 147 (2009)].

We investigated proton-induced nuclear reactions on enriched tin $^{124}$Sn (91.9%) at energies up to 18 MeV. Besides measuring the production cross-section of the $^{124}$Sb isotope ($T_{1/2}$ = 60.2 d), formed in the $^{124}$Sn(p,n) reaction, we also measured the cross sections of the reactions $^{124}$Sn(p,pn)$^{123m}$Sn and $^{124}$Sn(p,3n)$^{122}$Sb. The threshold of the first reaction is $E_{th}$ = 6.31 MeV, and the half-life of the residual is $T_{1/2}$ = 40.06 min. For the second reaction, the threshold is $E_{th}$ = 16.96 MeV, and the half-life of the residual is $T_{1/2}$ = 2.72 d. The excitation function of the $^{124}$Sn(p,n)$^{124}$Sb reaction has a maximum at 8–9 MeV, and the influence of the $^{122}$Sb impurity can be easily avoided by choosing an initial beam energy of less than 16.96 MeV. The co-produced $^{123m}$Sn isotope is short-lived.

However, the presence of a small impurity (2.4%) of the $^{122}$Sn isotope in the target material resulted in a strongly pronounced gamma line at 158 keV (the interference line of $^{117m}$Sn ($T_{1/2}$ = 13.61 d), $^{117}$Sb ($T_{1/2}$ = 2.8h), $^{117m}$In ($T_{1/2}$ = 1.94 h), and $^{117g}$In ($T_{1/2}$ = 43.8 min). Therefore, the isotopic purity of the target is critical for the production of $^{124}$Sn.

# Risk management in a testing laboratory using thermoluminescent detectors to determine absorbed dose to water for dosimetry audits of radiation therapy centers

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The Secondary Standards Dosimetry Laboratory (SSDL) in Warsaw in Poland has been accredited by the Polish Centre of Accreditation for the conformity with the ISO/IEC 17025 standard *General requirements for the competence of testing and calibration laboratories*. The accreditation No. AB 1499 was granted on April 9, 2014. It covers the determination of absorbed dose to water for X-ray beams in the range of accelerating potentials of 4 MV to 25 MV and for electron beams in the energy range of 4 MeV to 22 MeV. The status of accreditation and validity of the scope of accreditation can be confirmed at PCA website www.pca.gov.pl. The Polish SSDL performs measurements in the aforementioned accreditation scope for the purposes of dosimetry audits of radiation therapy centers in Poland.

In this work, the ways of implementing requirements of the ISO/IEC 17025:2017 standard regarding actions to address risk and opportunities associated with the laboratory activities are presented. These requirements (see section 8.5 of the ISO/IEC 17025:2017 standard) are as follows: consideration of risks and opportunities associated with laboratory activities, planning and taking actions in relation to risks and opportunities and assessing the effectiveness of these actions.

Due to the fact that the ISO/IEC 17025:2017 standard does not recommend the use of specific risk management methods, each laboratory can define its own methodology. At the Polish SSDL, it was assumed that risk management is the overall process, as shown in the ISO 31000:2018 standard *Risk management – Guidelines*. Due to this standard, risk can be defined as effect of uncertainty on objectives. This effect is a deviation from the expected and it can be positive, negative or both, and can address, create or result in opportunities and threats. The risk management process involves such activities as communication and consultation, establishing the scope, the context and criteria, risk assessment (i.e.: risk identification, risk analysis and risk evaluation), risk treatment, monitoring and review risk and recording and reporting risk.

In this work, activities concerning the risk assessment a s well as recording and reporting risk will be discussed in detail using several selected threats important from the Polish SSDL point of view.

We hope that the practical examples of risk management presented in this work will help other testing laboratories manage risk in their routine activities.

# The most common errors during dosimetry audits in radiotherapy

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Dosimetry audits in radiation therapy are designed to ensure safe radiation therapy for the patient and to improve its quality. It is an independent external dosimetry audit. It makes it possible to check the correct calibration of the beams on the therapy devices, the correctness of the geometric reproducibility of the planned therapy beams, the correctness of the data entered into the treatment planning system and the precision of the calculated dose distributions. Such an audit also indirectly makes it possible to check the competence of dosimetry teams at the radiotherapy centers. Dosimetry audits have been performed annually in Poland since 1991. The outcome measure is the *delt*a parameter, which is the percentage difference between the dose declared by audit participants and the dose determined in the Polish Secondary Standards Dosimetry Laboratory (SSDL) taking into account a number of corrections.

The value of the *delta* parameter is not always consistent with the expectation of the audit participant. In this case, it is necessary to explain the reason for the discrepancy, eliminate the causes and repeat the audit. Dose values estimated by thermoluminescence dosimetry (TLD) are subject to uncertainty. The total expanded uncertainty of the TLD determination of absorbed dose to water (type A and B uncertainties) is 3.4% with an expansion factor of $k$ = 2.0.

Errors encountered during a dosimetry audit are both systematic errors, e.g. incorrect calibration of equipment, improper alignment of detectors with respect to the beam, and random errors, i.e. related to the accuracy of measurements, and are usually human errors.

The most common error is an improperly set SSD. The audit methodology dictates that the TL powder capsule should be irradiated with a dose of 200.0 cGy under geometric conditions according to the instructions. A difference of 2.0 cm in SSD positioning results in a change of as much as 4.0% in the dose recorded by the TL detector.

Another type of error encountered is due to careless positioning of the detector capsule in filter free beams. Moving the detector by 1.0 cm results in a change of about 1.0% in the estimated dose.

Incorrectly selected beam parameters on the radiotherapy device in relation to those declared in the measurement protocol, such as beam energy, are common causes of discrepancies in results. When performing a dosimetry audit, it is important to remember that the dose rate is affected by the size of the radiation field. When performing an audit under conditions other than reference, it is important to pay attention to the dimensions of the field. The difference in the dose estimated by a TL detector for 5 cm x 10 cm and 10 cm by 5 cm fields is 1.0%.

As a result of improper operation of a radiotherapy device, the TPR can change by up to 0.5%.

Accurate calibration of such a device is therefore important.

Other errors are related to leaving detectors in the bunker of the radiotherapy device during irradiation, or erroneous completion of measurement protocols (wrong TPR or absorbed dose to water).

Any of the above-mentioned factors can significantly affect the correctness of a dosimetry audit, so it is important that the audit is carried out in a comprehensive, systematic manner and in accordance with the highest quality standards.

# Characteristics of high energy unflattened photon beams using GATE/GEANT4 simulations

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Recently, special attention was paid to the implementation of medical linear accelerators operating at flattening-filter-free (FFF) mode in radiotherapy. Unflattened photons beams offer several potential advantages over standard flattened ones, such as increased dose rate, reduced treatment delivery time, and a considerable reduction in the out-of-field exposure to the untargeted volumes.

An 18 MV unflattened photon beam from a Varian Clinac 2100C medical linac was simulated using GATE/GEANT4 Monte Carlo code. Physical and dosimetric characteristics of FFF photon beams including (PDDs, dose profiles, surface dose, and beam quality specifiers) were calculated in water and compared to FF ones. Photon fluencies and energy spectra were calculated at the isocenter for different field sizes ranging from 10x10 to 40x40 $cm^2$. Our calculations revealed an increase of 9% in the surface dose and a decrease in the out-of-field dose for the unflattened beams. The calculated photon fluence for the unflattened beams was 5.5 times higher than the flattened beams. The obtained results confirm the usefulness of flattening-filter-free beams for clinical applications.

**Keywords:** GATE/GEANT4, medical linac, unflattened beams, beam characteristics

# Variability in radiotherapy outcomes across cancer types: A comparative study of glioblastoma multiforme and low-grade gliomas

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Radiotherapy is a crucial treatment option for various cancers. However, the results of radiotherapy can vary widely across different cancer types and even among patients with the same type of cancer. This variability presents a major challenge in optimizing treatment strategies and improving patient survival. Here, we collected radiotherapy phenotype and expression data from 32 TCGA cancer datasets and performed overall survival analysis for 32 cancer types. Additionally, we conducted a signaling pathway enrichment analysis to identify key pathways involved in radiotherapy resistance and sensitivity. Our findings show that radiotherapy improves survival outcomes in certain cancer types, such as glioblasoma multiforme (GBM), while worsening outcomes in others, such as low-grade glioma (LGG). Next, we focused on exploring the differences in radiotherapy outcomes between GBM and LGG, focusing on the molecular mechanisms contributing to these variations. We identify differential regulation of pathways related to programmed cell death, DNA repair, telomere maintenance, chromosome condensation, antiviral responses, and interferon signaling between GBM and LGG patients perhaps explaining radiotherapy efficacy. A genetic analysis confirmed the importance of immune response and radiotherapy outcome for LGG patients. These insights underscore the importance of personalized treatment approaches and the need for further research to improve radiotherapy outcomes in cancer patients.

# Study of characteristics of *Primula vulgaris* using Raman spectroscopy

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Primrose, or *Primula vulgaris*, is a perennial herb that has long been prized for its therapeutic qualities. The entire plant is used for its expectorant, anti-inflammatory, analgesic, antispasmodic, and healing-promoting properties. *P. vulgaris* is effective to treating rheumatic disorders, gout, insomnia, anxiety, respiratory tract infections, and bronchitis. This study examines the ecological variation of *Primula vulgaris* from two locations: Dajti Mountain, which is 1023 meters above sea level and the Tirana peripheral hills, 217 meters above sea level. These locations provide different environmental conditions, making possible to investigate how these ecological variations might affect the traits of plants. Leaf dimensions (length and width), chlorophyll content were measured and statistical analysis were performed using Mann-Whitney U test. The findings showed that there was a statistically significant variation in leaf size, with Dajti Mountain plants having shorter leaves. For this study, Raman spectroscopy measurements were performed using a B&W Tek i-Raman Ex Raman spectrometer with a wavelength of 1064 nm, a laser power that ranges from 45 to 70%, and a measurement time that varies from 50 to 240 seconds, depending on the sample type. The measurement resolution ranges from 26 to 90 wavenumbers, or 3 to 13 nm. We have encountered the presence of Rutin and Tangarine essential oil, from the characteristic peaks present in the Raman spectra. These findings provide insights into the morphological and chemical variability of *P. vulgaris* in different environmental conditions.

# The use of ChatGPT for conference organization and scientific purposes

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The integration of artificial intelligence (AI) tools into academic and professional workflows has opened new possibilities for optimizing time-consuming and cognitively demanding tasks. This study explores the practical application of ChatGPT, a large language model developed by OpenAI, in two primary domains relevant to academia: (1) the organization of scientific conferences and (2) support for scientific research and writing.

In the context of conference organization, ChatGPT has demonstrated significant possibilities in content creation across various communication formats. This includes generating invitation and confirmation emails, writing various announcements, producing engaging social media content, and tailoring website and promotional texts. These outputs are easily customizable in tone, style, and language, enabling organizers to rapidly produce high-quality, audience-specific content. Additionally, the tool provides strategic guidance for email campaign optimization, offering insights on language patterns and formatting techniques that reduce the risk of spam filtering and domain blacklisting—issues increasingly relevant in large-scale academic communication.

On the scientific front, ChatGPT functions as a valuable research assistant, particularly in the early phases of project creation and literature exploration. Researchers can use the model to brainstorm topics, formulate research questions, and identify emerging areas of interest within specific fields. Furthermore, ChatGPT can summarize known findings, present overviews of relevant theories, and suggest potential sources and databases for literature reviews. Although it cannot replace comprehensive database searches or critical reading, it can efficiently provide preliminary direction, thus saving time and enhancing research design.

The presentation will include the discussion about the advantages and limitations of ChatGPT's current capabilities, emphasizing the need for critical oversight, especially in terms of scientific accuracy and source validation. Nevertheless, the model presents a promising tool for academics seeking to streamline administrative workflows and support scientific inquiry. Its adoption may signal a shift toward more AI-assisted processes in academic and research ecosystems.

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