NUTECH–2023

Krakow, 20–22 September 2023

International Conference on Development and Applications of Nuclear Technologies

BOOK OF ABSTRACTS

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CONTENT

ABOUT CONFERENCE

The NUTECH-2023 is a continuation of the National Symposia on Applications of Nuclear Techniques in Industry, Agriculture, Medicine and Environment Protection, which have been held in Poland since 1960, almost every three years. From 2008 it attained the international status. With a significant number of foreign participants the NUTECH conference provides a platform for the nuclear science community to share the experience and to learn about the recent developments going on in nuclear research and their practical applications. NUTECH covers wide range of topics that are related to different uses of nuclear technologies, ranging from nuclear energy to nuclear medicine and whole spectrum of industrial applications of nuclear techniques.

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- current status of nuclear energy
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- new reactor technologies
- research reactors
- production of radiopharmaceuticals
- nuclear medicine
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- radiation processing of materials
- radiation sterilization and health care products development
- food irradiation
- industrial application of the nuclear techniques
- environmental application of the nuclear techniques
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ABSTRACTS

Canberra Packard Sp. z o.o

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Keywords: measuring equipment, monitoring, radiological safety

In Poland, Canberra Packard Sp. z o.o. is a sales and service representative of the world's leading manufacturers of apparatus and systems for measuring, controlling, monitoring and ensuring radiation safety in all installations where ionising radiation and radiological exposure of the environment, workers or patients occur. Systems from MIRION Technologis (Canberra, MGP, MGPiH&B, Biodex, Capintec) and Berthold Technologies, PTW Freiburg, Tema Sinergie, Kromek, and automatic alpha/beta/gamma scintillation counters from REVVITY (PerkinElmer) are used in nuclear installations, scientific and research institutes, radiopharmaceutical production facilities, oncology centres, nuclear medicine facilities, environmental measurement laboratories, and uniformed services.

MIRION (Canberra) is a world leader in the manufacture of ionising radiation spectrometers, comprehensive radiological monitoring systems for the environment, nuclear facilities, radioactive waste assessment and selection, alpha, beta, gamma, neutron radiation instruments and detectors. Berthold Technologies is an established manufacturer of neutron detectors, radiomonitoring systems in research facilities, hand-leg gates and contamination control instruments.

PTW Freiburg is a highly respected manufacturer of systems and detectors, instruments and phantoms used by medical physicists for planning and quality control in radiotherapy and X-ray diagnostics.

Tema Synergie is a widely present supplier of advanced hot chambers for the production and distribution of radiopharmaceuticals (PET), manual and automatic radiopharmaceutical dispensers.

REVVITY's (PerkinElmer) automatic alpha/beta cis-cyntial counters and automatic gamma counters division is a world leader in the production of unique, super-low-carbon instruments for environmental research (Quantulus GCT, TriCarb) and research and diagnostic equipment in nuclear medicine (Wizard series of counters). Capintec and Biodex are a US-based supplier of a wide range of equipment used in nuclear medicine. Kromek - is an extremely fast-growing company from the UK, manufacturer, among other things, of innovative portable spectrometers for CBRN applications.

Advancements and applications with the μDOSE and μDOSE+ Systems for Environmental Radioactivity and Dosimetry

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Keywords: alpha beta pulse separation, decay pairs, uranium thorium decay chains, building materials hazard indices, alpha beta indices

The μDOSE and μDOSE+ systems (Fig. 1) represent the state of the art in radiation detection methodologies. While many conventional systems measure only α or β particles, the μDOSE and μDOSE+ systems are equipped with pulse analyzers that can classify alpha and beta particles based on their pulse shapes. Moreover, these systems measure the time interval between pulses, which is used for detecting four decay pairs: ^{220}Rn/^{216}Po, ^{219}Rn/^{215}Po, ^{212}Bi/^{212}Po, and ^{214}Bi/^{214}Po. These pairs arise from the ^{238}U, ^{235}U, and ^{232}Th decay chains. A distinguishing feature of the μDOSE+ system is the implementation of machine learning in its active shielding module. This innovation significantly improves pulse classification, leading to a substantial reduction in background counts and increased counting efficiency.

The system is primarily designed for dose rate determination in trapped charge dating but also offers versatility in its applications. It can determine building materials hazard indices such as: Radium equivalent activity, evaluate the Representative Level Index, measure absorbed gamma dose, and calculate the annual effective dose rate. Additionally, it provides functionality for monitoring low-level α and β indices without the need for time-consuming sample preparation, as is required in liquid scintillation counting.

Figure 1. *μDOSE+ advanced system, equipped with active shielding, designed for measuring low-level alpha and beta radiation*

The Optimization and Testing of Gamma-Ray Detection Analyses

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Keywords: naturally occurring radionuclide, gamma-ray, spectral analysis, Delta Underwater Gamma System (DUGS)

The measurement of naturally occurring radionuclide concentrations in the environment, poses various challenges. The concentrations of naturally occurring nuclides are typically determined by the characteristic gamma-ray emissions from the progenies in the decay chains of these nuclides. Several gamma detectors have been developed to detect gamma-ray energies of natural radionuclides. Natural radionuclides are commonly characterized by low concentrations and the optimization of the spectral analysis method is consequently vital. The latter involved full spectrum and energy window analyses (or a combination thereof) as possibilities for optimal extraction of nuclide concentrations. This study, investigates and tests these factors to optimize the spectral analysis method. To determine the optimal method for extracting the activity concentrations of the nuclides in the environment a comparison between window and full spectrum analysis had to be performed. To achieve this, a Delta Underwater Gamma System (DUGS) was used to survey the Berg River Estuary on the west coast of South Africa. The results from these measurements were analyzed using these two methods and a comparison was made. These methods and results are discussed in this paper.

Numerical Simulation of Calibration Map for Radioactive Particle Tracking Technique Using MCNPX Code

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Keywords: radioactive particle tracking, calibration algorithm, multiphase chemical reactors, hydrodynamic behaviour, MCNPX code

Radioactive Particle Tracking (RPT) technique has emerged as a potential and versatile technique, both in terms of information richness and applicability to a variety of multiphase flow systems. Radioactive particle tracking technique is better suited for flow visualization and mapping in opaque multiphase systems and can provide reliable insight about mixing and flow patterns.

In classical approach, the calibration process is used to obtain the number of counts measured by the scintillation detector where the corresponding tracer positions are known. In this calibration process, static hold method is used using special equipment to hold the radioactive particle tracer at different selected position in the column while gathering data counts of gamma radiation detected by group of detectors. As a result, a map of distance-counts is obtained for each radiation detectors. However, this manual calibration process is inefficient, tedious and long exposure to radiation. Obtaining high accuracy particle tracking is difficult and time consuming because the calibration data map of the new column or vessel model is need to be developed each time the experimental conditions and mechanical change. Few researchers have conducted calibration using automated RPT calibration device, but sometimes it was not conducted at normal operation condition, real vessel environment, and the equipment probably interfering the gamma radiation detection by certain scintillation detectors.

Therefore, calibration process by numerical simulation strategy is introduced where the tracer position and counts were obtained without physical calibration and tools. This article presents a detailed application of radioactive particle tracking technique and utilization of a code for calibration of the tracer position during the radioactive particle tracking using the Monte Carlo N-Particle radiation transport code (MCNPX) in the performance calibration procedure.

As a result, numerical calculations using MCNPX was conducted and a distance-count calibration map for 10 scintillation detectors with better accuracy was satisfactory obtained. With the aid of calibration data and actual tracking data, reconstruction algorithm is applied during the reconstruction process to identify and rebuild instantaneous positions of radioactive tracer. As a consequence, the constructed tracer particle histories (calibration data map) are used for tracking the real position during tracking experiment where the naturally buoyant radioactive tracer particle is left inside the investigated column at selected time interval.

Acknowledgments
The authors gratefully acknowledge the collaboration between Prof. Volodymyr Mosorov from Computer Engineering Department, Technical University of Lodz, Poland and Malaysian Nuclear Agency researchers for his new development on particle reconstruction algorithm for radioactive particle tracking technique.

The efficiency and spatial characterization of an Underwater Gamma-Ray Detection System (DUGS) for aquatic sediment

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Keywords: efficiency, spatial, characterization, gamma-ray, underwater, sedimentation

Sedimentation can cause numerous problems in rivers, estuaries, harbors, and coastal areas. It is therefore important to trace and model the movement of sediments. The radioactive fingerprint of the sediment can be used for this purpose since it contains naturally occurring radionuclides, thorium, uranium, and potassium, which can be measured through gamma-ray spectroscopy. To this aim, a delta underwater gamma-ray system (DUGS) was developed to map the radionuclides of aquatic sediments. Though the system has been tested for radiometric accuracy by in-situ measurements in Saldanha harbor and the Berg River Estuary in South Africa, the sediments were characterized by low concentrations. Additionally, their gamma radiation was attenuated by the water and the detector enclosure. This necessitated an evaluation to determine the detection efficiency of the system and extract the efficiency coefficient**.** The survey speed and accumulation time of the system were also determined experimentally. Surprisingly, an exponential decrease with an increase in distance was found for all energy peaks, implying a constant detection efficiency for all radionuclides in aquatic sediment. In 4π geometry, the radiometric sphere of the detector was measured to have a radius of 30 cm. The optimal speed for measurements using the DUGS was determined to be 1 ms^{-1}, with an optimal accumulation time of 5 s, which yields a spatial resolution of 5 m.

International Standardization of Basic Industrial Radiotracer and Radiation Applications – Current State

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Keywords: international standards, ISO, radioactive tracers, radiometric methods

The International Atomic Energy Agency (IAEA) in cooperation with the International Society for Tracer and Radiation Applications (ISTRA) promotes the international standardization of basic industrial radiotracer and radiation applications. On behalf of IAEA and ISTRA experts from many countries employed in leading research centers and renowned industrial companies analyze existing international standards regarding the necessity of their update or amendment as well as the need for new standards in this field.

In June 2020, a new international standard on "Non-destructive testing - Gamma ray scanning method on process columns" was published as ISO 23159. About three years before, the experts detected the need to standardize this method, which is widely used in petrochemical and chemical plants to identify and locate the cause of malfunction inside various process columns.

In the field of flow rate measurements of fluids in conduits using radioactive tracers, a proposal for a new international standard was prepared in 2021. It united several old international standards in this technical field: measurement of water flow in closed conduits (ISO 2975), measurement of gas flow in conduits (ISO 4053) and measurement of liquid flow in open channels (ISO 9555). The new international standard with the title "Measurement of Fluid Flow Rate in Closed Conduits – Radioactive Tracer Methods" has now the state of a Draft International Standard (DIS) and will be published as ISO 24460 in this year.

Furthermore, two other international standards using radioactive tracer methods are under development. One of them is on leak testing in pressured vessels and underground pipelines, another one is on determination of concentration or density of suspended and deposited sediment in water bodies by radiometric methods. Both has already passed the New Work Item Proposal (NWIP) stage. The first one is being edited in ISO Technical Committee 135, Sub Committee 6, Working Group 1 (ISO TC 135/SC 6/WG 1), has the stage of a Committee Draft (CD) now and will be published as ISO 6640 in the middle of next year. The second one is being edited in ISO TC 113/SC 6/WG 5, has still the stage of a Working Draft (WD) and will be published as ISO 6366 also next year.

ISO standards are part of accreditation of radiotracer and radiation applications groups, facilitating the promotion and implementation of these competitive technologies in national, regional and international scale.

Radiotracer-loaded nanoparticles as oil detectives

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Keywords: radiotracers, nanoparticles, oil reservoirs, soil, NAPLS, organic saturations

Residual or remaining concentration of oil in oil reservoirs or naturally occurring petroleum liquids, NAPLS, (read: organic contaminants) in soil may be measured by two tracer-based methods, - one being well-to-well and the other single-well push-and-pull tracer operations. The first method requires the presence of two or more wells and extended experimental time (months). The second method is faster (days) and one well is in principle sufficient.

The prevailing experimental method for single-well push-and-pull operation is based on injection of a reacting, most often hydrolyzing, and oil/water partitioning chemical compound (ester). After a slug injection as an expanding doughnut around the well, the well is shut in for several days until around 50 % of the tracer compound has hydrolyzed and produced a pure water tracer as one of the hydrolysis products. Back-production is then started. The pure water tracer moves fast and the remaining ester moves slower towards the well. The difference in appearance time is a relative measure of the oil saturation present in the probed volume around the well.

This is an aging technology and encumbered with a number of possible sources of error in addition to relatively high operational costs. New on-going developments aim at preventing or reducing the most important sources of error in addition to being much faster, i.e. no well shut-in time is required.

The principle is as follows: Radiotracers, i.e. radiolabeled pure water tracers and radiolabeled water/oil partitioning tracers, may be enclosed together in nanoparticles [1] which can be of different kinds like dendrimers, polymeric nanogels [2], porous silica and more. The nanoparticle operates as a transportation vehicle for the two tracer types when injected into the reservoir around a well. The particles are surface functionalized to ensure a slower transport than water (water/oil partitioning or reversibly sorbing to rock). The bank of nanoparticles is chased by an engineered liquid, which acts as a tracer release trigger and with a faster transport than the nanoparticles. The trigger mechanism may be pH, ion strength or temperature. When the triggering liquid overruns the bank of particles, there is an instant release of the radiotracers. Back-production can start immediately with the two tracer categories starting at the same starting line. Again, the difference in transportation rate is proportional to the oil saturation in the probed volume, and important saving of time and cost is the goal.

The present talk will describe the principle of the method and the advantages compared with presently prevailing experimental field methods.

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Terminological and methodological discrepancies concerning the radionuclides' effective, environmental and biological half-lives

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Keywords: effective half-life, environmental half-life, ecological half-life, biological half-life

At the basis of most risk assessments aimed at determining the long-term trends in changes in the activity of radionuclides in the environment and thus exposure to ionizing radiation, various concepts of half-lives are used, particularly: biological, environmental (ecological) and effective one. There is a clear lack of consensus on the terminological level and, more importantly, on the methodological level regarding the determination of these half-lives. This manifests by a divergent methodology and the existence of two main, but contradictory concepts. In the first, empirically determined half-life is referred to as environmental or biological. The effective half-life is extrapolated at a later stage after taking into account the physical decay. In the second concept, the effective half-life is the one empirically determined and the remaining half-lives can be extrapolated after correction for physical decay. As both concepts seems to be incompatible with each other, the aim of this work was to thoroughly analyze their theoretical assumptions, conditions, strengths and weaknesses and to define the conditions that must be met in order to enable comparison of the results obtained with the use of two separate concepts. In case of the environmental components the suggested approach is to empirically determine the effective half-life, and subsequently, to extrapolate the environmental and/or biological half-lives [Fig. 1].

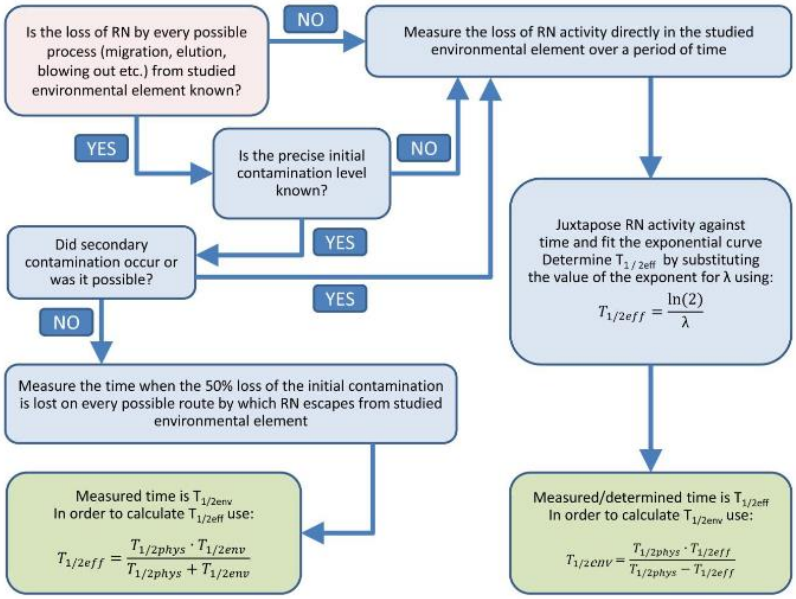

***Figure 1**. Suggested procedure for $T_{1/2eff}$ and $T_{1/2env}$ estimation in case of an environmental element (including biota)*

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Residence Time Distribution formulation and applications using radioactive tracers

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Keywords: Residence time distribution, radioactive tracers, process troubleshooting and modelling

The residence time distribution (RTD) is a probability distribution function that describes the distribution of time that a fluid element could spend inside a system. The RTD of the fluid in processing vessel determines its performance. The RTD has been employing for the analysis of any kind of processing vessels and reactors; the RTD provides parameters for their troubleshooting, diagnosing and modelling. Since its introduction into chemical engineering by Danckwerts in 1953 the concept of residence time distribution (RTD) has become an important tool for the analysis of industrial units. In spite of this "old age" RTD is still subject of many publications in national and international journals concerning its formulation and applications. RTD provides parameters for:

- Troubleshooting
- Investigation of flow patterns
- Investigation of design and scale-up of processes
- Development /verification mathematical models

Tracers are mostly used to measure the RTD function in field conditions; the response function to an instantaneous pulse injection of the tracer at the inlet of the system to be investigated is called residence time distribution (RTD). There are many kinds of tracers. Radioactive tracers are the most competitive for online RTD measurement in harsh industrial environments, outside of the vessel while the process is in operation. The main advantages of radioactive tracers compare to conventional tracers are:

- high detection sensitivity for extremely small amounts, that is why, when injected, radioactive tracer does not disturb the dynamics of the system under investigation.
- radioactive tracer emitting gamma radiation can be measured from the outside of a pipe, vessel, tank or pond, without disturbing the process.

Though the RTD method is applicable across a broad industrial spectrum, the petroleum and petrochemical industries, mineral processing and wastewater treatment sectors are identified as the most appropriate target beneficiaries. These industries are widespread internationally and are of considerable economic and environmental importance. RTD method has been extensively used to optimize processes, improve product quality, save energy and reduce pollution. Technical, economic and environmental benefits have been well demonstrated and recognized by the industrial and environmental sectors.

Use of nuclear techniques for optimization of hydrometallurgical processes

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Keywords: ballast water treatment, electron beam

Strategic metals refer to vital minerals used in high-tech, renewable technology, and other rapidly emerging sectors. Mn and Zn are strategic metals for steel, batteries, electronics, chemicals, medicines, and nonferrous alloys industrial sectors. With the constant and fast expansion of such industries in recent years, the need for Mn and Zn metal has expanded substantially. It is critical to extract Mn and Zn metals from ores and secondary sources such as mine tailings to reduce ecological hazards as per the circular economic model. The development and improvement of hydrometallurgical processes integrating current nuclear techniques may be the future of the mining sectors.The objective of the current study was to develop a radiometric method based on radiotracers to optimize the process of metals leaching from Ti ore, Cu mine tailings, and Zn-Pb mine tailings. Energy Dispersive X-ray Fluorescence (XRF), Total X-ray Fluorescence (TXRF), Scanning Electron Microscope (SEM), and Inductively Coupled Plasma-Mass Spectrometer (ICP-Ms) were used to characterize the samples. The study presented a Neutron Activation Analysis (NAA) method for optimizing the extraction of elements to the liquid phase by leaching using a deuterium-tritium neutron generator and gamma spectrometry. The offered methodology based on low radioactivity led to a fast readout of chemical process efficiency that doesn't influence sample composition and can be used for optimizing the industrial metal recovery processes. As proof of qualitative concept, lab-scale Mn leaching from Ti ores, Cu tailings, and Zn-Pb tailings was chosen at different process conditions, measuring delayed gamma-rays of 56Mn with a half-life (T1/2) of 2.6 hours. It was discovered that Mn leaching depends on the sample type, leaching time, temperature, and concentrations of HCl. For online monitoring of leaching processes using a Scintillation detector, ^{65}Zn (T1/2 = 244 days) was chosen to demonstrate the method by using NAA grounded on Maria nuclear research reactor which offered the possibilities of real-time tracking Zn leaching in Ti ore, Cu tailings, and Zn-Pb Tailings. Zn leaching was found to grow with the increase in leaching time where after 300 minutes, 68 % of Zn was leached in Ti ore, 72% in Cu tailings, and 75 % in Zn-Pb tailings. The online neutron activation analysis results for Zn were compared with offline XRF analysis done on the leached samples under different conditions of the time. Though handheld XRF was not ideal for liquid samples due to weak sensitivities, it was able to confirm that the leaching of Zn increased with the increase in leaching time. The study concluded that the kinetics of mineral dissolution generally depends on the leaching time, sample composition, temperature, and HCl concentrations. XRF and NAA were found to be promising for offline and online monitoring of mineral leaching respectively and can therefore be applied in the mining industries.

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The work has been carried out under the Institute of Nuclear Chemistry and Technology's own research in tasks: "Environmental and industrial aspects of radiometric measurements to optimize technological processes" with support of IAEA TC Regional Project RER1023: "Harmonizing Implementation of Radiotracer and Sealed Sources Techniques for Efficient Use of Natural Resources and Environmental Monitoring".

Sewage sludge hygienization using EB and fertilizing properties of irradiated sewage sludge and methane fermentation digestate

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Keywords: sewage sludge, electron beam, irradiation, hygienization, pathogens, fertilizer

Human population over the world is constantly growing what is reflected in increased wastes production including sewage sludges. In Poland annual production of sewage sludge (preliminary sludge and waste activated sludge, municipal and industrial) is around 1000 thousand tons of dry mass, however there is a slight tendency of increase. This brings on a necessity to utilize or dispose sewage sludge especially that landfilling is not allowed by the law anymore. One of the possibility is agricultural use as a fertilizer. Sewage sludges are rich in nutrients but also contain pathogenic microorganisms and intestinal parasites ova. For this reason hygienization process in necessary before dumping sludge on the field [1]. To remove harmful pathogens ionizing radiation can be used.

To test influence of electron Beam (EB) on presence of commonly occurring pathogens e.g. bacteria: *Salmonella spp*., *Clostridium Perfrigens*, *E. Coli* and intestinal heminths ova - ATT (*Ascaris sp., Trichuris sp.* and *Toxocara sp.*) in sewage sludge following samples were irradiated with a dose range of 1-10 kGy: preliminary sludge, post-flotation sludge from aerobic purification process and mixed thickened sludge, all collected from two separate Wastewater Treatment Plants (WWTPs) in central Poland. Experiments showed that 4 kGy irradiation dose is necessary to remove mentioned pathogens in case of first two examined types of sludge while for mixed thickened sludge 5,5 kGy was necessary.

To test usefulness of irradiated sludges as fertilizer following types of samples were used to cultivate cereal: non irradiated waste activated sludge (WAS), WAS irradiated with a dose of 5 kGy, digestate from WAS, digestate from WAS irradiated with a dose of 5kGy, irradiated digestate from WAS (5kGy). Following parameters were measured: number of germinated seed, germination in time, total solids (TS) of a plants, roots and leaves, dry mass (DM) of a plants, roots and leaves, roots and leaves length. The best results were obtained for non-irradiated WAS but for other samples tested values were also significantly better in comparison to reference sample, among digestate samples irradiated digestate gave the lowest values in the test, however still higher than reference culture.

Acknowledgments
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INCT leak detection method for industrial application

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Keywords: leak detection, Kr-85, radioactive, NDT

A method of leak detection using Kr-85 or methyl bromide labeled Br-82 as a radioactive tracer, has been developed in the Laboratory of Diagnostic Methods at the Institute of Nuclear Chemistry and Technology in Warsaw. The radioisotope tracer is delivered into a controlled object which is connected to a pressure-compensating tank and a container with a radioisotope tracer, using a system of tubes. The scintillation probes covered with collimators, positioned on one of the measuring system's tubes in precisely defined locations, enable for the registration of the tracer location in the tube. The detectors were set next to one another, and each pair of detectors spaced 2m apart. The measuring time for the system is set at 1s, and the radiotracer movement is registered (for Kr 85-0,1 or Br -82 1 MBq for each test). Using specialist software, the transit times between two successive detectors are determined and converted to the flow rate parameter Q [dm^3/h]. If the Q is > 0.5 dm^3/h then the leak is considered into the installation. In such a case the method for the precise location of leaks might be used. This work presents methodological concepts and sample experiment outcomes. The technique has been tested in real industrial conditions at facilities for oil refineries and it has been regularly used for many years [1].

Acknowledgments
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Nuclear safety aspects of the decarbonization of energy sector in Poland through the use of nuclear reactors

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Keywords: decarbonization, nuclear reactors, small modular reactors

The Polish power sector is based mainly on combustion of fossil fuel, of which more than 70% is hard coal and lignite. Current climate policy foresees a significant decrease of CO_2 emission to the environment leading to the need for urgent transformation of Polish power industry into a low-carbon emissions sector. To meet this goal, the reduction of the share of the hard and brown coal-based power industry in the total energy mix is crucial. When selecting a decarbonization pathway, it should be considered whether a chosen method is technically feasible and economically viable. A new and very promising direction of decarbonization of power industry is its modernization towards the use of nuclear reactors [1, 2].

The development of the plan for the decarbonization of the domestic commercial power industry through modernization with the use of generations III and IV nuclear reactors is a goal of the ongoing project entitled "Plan of decarbonisation of the national power industry through modernization with the use of nuclear reactors" (DEsire). This plan will contain general criteria for assessing energy generation systems in the context of the feasibility of decarbonization investments. In this aspect nuclear safety related issues of an entire process are crucial for its successful implementation. For this reason an extended analysis of the "coal-to-nuclear" process has been performed in terms of its safety. As a main important areas of the analysis the following have been identified:

- formal requirements and recommendations imposed by international and national organizations on the process of designing and operating nuclear power systems.
- potential nuclear hazards to the personnel of the nuclear reactor unit and local population.
- the applied solutions of the security systems of the reactor itself, the heat cycle of the steam turbine and the auxiliary infrastructure.
- management of spent nuclear fuel and radioactive waste.

As a result of these analyses, key criteria were identified that may be an obstacle to modernization in the locations of currently operating coal-fired units.

Acknowledgments
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System for purifying waters collected on a floating dock using electron accelerator

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Keywords: ballast water treatment, electron beam

The "International Convention for The Control and Management of Ships Ballast Water Ballast Water and Sediments" (BWM Convention) established few years ago by International Maritime Organization has imposed requirements to minimize the transfer of harmful aquatic organisms and pathogens in ships' ballast water. Regulation D-2 restricts concentration of viable microorganisms. The concentration of indicator microbes involves *E. coli*, *Enterococci*, toxicogenic *Vibrio cholerae* is limited to less than 250, 100 and 10 per milliliter, respectively. In the result of these new strict standards ships and shipyards have to use advanced technologies for ballast water treatment (BWT). Currently applied solutions involve hybrid systems combining filtration with UV-irradiation, electrolysis, chemical or ozone treatment. The new approach proposed in this work is application of electron beam irradiation to reduce biological contamination in ballast water. Having such a purification system at floating dock will allow a shipyard to service ships that do not have BWT systems or have failed. Technological line of water treatment will also include systems for removing solid particles, ions and other chemical impurities in order to achieve other benefits. Firstly, it will be possible to use salt water taken from a port canal for technological works on dock, such as washing ships. Secondly, reducing solids content to level required in the integrated environmental permit will allow the treated water to be discharged into port basin. Presented work is a part of the project aimed to construction a complete system for ballast water treatment in the shipyard dock. The obtained results of laboratory tests are a preliminary stage for the implementation of this technology in commercial scale, based on evaluation of ballast water samples from five ships cruising on the lines outside of the Baltic Sea.

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Electron Accelerators for Radiation Processing - What are the Limits

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Sources of ionizing radiation are vital components in radiation technology. The use of electron accelerators as a radiation source, and at times equipped with an X-ray converter, is the major alternative to ^{60}Co-based radiation processing applications. Direct current accelerators, single resonant cavity accelerators, and microwave source-powered linear accelerators have been found to be the most suitable for radiation processing technology. Electron accelerators are of three types: DC type, where a constant beam is extracted; microwave pulsed type where the output beam is repeated at a low frequency (repetition rate); and pulse or continuous wave type, where lower radiofrequency accelerates electrons with each amplitude. All of them - DC, RF and microwave accelerators - have become the work horse of radiation processing and are extensively employed. The main challenge for EB was the limited penetration of electrons in irradiated materials, which hampered the use of this technology for treatment of high density products and whole pallets. The efficiency of electron to X-ray conversion is relatively low and depends on the composition of the target material and the energy of the electron beam. Therefore this technology has been implemented at the industrial scale when high-power accelerators for radiation processing have been developed,

There is a growing need for compact, high-average power electron sources for many applications. However, there has been limited progress in the field, particularly in the area of electron sources integrated with superconducting radio-frequency (SRF) systems. Exploiting recent advances in superconducting, radio-frequency (SRF) cavities and RF power sources as well as innovative solutions for the SRF gun and cathode system. In literature a design concept for a truly compact, SRF, high-average power electron linac source integrating a thermionic cathode system has been presented. Potentially capable of 50 kW average power and continuous-wave operation, this type of accelerator may produce electron beams with energies up to 10 MeV. Another equally innovative design is an accelerator for radiation technology using a superconducting structure accelerating electrons. The acceleration section of this type is characterized by 10^6 times less surface resistance, which translates into negligible power losses and increases the efficiency of the device. At the same time, the higher goodness of the structure means less energy demand for the cooling of the structure, and the power HF it is almost entirely transmitted to the electron beam. But up to now these solutions were not implemented for practical use.

The special limitations are observed in the application of electron accelerators in the environmental applications for which high power & high electrical efficiency, low cost, accelerators are required. Some hope came from the devices using superconducting systems, however their pro - and contras - were not demonstrated on full industrial scale. The fact that they need magnets cooling systems may reduce their predicted energy efficiency. The use of renewable energy sources to supply electricity to run accelerators may improve the situation.

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Chloroquine degradation under electron beam irradiation in simulated wastewater

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Keywords: pollution control, pharmaceutically active compounds, electron beam treatment

Pharmaceutically active compounds pose a substantial threat to the environment and living organisms because of their huge production, consumption, pharmacokinetics, side effects, and contraindications. Industries, health institutions, and domestic sources discharge them as sewage effluents in their intact form or as metabolites [1]. The limitations of conventional wastewater treatment in removing these recalcitrant pollutants instigates the development of robust techniques in the handling of wastewater. Electron beam technology is efficient for non-targeted wastewater treatment [2]. In this study, Chloroquine (CQ) a prominent antimalarial and recently proposed covid 19 drug was degraded by 75 to 100% under electron beam irradiation at doses between 0.5 to 7kGy. The initial concentration of CQ, pH, and dose influenced the degradation efficiency. Though initial concentrations diminished with dose, COD and TOC were not significantly reduced therefore indicating the transformation of CQ into less degradable organic intermediates.

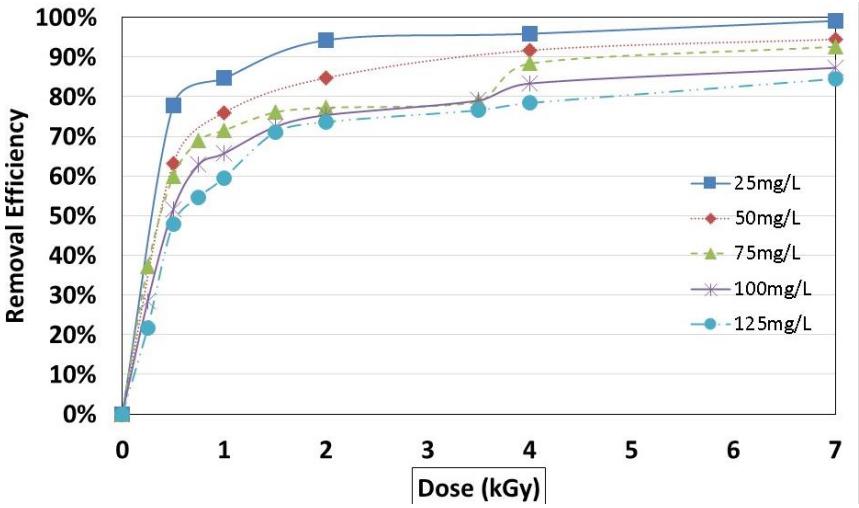

***Figure 1**. Removal efficiency for different concentrations of Chloroquine solution observed at 343nm at electron beam doses ranging from 0 to 7kGy*

Acknowledgments
This work is financed by IAEA CRP project (contract no. 23165/R0), Polish MNiSW statutory task no. III.4, by European I.FAST project (grant Agreement No 101004730) & and co-financed by the program of Minister of Science and Higher Education "PMW" in the years 2021–2025(contract no.5180/H2020/2021/2).

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Degradation of hydroxychloroquine from simulated wastewater under electron beam treatment

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Keywords: pollution control, pharmaceutically active compounds, electron beam treatment

The discharge of unmodified pharmaceutically active compounds and their corresponding metabolites into wastewater and subsequently into the aquatic environment poses significant risk to the environment and living organisms especially since conventional wastewater treatment processes do not adequately remove them or otherwise transfer them from one form to another in sludge, biosolids and manure [1]. Electron beam process is able to initiate reductive and oxidative destruction of contaminants into less harmful forms[2]. Hydroxychloroquine (HCQ) sulfate, a synthetic quinolyl derivative was degraded under E-Beam with >76% removal efficiency at doses between 0.5 to 7kGy. The changes in TOC and COD with increasing dose indicated the formation of other organic compounds not easily susceptible to degradation by electron beam irradiation. The changes in dose, initial concentration, and pH influenced degradation efficiency.

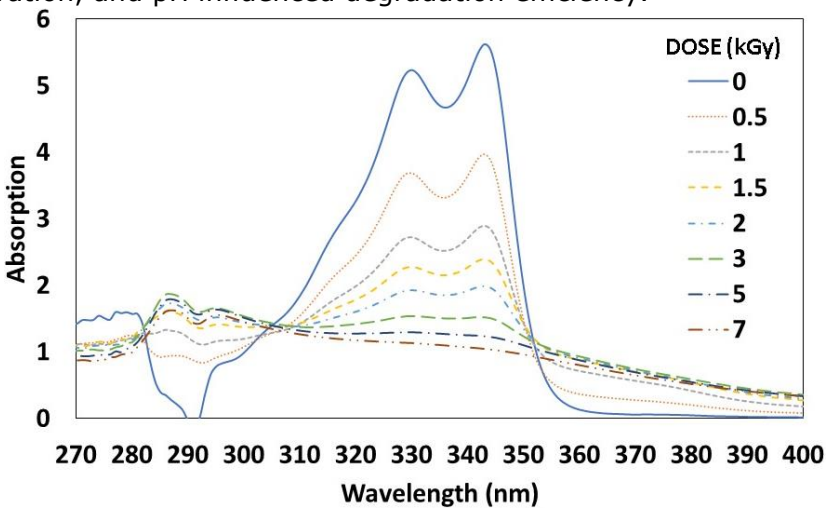

***Figure 1**. Uv-Vis absorption spectrum for 2.8x10^{-4}M hydroxychloroquine sulfate solution observed at 343nm at doses ranging from 0 to 7kGy*

Acknowledgments
This work is financed by IAEA CRP project (contract no. 23165/R0), Polish MNiSW statutory task no. III.4, by European I.FAST project (grant Agreement No 101004730) & and co-financed by the program of Minister of Science and Higher Education "PMW" in the years 2021–2025(contract no.5180/H2020/2021/2).

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Noble metals nanoparticles labeled with Auger electron emitter ^{125}I for hepatocellular carcinoma therapy

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Keywords: nanoparticles, radiopharmaceuticals, Auger emitters

Hepatocellular carcinoma (HCC) is the most common primary liver tumor, accounting for approximately 90% of cases. It accounts for approx. 5.4% of all malignancies. For the treatment of very small neoplastic lesions or small metastases with radiopharmaceuticals, the best results were obtained for radionuclides emitting short-range α radiation or Auger electrons.

In our work, for the treatment of liver cancer, we propose the use of ^{125}I, an efficient Auger electron emitter, attached to small (2-6 nm) nanoparticles (NPs) of Pd, Pt and Au, to which iodine anions have a high affinity. It was found that HepG2 liver cancer cells contain a high concentration of H_2O_2 [1], so we assume that due to oxidation, ^{125}I will be released from the surface of Au, Pt, or Pd nanoparticles and transferred to the cell nucleus near the DNA.

The maximum iodine attachment to nanoparticles has been set at about 200 MBq/mL of nanoparticles ($6.87*10^{13}$ NPs/mL). Labeled nanoparticles were covered with 5000 Da PEG (Polyethylene Glycol) for preventing the agglomeration of NPs and improving the stability of nanoparticles in the solution. The stability of PEGylated nanoparticles labeled with radioactive iodine was checked in biological solutions like a human serum, phosphate buffer, and saline. In all tested solutions bonding between iodine and nanoparticles was stable.

To check the toxicity effect of ^{125}I(MeNPs)@PEG MTS test with HepG2 liver cancer cells was performed. The results were compared with the toxicity of the same activity non-conjugated ^{125}I. The comparison of the results shows that non-conjugated ^{125}I has no toxic effect but for ^{125}I(MeNPs)@PEG toxic effect is high, even for the lower dose of 12.5 MBq/mL. Also, the concentration of radioactive Iodine released from nanoparticles in the cell nucleus was checked. Almost 60% of radioactive Iodine internalized into cells was found in the cell nucleus, which could have a high influence on the toxicity effect of the radioconjugates.

Obtained radioconjugate ^{125}I(MeNPs)@PEG meets the requirements of an effective therapeutic radiopharmaceutical. These requirements include high specific activity, bounds stability, and high toxicity. Short range and high Linear Energy Transfer of Auger electron ensures high efficiency in destroying cancer cells without negatively affecting the surrounding healthy cells. Moreover, metallic nanoparticles covered with PEG can be a base for the production of targeted radiobioconjugates.

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Protective layers of zirconium alloys used for claddings to improve the corrosion resistance – INCT study

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Keywords: corrosion resistance, accident tolerant fuels (ATF), protective layers, SiC, YAG, zirconium alloys

Zirconium and its alloys is used as cladding material for fuel elements in nuclear reactors. In the case of severe accident conditions, the possible very fast oxidation of zirconium at steam or/and air atmosphere may result in intense hydrogen generation and hydrogen-oxide mixture explosion. Advanced cladding technologies for the increasing of claddings' corrosion resistance are investigated in two directions: (i) protective coatings on Zr alloys - as for example: on the base of silicon, multielemental (Zr, Cr, Si), MAX ceramics, FeCrAl alloys, SiC, $MoSi_2$ and (ii) developing of new materials for claddings production - as for example: SiC composites, FeCrAl alloys, ferritic martensitic alloys.

The aim of INCT works was to develop, form and investigate protective coatings on zirconium alloys.

Multielemental Zr-Si-Cr coatings using physical vapour deposition (PVD) method and SiC coating with (SiC+YAG) material using the method of suspension plasma spraying (SPS) were formed. Long term corrosion tests in conditions: 360oC/195 bar/21 days period/water simulating water used in PWR were carried out. Initial, modified and tested materials were characterized with SEM (morphology observations), EDS (elemental composition determination), XRD (phase composition analysis) and weight changes.

Obtained results showed protective character of formed layers in defined experiments parameters range.

Acknowledgments
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Study of the wear of a 155mm gun using Thin Layer Activation Method

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Keywords: radioactive tracers, wear measurement, thin layer activation, gamma spectrometry

The Terrestrial Armamant Establishment of Bourges wished to study the action of various different anti-wear additives in modular powder loads by measuring the wear of a tube of a 155 mm / 42 caliber weapon. Such tube , the biggest of the French army, is used for field artillery in general and actually on the CAESAR system. The tube is equipped with an insert with, in its middle, a fragment of a scratch of the tube. Part of this fragment is activated by a beam of charged particles. Knowing the distribution of activity as a function of depth, it is possible by measuring the remaining radioactivity to quantify the thickness of eroded metal after each series of shots. The insert is an integral part of the weapon tube. It is located shortly after the scratch grip of the tube. The maximum wear expected during these tests being about 350 µm, it was decided to activate the insert to a depth of about 400 µm. The characteristics of the beam used were: proton energy: 15 MeV (14.6 MeV on target), angle of incidence: 0°. The dimensions of the activation spot are 7 mm long and 2 mm wide. The axis of this spot is offset by 0.5 mm from the longitudinal axis of the scratch. This area presents the most homogeneous wear.For this study, the wear measurements were carried out according to two series of tests, for different powders, anti-wear additives, loads and at different temperatures of powder, using both autoradiography and gamma spectrometry. During the first series of tests, the total wear measured was 113 ± 1.1 µm for 59 shots. During the second one, the total wear measured was 131 ± 1.9 µm for 80 shots. This study demonstrated that two test sessions could be carried out with the same insert activated before the first session when the time between the two series was relatively short (a time of one month and a half to two months seems the maximum possible period).The problem discovered by a densitometric reading of the stain (Cf. 8.2) shows that it is essential to take this reading after each test session to ensure the uniformity of the wear and therefore of the more or less reduced validity of measurements. Due to its high sensitivity, TLA allows shortening the tests compared to other wear measurement methods, reducing the number of shots and thus leading to high savings for performing the whole field campaign

Comparison of gamma and e-beam radiation effects on polymer materials commonly used in medical devices

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Keywords: gamma, electron beam, medical devices, polymer

Currently, over 90% of industrial radiation sterilization plants are isotope devices operating based on the radioactive isotope of cobalt ^{60}Co (mostly) or cesium ^{137}Cs (approx. 10%). The drawback of this type of device is the power drop caused by the decay of a radioactive element and the resulting need for periodic replenishment of the isotope. It is a technically difficult and costly operation. Worldwide, there are over 200 gamma installations in 55 countries with a total activity of 220 MCi, and in addition, nearly 60 electron accelerators are used for radiation sterilization. The number of accelerators used for radiation sterilization, increasing every year, includes the result of the intensive development of accelerator technology (high power and high-reliability accelerators) and the fact that their prices are not rising as fast as ^{60}Co prices. Due to the aforementioned advantages of e-beam over gamma radiation for sterilization purposes, a transition to accelerator-based sterilization is observed [1, 2].

The research aimed to determine the influence of the radiation modality (e-beam vs gamma) on the irradiated material properties. The experimental design of the studies takes into account irradiation conditions, namely total dose, dose rate and irradiation environment (normal or oxygen-free).

The TGA measurements gave the thermograms characteristic for each polymer type, but no clear differences can be seen at this stage of the project depending on the dose. The wettability test does not show any pronounced differences between samples irradiated with gamma and electron beams. The most pronounced changes are observed by UV-VIS reflectance spectroscopy and mechanical tests.

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Radiolysis of composite polypropylene/hemp fibers

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Keywords: polypropylene, hemp fibers, composites, degradation, radiolysis

The mechanical properties of natural fibers justify their use as fillers in thermoplastics. Compared to synthetic fibers, they are: renewable, lighter, more readily available, chemically resistant. It is assumed that at the same time "green fillers" will increase the biodegradability of the stored waste mass [1].

The influence of ionizing radiation on the properties of the composite, in which the polymer matrix was polypropylene (PP), and the dispersed phase was hemp fibers, was described. In the radiolysis tests, granulate and compacts formed from it were used with hemp content: 10, 20, 30 and 40% by mass, as well as pure: PP and fibers. The following were used for radiation treatment: a cobalt source of gamma radiation (dose rate: 1.70 kGy/h) and a beam of electrons generated from the Elektronika 10/10 accelerator (dose rate: 14,000 kGy/h). Using gas chromatography (GC), the yields of radiolytically released hydrogen (G_{H_2}) were determined, which are proportional to the number of initially formed macroradicals. A slight protective effect of aromatic lignin (a component of hemp in the amount of 5-10%) was observed on the radiolysis of the composite. Oxygen uptake (G_{O_2}) efficiencies were also determined by GC: during irradiation, 24 hours after irradiation, and during 30 days aging at room temperature. The influence of gamma radiation (dose 25 kGy, air atmosphere) on selected properties of the composite was determined. The following were tested: tensile strength, relative elongation at break, modulus of elasticity, bending strength, bending stress at the conventional deflection arrow, modulus of elasticity during bending, impact strength and mass flow rate. The research work performed showed that radiation treatment of PP/hemp fiber composites accelerates their degradation [2]. It is worth noting that this effect applies to both hemp and PP. Interestingly, PP accelerates the postradiation degradation of hemp. This may be a starting point for further research aimed at developing new types of composite materials that can be designed in such a way that they have a specific "lifetime". The phenomena of postradiation degradation can be controlled both by the content of PP in this case and the amount of aromatic compounds in hemp. In the longer term, it is also worth striving to develop environmentally friendly PP/hemp fiber composites with an accelerated degradation time, and perhaps complete mineralization.

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Synthesis of 103/109 Palladium- Bipyridyl -Bisphosphonate complexes for the treatment of bone metastasis cancer

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Keywords: Auger emitting electron, bisphosphonate, bone

Over the past few years, the Auger emitting isotopes drew more attention in radiopharmaceuticals because Auger electron have short range of energy deposition (nanometer to micrometer range). Auger emitters don't show toxicity when they travel through the bloodstream and they do not damage bone marrow but they are toxic after entering the DNA target. It enables their usage for treating small cancers or metastatic types of cancer. The promising for Auger electron therapy is the application of *in vivo* generators like ^{103}Pd/^{103m}Rh and ^{109}Pd/^{109}Ag. The aim of this study was to synthesize and characterize the complex of ^{109}Pd/^{103}Pd with bisphosphonates for bone therapy. By mixing palladium chloride with bipyridyl and alendronate we obtained yellow, water-soluble complex which was studied by use of different methods. FTIR spectrum confirmed the presence of bisphosphonates, ligands in the complex, and the coordination linkage between palladium and bisphosphonates. The mass and structure of the complex were confirmed by mass spectroscopy. HPLC for both radioactive and stable complexes showed a retention time of around 6 min with a water/acetonitrile gradient. UV spectroscopic measurement was carried out and the calibration curve was linear in the range of 5-100µg/ml. To study the sorption percentage of the complex into the bone, an experiment was carried out with Hydroxyapatite (Bone matrix). The cytotoxicity studies of non-radioactive complexes were performed with SKOV-3 & LNCAP cell lines. After 72 hr cytotoxic effects were seen in both cell lines. Studies will continue with radioactive ^{109}Pd and ^{103}Pd isotopes.

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The chemical and radiochemical characterization of phosphogypsum from Poland

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Keywords: radiometric methods, phosphogypsum, radioactive isotopes

This study will present the results of the chemical and radiochemical characterization of phosphogypsum (PG) from a heap in Wizów. Phosphogypsum contains components such as fluorides, phosphates, sulfates, heavy metals, iron, silica, REE and naturally occurring radionuclides in concentrations greater than the natural background [1]. The phosphogypsum stacks containing material that is a by-product of fertilizer production are an environmental issue today [2,3]. The global amount of phosphogypsum produced worldwide is estimated at about 100 - 280 million ton per year [4].

The project "Phosphogypsum Processing to Critical Raw Materials" currently realized at INCT focuses on the use of phosphogypsum from Polish stacks as a material for REEs recovery from it and use the remaining gypsum matrix as an inexpensive material in construction. The analysis of the radioactivity of this material seems necessary. It is known that usually the naturally occurring radionuclides, the 238U decay series daughter isotopes, such as 40K, 226Ra, 210Pb and 210Po are present in phosphogypsum [5]. The methods used for the determination of radioactive isotopes in phosphogypsum samples are using radiometric methods, or directly counting their atoms, i.e., mass spectrometric methods and/or alpha and gamma spectrometry techniques.

Full characterization of materials is also important for the environmental impact assessment that will be done in the next years.

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Control requirements of electron beam for very high dose rate electron beams (FLASH) for radio therapy

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Keywords: FLASH radiotherapy, dosimetry, alanine

In radiotherapy, ionizing radiation is used to target and destroy cancerous cells inside the patient's body. Too little radiation can be ineffective, while too high dose can be harmful. Therefore, a care must be taken when administering a radiation dose. For this reasons dose measurements must be performed with a high precision.

Currently used in traditional radiotherapy dose measurement methods are mostly based on application of ionizing chamber. However, this approach is inappropriate when it comes to a very high dose rates like used in FLASH radiotherapy (FLASH-RT), due to charge collection inefficiency, where ultra-high dose-rates are used, thousands of times higher than that typically used in radiotherapy (40 Gy/s vs. 0.5–5 Gy/min) [1]. In FLASH radiotherapy duration of treatment is assumed to be less than 200 ms and average dose rate bigger than 40 Gy/s. Thus precise beam control and dose measurements is a challenge in terms of accuracy.

In presented work the concept of dual beam characterisation, with external and internal measurement system was proposed for electron accelerator constructed for FLASH-RT at the National Centre for Nuclear Research. As an external dosimetry material polycrystalline L-alanine was proposed, the dosimeter applicable for a wide range of doses and dose rates. According to ASTM/ISO 51607:2013(E) standard the alanine dosimetry system can be used for doses in a range between 1 and 1.5×10^5 Gy and dose rates up to 3×10^{10}Gy/s for pulsed radiation fields [2]. Alanine measured using EPR spectroscopy is a system widely used in radiation processing, which fulfills many of the required properties for clinical applications such as water-equivalent composition, independence of the sensitivity for energy range used in therapy, and high precision. As an internal beam characterisation system the beam current transformer was designed for the constructed electron accelerator.

The purpose of the presented work was to define the response of the internal system and describe it in a function of dose, measured using alanine, for defined set of the beam parameters.

Acknowledgments
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Applications of EPR-alanine dosimetry to dose measurements in FLASH radiotherapy

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Keywords: alanine, dosimetry, calibration, FLASH radiotherapy, oncology

Radiotherapy (RT) is a fundamental component of control and effective cancer treatment, either alone or in combination with surgery or chemotherapy. There are several available radiotherapy techniques (IMRT, SBRT, among others), however the probability of completing eliminating the cancerous tissues is dose dependent, which is limited by the risks of severe radiation-induced side effects [1]. Therefore, a new idea in oncology, known as a FLASH radiation therapy (FLASH-RT) is a promising technique to overcome this limitations. FLASH therapy is incorporating ultra-high dose-rate which is thousands of times higher than that typically used in radiotherapy (40 Gy/s vs. 0.5–5 Gy/min) [1]. Only „flashes" lasting a few microseconds are used for irradiation (hence the name FLASH). Thanks to such a short exposure time, the total dose absorbed by the body remains at a safe level.

The dose delivered to the tumor and its distribution in the tumor area is of critical importance to increase therapy response. Therefore, biological pre-clinical irradiations, as well as the transfer to in vitro trials, requires an accurate and repeatable dosimetry. Currently, polycrystalline L-alanine is the most popular EPR dosimetric material with linear signal-dose dependence in the range of 1-10000 Gy. Alanine/EPR dosimetry fulfills many of the required properties for several clinical applications such as water-equivalent composition, independence of the sensitivity for energy range used in therapy, and high precision. However, to be used for FLASH-RT in biological experiments and for clinical transfer to humans, the reading time needs to be reduced, while preserving a maximum deviation to the reference.

The purpose of the work was to examine and to optimize the dose mesurements of EPR dosimetry in the dose range from 1 to 50 Gy by using a compact and practical EPR dosimetry system. The plan of the work included: (1) establishing the optimal measurement parameters (microwave power, modulation amplitude, sweep time) for irradiated alanine using the EPR MS5000 spectrometer, (2) checking the repeatability of the EPR signal amplitude, (3) determination of calibration curves for alanine in the dose range from 1 to 50 Gy, (4) estimation of the budget of uncertainty.

Acknowledgments
This work was supported under the Wielkopolska Regional Operational Program for 2014-2020.

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Preparation and characterization of radiation-grafted polyimide membranes for gas separation applications

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Keywords: radiation grafting, Matrimid 5228, membrane, gas separation applications

Continuing interest in newly materials with functional and tailor-made surface properties has been observed in recent years. In this class of formulations, polymers are particularly important due to the possibility of introducing a variety of polar and nonpolar groups, and their derivatives, using many different methods, such as plasma, photo and radiation-induced grafting. Functional copolymers obtained by the modification of existing polymer matrices have a variety of biomedical, environmental and industrial applications [1]. For many decades, radiation-induced grafting has been an attractive way of functionalization of polymeric materials.

In this study, polyimdes: Matrimid 5218/PEG 200 (0–10 wt.%) flat sheet blend membranes were prepared via a film-casting method and Kapton HN were modified by radiation-induced grafting of acylamide. Then, obtained membranes were applied for the separation of CO_2 from a mixture of CO_2/CH_4. PEG was chosen as the low molecular weight polymer to blend with Matrimid 5218 due to its strong affinity for CO2 molecules and considerable acid gas solubility. The analysis of radiation induced paramagnetic species in tested materials was performed by EPR spectroscopy in order to evaluate the ability of polymers to form covalent bonds with monomer molecules. In order to optimize the process, selection of grafting conditions such as the concentration of monomer, the type of solvent, temperature and radiation exposure were studied. Two grafting methods: mutual and pre-irradiation techniques were used. After modification, the effect of PEG content as a CO_2-philic polymer on the morphology and gas separation properties of the membranes were investigated by the following surface characterization techniques: ATR-FTIR spectroscopy, thermogravimetry (TGA) and scanning electron microscopy (SEM). The wettability of polymer surfaces was evaluated by contact angle (CA) measurements.

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Development of control requirements for the process of low energy electron beam food irradiation

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Keywords: low energy electron beam, food irradiation, dosimetry

Food irradiation is a process of exposing food to ionizing radiation, for which the highly penetrating ionizing radiation sources have been used so far. The recent development of the food irradiation process is related to the use of low energy electron beams (LEEB). The advantage of such a solution is that low energy electrons do not penetrate the whole volume of food products thus interacting less with food components. The aim of LEEB food irradiation is microbial decontamination, assuming that microorganisms are localized on the surface or a sub-surface layer of food which electrons can reach.

In order to ensure that microorganisms are effectively inactivated in food products it is necessary to determine the dose on the surface and in depth of product. Either delivering a too low dose of radiation or too low energy of electrons may result in an insufficient reduction of microbial load in treated food [1].

During routine product processing, demonstration needs to be given that the irradiation process has been under control. It requires attention to all process parameters that can affect absorbed dose and the use of dosimetry measurements.

The scope of presented study was to determine parameters of LEEB food irradiation process and dose measurements procedures.

In the presented study, the two dosimetry systems were used to characterize the LEEB food irradiation process and provide information essential for ensuring repeatable irradiation conditions: B3 dosimetry films with RISOScan software and AerEDE/EPR alanine system. Also RayExpert (TRAD-France) software was used to simulate experimental conditions.

The examples of determined parameters are shown for peppercorn irradiation depending on the size of the batch and irradiation conditions (dose rate applied or energy of EB). Irradiation of peppercorn was performed at INCT facility using ILU-6 accelerator generating beam of electrons having energy of 300 keV. The uniformity of the dose on the surface was ensured by samples rotation during irradiation, and was characterized by B3 films and indirectly with alanine pellets mixed together with the product and submitted to same process.

It was finally shown that alanine dosimetry, can be implemented to monitor the routine process and demonstrate its conformity according to pre-defined and product dependent tolerance intervals.

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Application of electron beam irradiation for the preservation of old prints

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The application of electron beam (EB) accelerators for the disinfection of cultural heritage (CH) objects is still a new approach. This is caused mainly by some limitations of EB technology in the treatment of CH objects. However, careful selection of the objects and appropriate application of the EB irradiation allows performing disinfection of CH artifacts with EB successfully. To apply EB irradiation to CH objects we need to take into account the size of the object and the density of the material the CH object is composed of. The size of the object that may be treated is limited by the width of the conveyor (~ 0.5 m). The higher density of the object material we have the lower penetration of the electrons in the object. Therefore, thin objects or objects made of low-density materials are the most suitable for EB treatment. Additionally, proper packaging of CH objects is also a very important issue. Moreover, accelerators with higher beam energy (10 MeV) are recommended in this application to provide sufficient penetration of the electrons in the material.

The scope of the paper is to investigate the influence of electron beam irradiation used for the microbiological decontamination process on old prints. In the first step, modern handmade paper is being studied as the model material. The paper samples were irradiated in a wide range of irradiation doses with a 10 MeV electron beam accelerator. Simultaneously, dosimetric analysis necessary for the proper realization of the process (dose control with calorimetric analysis, determination of electrons energy, determination of dose distribution in the material) was carried out. Selected mechanical (tensile and tear tests) and physical properties like pH, color changes, etc. of unirradiated and irradiated paper samples were characterized. Moreover, different analytical methods such as Scanning Electron Microscopy (SEM), Energy-dispersive X-ray Spectroscopy (EDS), and Electron Paramagnetic Resonance (EPR) were applied to collect information on paper morphology and composition as well as radicals created in the material upon irradiation process. All tests were performed according to the ISO and TAPPI standards.

Applied methods provided information on the influence of different irradiation doses on the handmade paper which is crucial for the selection of the appropriate dose applied for the paper-based object disinfection.

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Recycling of cross-linked material from cable industry by ionizing radiation

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Keywords: recycling, EPDM, EVA, electron beam

Management of solid waste is an increasing problem in continuous economic growth and development. Due to the ability of the ionizing radiation to alter the structure and properties of bulk polymeric materials and the fact that it is applicable to essentially all polymer types, irradiation holds promise for impacting the polymer waste problem. Of special interest is the issue of cross-linked materials recycling [1]. Since radiation cross-linked cables are characterized by improved properties in comparison to those traditionally produced, it can be expected that the production of radiation-crosslinked cables will increase. This will generate larger amounts of polymer waste. Cable recycling involves only the extraction of copper, while the polymer insulation is landfilled or incinerated. Therefore, there is a need to develop technologies for the reuse of this waste.

This work aimed to define the possible outcomes of radiation processing to cross-link new materials containing cross-linked recyclate from the cable industry as a filler. A market analysis was carried out in terms of the selection of appropriate polymers for use in the crosslinked cable industry. Two polymers were selected from among those that are routinely used for the production of cables: ethylene-vinyl acetate (EVA) and ethylene propylene diene terpolymer (EPDM). Blends containing 5, 25 and 50% simulated recycled material were prepared. The samples were exposed to high-energy electron beams produced in the Electronika 10/10 accelerator.

The addition of even 25% of the simulated recycled (EVA) material does not cause significant changes in the value of the stress at break, while a significant decrease in elongation at break is observed. Irradiation with a dose of 160 kGy causes a significant increase in the stress at break of all samples to almost 10 MPa (regardless of the amount of simulated recycled material contained). The EPDM samples containing 5% of recyclate, after irradiation with 120 kGy, are characterized by higher stress at break, than the sample without recyclate and comparable values of elongation at break and Young's modulus. No significant changes in thermal properties were observed for the samples with different contents of recycled material, before and after compatibilization.

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Detection by thermoluminescence method of irradiation with low doses of dried fruits

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Keywords: thermoluminescence method, dried fruits, low doses

The aim of the study was to investigate the effect of the use of low doses of ionizing radiation, recently used in the food industry as an additional preservative in the combined thermal-radiation method, on the detectability of irradiation of dried fruit using the thermoluminescence method.

Dried fruits are a market product for home use and are used industrially as active ingredients of herbal pharmaceuticals, mainly dietary supplements, as well as teas and herbal infusions. Market research shows that the number of recipients of these products is constantly growing. Dried fruits, apart from spices and herbs, belong to the group of products that are relatively often treated with ionizing radiation for preservation purposes. Dietary supplements and medicines produced from dried fruits, must meet the requirement of low level of microbiological contamination and undergoes disinfection presumably with the use of ionizing radiation as well, in accordance with standard and European directives [1, 2, 3].

The subject of the study was 11 selected types of dried fruits used in the pharmaceutical industry for the production of phyto-preparations, mainly dietary supplements. The following fruits were investigated: dried strawberry, dried cherry, dried blackcurrant, dried raisins of two kinds, dried mulberry, dried cranberry, dried apricot, dried fig, dried dates and dried plum.

Dried fruits were irradiated with irradiation doses of 0.1 kGy, 0.3 kGy and 0.5 kGy. The irradiation was carried out with the Co-60 gamma source - Gamma Chamber 5000.

The TL study was to on EN-1788 European standard [4] for the detection of radiation treatment of irradiated food from which silicate minerals can be isolated.

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Optimization of eb irradiation parameters for functionalization of food packaging films

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Keywords: electron beam, dosimetry

Ionizing radiation may modify the physical, chemical and biological properties of materials. Materials modification using electron beam is the most developed industrial application of electron accelerators, with the most often used radiation induced crosslinking. The machines used in industry can be characterized by different process parameters, the energy of electrons and the power of the beam, depending on the purpose of the process and the type of treated materials.

The application of ionizing radiation for food packaging is usually used for its sterilization or functionalization. As most often food packaging are made of polymers such as: PE, PVC, PET or PS but also more recently biobased and biodegradable plastics such as PLA, the irradiation conditions must be selected to ensure achievement of the expected effect not influencing negatively properties of the treated material.

In the presented study, the parameters of the electron beam were optimized for the process of functionalization of food packing films in order to create a reactive surface for bioactive compound binding. In performed experiments, the foils were irradiated using electron beam of energy ranging from 0.2 to 1,7 MeV generated using accelerator ILU 6 and of energy 10 MeV using accelerator Elektronika at INCT. Such parameters of the beam were controlled as the energy of electrons and the depth dose curve, dose rate, temperature, and atmosphere. The dosimetric system used in this study were film dosimeters, CTA and B3 with RisoScan software, and alanine pellets with EPR MS500 spectrometer.

The dose rate, the parameters important for the processes for which the stability of radicals depends on time, was controlled to ensure the highest reactive species generation for graft functionalization of film surfaces. The energy of the beam can be modified influencing penetration of the electron, and for radiation sensitive materials can be limited to surface and subsurface layers.

The optimal parameters of electron beam were determined using EPR spectroscopy based on the stability of received radical species detected for tested samples and achieved grafting yield.

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Thin layer activation technology for wear measurement and visualization of the tracer distribution

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Keywords: thin layer activation, charged particle irradiation, wear measurement, radioactive tracer, positron emission tomography(PET)

The application of radioactive isotopes as tracers to follow industrial, medical, biological and agricultural processes is common nowadays. Its special area is the Thin Layer Activation (TLA), in which the tracer radioisotope is produced from the basic material itself by charged particle or neutron activation thorough nuclear reaction [1,2]. The part to be investigated are of very wide range in size. The tracer radio-isotopes, should be placed at the critical points from the point of view of wear, corrosion or erosion. In this case the position and the depth distribution of the activity is very critical, in order to couple the change in activity with the word (corroded or eroded) amount of material, so the gamma spectrometry sometimes is not enough. For these cases the positron emission tomography (PET) was applied by using the home designed mini-PET (see Fig. 1).

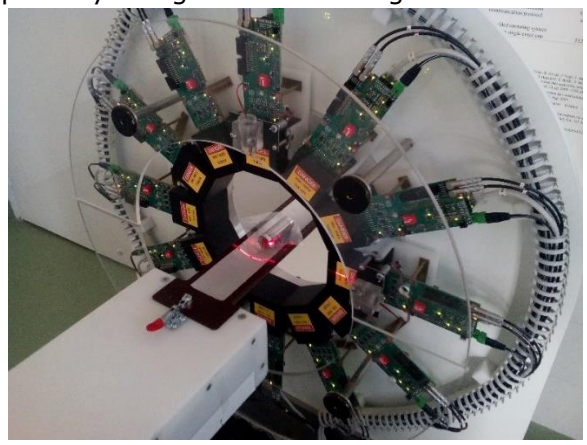

***Figure 1**. ATOMKI Mini-PET with the irradiated machine part*

The easiest case, when the desired radiotracer is positron emitter, which is the case of ^{56}Co produced from iron by proton irradiation. The other possibility to investigate iron containing material is the production of ^{57}Co by deuteron activation, but unfortunately the ^{57}Co is not positron emitter. In this case the co-produced short-lived/high activity ^{55}Co or the ^{58}Co can be used for PET imaging, where the depth distribution is different from that of ^{57}Co, but the lateral distribution is the same.

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Synthesis of gold nanoparticles labeled with Auger electron emitters: ^{197}Hg/^{197m}Hg as potential therapeutic radiopharmaceuticals

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Keywords: mercury radionuclides, gold nanoparticles, Auger electron emitters, radiopharmaceuticals, cancer therapy

The occurrence of cancers that affect women, such as ovarian and breast cancer, is a significant health concern, with 1 in 78 women being diagnosed with ovarian cancer and 1 in 8 women being diagnosed with breast cancer during their lifetime.
Auger-emitting radionuclides possess significant potential for cancer therapy, primarily attributed to their exceptional cytotoxicity and localized biological effectiveness over short ranges. Auger electrons are characterized by the smallest range in tissue (up to 10 μm). They deposit their energy at short distances with a high LET (4 to 26 keV/μm), thereby reducing the cancer cell's ability to repair DNA damage by causing double-strand breaks.
Our research focuses on synthesizing mercury conjugate for use in the brachytherapy of breast and ovarian cancers.

Mercury radionuclides, ^{197}Hg and ^{197m}Hg, exhibit exceptional efficacy and are highly suitable for implementation in Auger electron therapy.To achieve stable binding and high specific activity of synthesized compounds, we propose the use of gold nanoparticles (AuNPs) as carriers for $^{197/197m}$Hg. ^{197}Hg and ^{197m}Hg radionuclides were produced using two routes: in the cyclotron of the Duke University (Durham, NC, USA) through ^{197}Au(d,2n)$^{197/197m}$Hg reaction, and in Maria nuclear reactor (NCBJ, Poland) through thermal neutron irradiation ^{196}Hg(n,γ)$^{197/197m}$Hg.

The specific activities obtained in both production methods were calculated, and the methods were compared. The produced radionuclides were successfully attached to 5 nm AuNP nanoparticles and amalgamated on their surface (Au_3Hg). We conducted studies to evaluate the relationship between time, mercury mass, and labeling efficiency. Our findings indicated that the labeling process exhibited the highest efficiency after one hour, with a maximum mercury mass of 10 μg.

In the final step, the Au(Hg)NPs were coated with polyethylene glycol (PEG) - 5000 g/mol (1:95 AuNPs: PEG) to increase their stability. To evaluate the therapeutic potential of this radiobioconjugate, we conducted *in vitro* studies to assess its stability, internalization, and cytotoxicity on SKOV-3 and MDA-MB-231 cell lines.

Acknowledgments
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Chemical elements in air particulate matter samples from Krakow – determination from low atomic number using energy dispersive X-ray fluorescence spectrometer

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Keywords: EDXRF, PM2.5, PM10

Nowadays the composition of air pollutants is frequently discussed topic of scientific research. Sources of pollution can be identified based on the chemical composition of air pollution.

During this presentation, we will show methods and results for research of chemical elements composition of air pollution samples. Sampling of PM2.5 and PM10 aerosol fraction was conducted during one year campaign in 2020/2021.

Chemical elemental composition of air particulate matter samples was determined by energy dispersive X-ray fluorescence spectrometer at the Faculty of Physics and Applied Computer Science, AGH University of Krakow, Krakow, Poland. The in-house developed and constructed secondary target spectrometer (EDXRF) has been designed for optimal analysis of air particulate matter samples. Selection of appropriate secondary target combined with optimized geometry of the EDXRF spectrometer system enabled extension of the method analytical range towards low-Z elements such as Al, Si, P, S, Cl.

The result shows that the highest concentration for S, Cl, Br and Pb, both for PM2.5 and PM10, were presented in winter. Higher value for concentrations were observed for Fe and Zn in PM10 than in PM2.5, but seasonal changes weren't observed for these elements. During talk we will present potential sources of air pollution which were identified based on chemical composition of pollutions.

Radioiodinated anti-HER2 monoclonal antibodies as potential therapeutic radiopharmaceuticals

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Human epidermal growth factor receptor type 2 (HER2) is overexpressed in various cancers, resulting in aggressive phenotype with poor prognosis. Developed therapeutic monoclonal antibodies (mAbs) targeting HER2-receptor could be useful for Targeted Radionuclide Therapy (TRT). Iodine has a number of radionuclides suitable for SPECT (^{123}I) or PET (^{124}I) imaging and radiotherapy (^{123}I, ^{125}I, ^{131}I).

The aim of this study was to optimize radiolabeling conditions of anti-HER2 mAbs (trastuzumab and pertuzumab) with $^{125/131}$I, determine radiochemical purity of final products, binding affinity, specificity, internalization properties and cytotoxicity evaluation. MAbs were radiolabeled with $^{125/131}$I *via* Iodogen and purified on SEC PD-10 columns. Biological properties were evaluated on HER2-positive SKOV-3 and HER2-negative MDA-MB-231 cell lines. Various doses of $^{125/131}$I-mAbs were used to determine the EC_{50} and D_0 values.

Radiolabeling took *ca*. 10 min with yield of 90-99% and radiochemical purity above 98%. The $^{125/131}$I-mAbs retained their high affinity and specificity towards HER2-receptor as confirmed by negligible binding on SKOV-3 cells. They showed also cytotoxic effect, in an HER2-mediated manner, extent of which was mediated by both the added radioactivity and incubation time.

This study shows that $^{125/131}$I-mAbs are promising radioconjugates for TRT, especially the highly internalizing trastuzumab labeled with Auger's electrons emitter ^{125}I.

ISO 19443 The new quality management standard for the nuclear supply chain

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Keywords: quality management system, supply chain, nuclear (safety) culture

Major accidents in the nuclear energy sector can have enormous consequences, which is why the nuclear industry is strictly regulated and the awareness for nuclear safety must be cascaded through the whole supply chain. ISO 19443 [1] is a nuclear-specific quality management standard designed by the nuclear industry to develop a high-level nuclear safety culture, at all levels of the supply chain. It is applicable to all companies and organizations in the nuclear industry supplying products and services with the potential to affect nuclear safety. The aim of ISO 19443 is to achieve a clear understanding of the customer and applicable regulatory requirements in the supply chain, combining best practices with operational excellence.

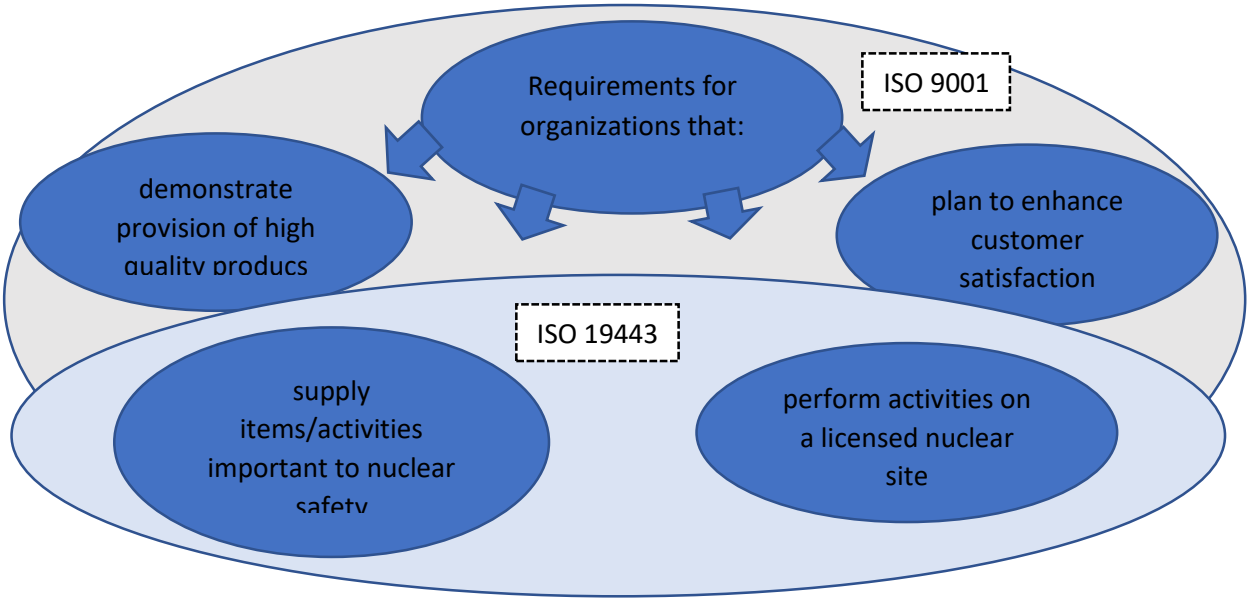

***Figure 1**. Scope of ISO 19443*

This work provides insights into the new standard ISO 19443, which is based on the well-known quality management standard ISO 9001 and has been tailored for use by the nuclear supply chain.

Acknowledgments
I would like to show my gratitude to my colleague Dr. Clemens Treier, Senior Expert Human Factors, for sharing his knowledge with me and looking over this presentation.

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Luminescent on-line dosimetry at an industrial electron accelerator

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Keywords: radiation technologies, electron accelerator, dosimetry, cathodoluminescence

Quality control in industrial product processing at an electron accelerator requires continuous monitoring of critical parameters of the irradiation regime, first of all, of absorbed dose. In the report, a method of contact-free on-line measuring the surface distribution of the absorbed dose in a processed object is described. The novel technique is based on the use of optical radiation induced in the object with an electron beam (cathodoluminescence, CL).

The mechanism of CL in amorphous dielectrics, to which the technical materials commonly used in radiation technologies belong to (packaging carton, polymers, etc.), is studied.

The optical scheme and equipment for the CL registration at an industrial electron linac (10 MeV, 10 kW) are described. The kinetics of the CL signal generated with the electron beam of microsecond pulse duration is investigated. It is shown, that the intensity of CL is proportional to the absorbed dose rate.

Calibration coefficients for the dependence of the CL yield against the absorbed dose in the industrial dose range have been obtained. The possibility of controlling the CL output by selecting the material of the CL radiator, as well as its thickness, is shown. A version of a multiuse radiator with high radiation resistance (up to $4 \cdot 10^6$ Gy) is presented.

In contrast to the known methods of luminescent dosimetry based on thermo- or optically stimulated luminescence, the novel technique does not require a special material for detector, as well as its off-line extra stimulation to read out the dosimetry information.

Study of the Diffusion Neutron Flux Using Monte-Carlo Method

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Keywords: diffusion, neutron flux, Monte Carlo method, angular spectrum, buildup factor

The attenuation law due to absorption or scattering of the narrow beam of particles is not applicable to the non-collimated diffusion flux. The using of a buildup factor for adjustment this law requires a more deeply theoretical justification [1, 2].

A neutrons diffusion model using the Monte Carlo method is developed, which allows you to determine the characteristics of a scattered neutron flux. During diffusion, the neutron crosses the flat boundary between the scatterer and the absorber, and after that the calculation of the neutron track is completed. Model parameters were optimized.

It has been studied how and which the neutron flux is formed during scattering in the material layer. The following characteristics are defined:

- Distribution in the thickness layer of final scattering before crossing the boundary
- Total number of scatterings during neutron diffusion
- The probability of crossing the border after scattering from a certain distance to boundary
- Angular spectrum of the neutron diffusion flux (see Fiug.1)

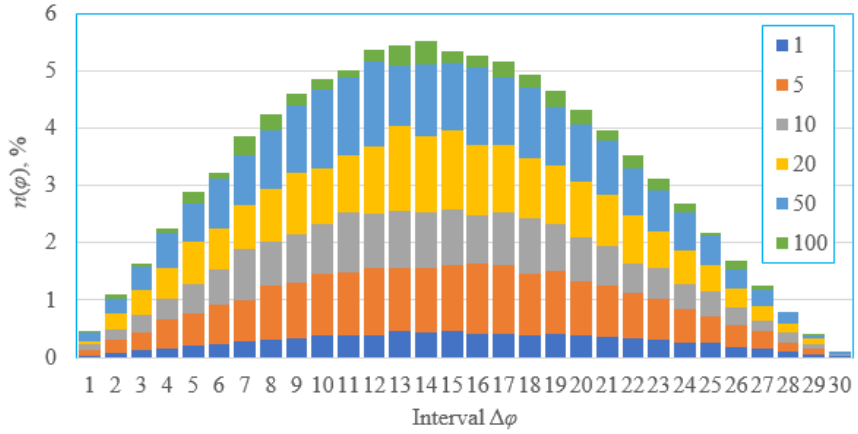

***Figure 1**. Angular spectrum of the diffusion neutron flux through a flat boundary*

The interval of possible values of the boundary crossing angle φ = 0...π/2 is divided into 30 intervals. The evolution of the angular profile is observed as the number of calculated steps along the neutron track k = 1-100 increases. A certain asymmetry of the spectrum is noted due to the features of the flux formation.

The obtained characteristics of the neutron flux are useful to further study the flux attenuation when passing through the absorber layers.

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Effectiveness of radioactive tracer technology in characterising industrial process fluid dynamics

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Keywords: radioactive tracer, wastewater, fluid dynamics, perfect mixers in parallel

Radioactive tracer technology is well known for its effectiveness as online and non-invasive tool for plant health monitoring, troubleshooting and optimization of industrial processes. In this study, radioactive tracer technology method was used to investigate the fluid dynamics in two sedimentation tanks (ST) at the wastewater treatment plant of a textile manufacturing company. The objectives were to: (1) appraise the performance of the STs; (2) ascertain and validate the flow model in the STs. The two tanks were connected in series and the inlet of sedimentation tank 1 (ST1) is made up of two closely placed parallel pipes which discharge wastewater into the tank, and its outlet is of the same pipe configuration as its inlet pipes which discharges the wastewater into sedimentation tank 2 (ST2). The outlet of ST2 is made of only one larger pipe. This design is to ensure gentle flow of the wastewater into the tanks in order to enhance sedimentation of materials to the bottom of the tanks and hence promote the intended function of the STs [1]. The volume of wastewater in ST1 and ST2 as measured at the time of the investigation was 38.88 m^3 and 29.97 m^3 respectively. A steady flow rate of 17.8 m^3/h through the circuit was estimated by transit time method at the time of the investigation and this gave mean residence time of materials in ST1 and ST2 as 2.18 h and 1.68 h respectively. The data was collected by injecting a pulse of technetium-99m of activity 296 MBq at the inlet stream of the tanks and the gamma signals were detected with collimated thallium activated NaI detectors placed at the outlets of the tanks. The data was processed after which Residence Time Distribution (RTD) curves for the outlet tracer concentration were generated and the experimental Mean Residence Time (MRT) was determined by the method of moments [2]. Analysis of the results gave the experimental MRT for ST1 and ST2 as 1.88 h and 1.44 h respectively. Even though industrial process flow equipment are designed on the principle of ideal flow model, these equipment, however, deviate considerably in practice from the assumed ideal flow patterns due to the occurrence of flow anomalies, and do not perform optimally when in operation. Therefore in order to determine the fluid dynamics of materials in the tanks studied, non-ideal flow mathematical models were fitted with the experimental data. Several mathematical models were tried until the best fit was obtained through the method of parameters optimisation using DTS Pro and RTD software [3]. The fluid dynamics of material in ST1 was best described by Perfect Mixers in Parallel (PMP) model and that of ST2 was Perfect Mixers in Series with Exchange (PMSE) model. The model MRTs obtained were 1.61 h and 1.46 h for ST1 and ST2 respectively and this translates into percentage stagnant volume in ST1 as 26.1% and that of ST2 as 13.1%. The implications of the results for the studied STs were discussed and recommendations given.

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^{210}Pb and trace element concentrations in Helsinki urban air, Finland

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Keywords: radioactive tracer, long-term observations, atmospheric pollutants

About ~600 air filter samples collected from the Helsinki metropolitan area from 1962 to 2005 in Finland and analyzed by a high-resolution energy dispersive X-Ray fluorescence spectrometer. The concentrations of trace elements Si, Zn, Pb, as well as the radioactive isotope ^{210}Pb, were determined to evaluate the influence of different pollutants with anthropogenic origin on the atmosphere and environment.

Trace elements and ^{210}Pb concentrations had decreased significantly, especially after 1980 (Si: 87%, Zn: 61%, Pb: 95%, ^{210}Pb: 51%). This coincided with the application of the first regulations for controlling and reducing air pollution in Europe.

The principal natural sources of trace elements are wind-borne soil particles, volcanoes, biogenic sources, wild forest fires and sea salt spray. Si, Zn and Pb are tightly connected with the soil-derived dust and their distribution is favored by dry conditions during the warm season.

Both Pb and ^{210}Pb were studied to understand their sources, dispersion and to identify the effects of anthropogenic activities. Most of Pb in the human environment is of technological origin. Pb extracted from mines having very low ^{210}Pb content. Pb concentrations have decreased since 1970s and are strongly correlated with lead smelters north of Helsinki, on-site incinerators, lead gasoline and fuel combustion.

Seasonal differences can cause significant changes in elemental concentrations, with the highest values occurring in cold season. ^{210}Pb concentrations showed greater fluctuations, with maximum values also appearing in the cold season. In winter, the lower troposphere becomes stratified, allowing air pollutants to stay close to the ground level. For all elements, the greatest reduction in their annual atmospheric concentrations occurred in the spring season (Si: 93%, Zn: 75%, Pb: 96%, ^{210}Pb: 59%).

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Determination of rare earth elements by neutron activation analysis to predict wildfire impact on soil

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Keywords: neutron activation analysis, rare earth element, soil, wildfire, Mediterranean

The study area was in Antalya in the Mediterranean part of Türkiye, where the wildfire continued between June 24-29, 2016. Soil samples were taken from an unburned area and from two different burned areas in 2019 to examine the relationship between rare earth element (REE) La, Ce, Nd, Sm, Eu, Tb and Yb and Sc concentrations. Samples were analyzed by instrumental neutron activation analysis (INAA) at the IBR-2 reactor of Frank Laboratory of Neutron Physics of the Joint Institute for Nuclear Research in Dubna, Russia. The relationship between the elements in soils was investigated using multivariate statistical methods and the enrichment factor (EF) (1). Soils of burned area (north-facing aspect) had higher concentrations of REEs (EF>1) (Figure 1). Pearson correlation coefficients of elements indicated a significant positive correlation ($p<0.001$, $r\geq0.94$) between Sc and REEs in the burned area (north-facing aspect). REE concentrations were higher on north-facing aspects because the ecological restoration impact is better and there is less erosion. As a result, heavy elements such as REEs cannot be transported as easily as they can on a south-facing slope in soil.

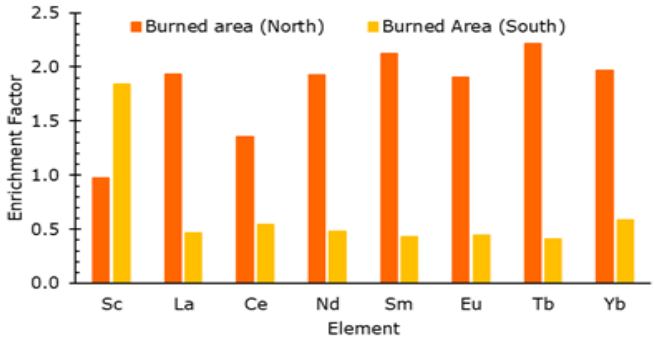

***Figure 1**. Enrichment factors of elements*

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The use of synchrotron X-ray fluorescence microscopy to assess the elemental composition of the brain of rats exposed to the ketogenic diet during prenatal life

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Keywords: synchrotron X-ray fluorescence microscopy, multi-elemental analysis, ketogenic diet, prenatal exposure, animal models

Ketogenic diet (KD) is a high-fat and low-carbohydrate diet that aim is to imitate a beneficial effects of fasting state but without depriving the organism calories demanded to growth and development [1,2]. It has been demonstrated that KD can be successfully used for the treatment of various types of epilepsy [1,3]. Because of the fact, that most anti-seizure drugs are teratogenic [4], such dietary therapy may be the chance to treat pregnant women suffering from seizures. However, the data concerning both short- and long-term effects of the ketogenic diet used during prenatal life on the nervous system development of the offspring are lacking. Therefore, the aim of this study was to evaluate the influence of KD used during rat pregnancy on the elemental changes occurring in the brains of offspring.

The subject of the study were male offspring of mothers fed with the ketogenic or standard diet during gestation. Depending on the experimental group, their brains were taken at 2, 6, 14, 30 and 60 day of postnatal life, deeply frozen in liquid nitrogen, cut using cryomicrotome and placed on Ultralene foil. Topographic and quantitative elemental analysis of the samples were performed using synchrotron radiation-based X-ray fluorescence microscopy. Two-dimensional maps of P, S, K, Ca, Fe, Cu, Zn and Se distribution were obtained and compared with the corresponding microscopic images of the examined tissues in order to identify important areas of the brain, such as white matter, cortex or hippocampal formation for which detailed elemental analysis was performed. The carried study allowed to evaluate how used prenatally KD modifies the progress of elemental changes occurring during postnatal brain development. This, in turn, shed the new light on the safety for offspring of KD treated mothers.

Acknowledgments
This work has been partially supported by the funds granted to the AGH University of Krakow in the frame of the "Excellence Initiative – Research University" project.

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The EURAD project as support for the action program for safe and sustainable management of radioactive waste and spent nuclear fuel in Poland

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Keywords: radioactive waste, radioactive waste repository, Euratom

The extensive nuclear power program in Poland requires a parallel radioactive waste management strategy. It is described in government documents, which include, among others the "National Plan for the Management of Radioactive Waste and Spent Nuclear Fuel". This document, adopted by Resolution No. 195/2015 of the Council of Ministers of October 16, 2015, was updated after public consultations in 2020. The actions provided for in the National Plan will ensure responsible, safe and sustainable management of radioactive waste and spent nuclear fuel, in accordance with Art. 57c of the Atomic Law.

The plan includes e.g.

1. Construction of a new surface repository for radioactive waste;
2. Preparation for the closure of the National Radioactive Waste Repository in Różan and ensuring safe operation of the repository until its closure;
3. Activities related to a deep geological repository of high-level radioactive waste and spent nuclear fuel.

Implementation of such an ambitious plan, combined with an equally ambitious nuclear energy programme, requires wide-ranging activities of all stakeholders, as well as full consent of the society involved in supporting the state's policy. The knowledge gained during realisation of EU framework projects and the EURATOM program as well as extensive international cooperation can help in planning these tasks and in their rapid implementation.

European program established under Horizon 2020, entitled "European Joint Program on Radioactive Waste Management" (EURAD), in which the Institute of Nuclear Chemistry and Technology has been participating for 4 years, is the implementation of the idea of common action for the management of radioactive waste in the Member States, which has been functioning in the European community for a long time.

It has been expressed in documents created as part of various European initiatives and joint projects, such as, for example, JOPRAD ("Joint Programming on Radioactive Waste Disposal"). One of the objectives of EURAD was to prepare the conditions for the establishment of a joint program for the disposal of radioactive waste combining various aspects of R&D activities carried out under national research programmes, in the case of which synergy and benefits from joint programming were found. This program, in addition to key R&D tasks, combines activities related to education and training as well as knowledge management.

The EURAD program is to help Member States implementing the Waste Directive of 9 July 2011 establishing a community framework for the responsible and safe management of spent nuclear fuel and radioactive waste (Directive 2011/70/Euratom).

Acknowledgments
The work was performed within the HORIZON 2020 project EURAD ("European Joint Program on Radioactive Waste Management"), EC Grant agreement no: 847593

Assessment of gender differences in elemental composition of chosen organs by the means of TXRF and ICP-based techniques

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Keywords: total reflection X-ray fluorescence, ICP-MS and ICP-OES, multi-elemental analysis, gender differences, elemental composition of body organs

Although animal models of diseases have been used in biomedical research over last decades, the focus has only recently turned to the need to conduct studies involving animals of both genders. The determination of differences between the genders and the development of drugs specific to them can be a milestone in the development of life sciences and an important direction in the development of personalized or precision medicine.

The analysis of elemental composition of cells, tissues and organs may be the source of important information about the progress of both physiological and pathological processes occurring in the organism [1, 2]. Additionally, the existing literature evidence shows that the elemental balance of tissues may depend on the gender. The studies carried out till now were done mainly on several types of fish, and the knowledge concerning the influence of gender on the elemental composition of mammalian tissues is still very narrow [2, 3]. Therefore, the purpose of this study was to analyse the gender dependent differences in the elemental composition of various rat organs. Our research consisted of two experimental groups – male and female Wistar rats. Groups of 6 animals each were bred in consonance with international standards up to the 60th day of age, when they were put down and brain, heart, kidney, liver and spleen were resected from every rodent for further proceedings. .The tissues were subjected to acid-supported digestion. Obtained solutions were then measured for elemental composition by TXRF method and ICP-MS for main, minor and trace elements in the organs.

The carried statistical evaluations revealed several differences in elemental composition of examined organs between male and female rats. They concerned both low atomic number and heavier elements. Obtained results suggest high importance of incorporating both genders experimental animals in *iv vivo* research for fuller and more in depth information in conducted research on physio- and pathological elemental anomalies occurring in the living organism.

Acknowledgments
This work has been partially supported by the funds granted to the AGH University of Krakow in the frame of the "Excellence Initiative – Research University" project (Action 4: A system of university grants for research carried out with the participation of doctoral students and young scientists, PL-Joanna Chwiej).

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Radiation-induced cross-linking polymerization: recent developments for coating and composite applications

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Keywords: radiation curing, polymerization kinetics, polymer networks, microstructure

The radiation-initiated crosslinking polymerization of multifunctional monomers is a very attractive method for the drying of solvent-free liquid coatings, inks and adhesive as well as for the fabrication of high performance composite materials. The method offers many advantages compared to thermal curing processes. Free radical and cationic polymerization have been investigated in details along the last years. A high degree of control over curing kinetics and material properties can be exerted by adjusting the composition of matrix precursors and/or by acting on process parameters (overall dose, dose rate, dose increment, initial temperature). This will be illustrated through various examples based on acrylate or epoxy monomers in the curable model formulations [1-3].

Several pending issues however require further investigations of basic and/or technological relevance:

- (i) The fast polymerization of multifunctional monomers generates micro-heterogeneous networks requiring detailed characterization and quantification by microscopic, thermo-physic and spectroscopic analyses;
- (ii) The adhesion and surface properties of radiation-cured coatings are quite sensitive to processing parameters;
- (iii) Significant enhancement of the toughness is needed to qualify potential matrices based on simple difunctional monomers for high performance composites.

Recent results show that the bulk and surface properties of radiation-cured materials can be improved by advanced formulation of matrix precursors and by a parametric study on processing factors [3,4]. Microstructural and surface properties of model formulations cured under various conditions will be presented and discussed. The radiation-triggered polymerization-induced phase separation of thermoplastic additives in epoxy matrices appears superior to thermal curing by yielding toughened materials with higher resistance to fracture propagation, K_{IC} value around or exceeding 2 MPa.m$^{1/2}$ [5,6]. This is interpreted in terms of low initial temperature upon incipient polymerization and very fast curing of the reactive blends which both limit the expansion of phase-separated thermoplastic domains, resulting in a favorable morphology for the matrix.

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TXRF study of ketogenic diet influence on the elemental composition of selected rat organs

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Keywords: total reflection X-ray fluorescence, ketogenic diet, elemental composition, rat organs

Ketogenic diet (KD), linked with the change of the main energy source for metabolism from glucose to ketone bodies (acetone, acetoacetic acid, β-hydroxybutyric acid), has been well known for its usefulness in the managing of drug resistant epilepsy as well as Type 2 diabetes [1,2]. Nowadays, it is also more and more frequently used because of its positive influence on the weight loss [1].
The long term treatment with KD may be connected with serious side effects [3]. Therefore, the purpose of the study was analysis of KD influence on the internal rat organs responsible for lipids metabolism (lipids) and organism clearance (kidneys and spleen). Especially, we were focused on the elemental abnormalities that appear in the organs as a result of KD use as well as gender differences in this range. To achieve the goals of the experiment male and female adult rats were fed with KD or standard laboratory diet for 30 days. Afterwards, their organs were subjected to microwave assisted digestion in 65% nitric acid. The concentration of elements (P, S, K, Ca, Fe, Cu, Zn and Se) in the liquid organ samples were then measured using the total reflection X-ray fluorescence method.

The statistical evaluation of the obtained measurement data showed significant differences in the accumulation of elements between ketogenic and standard diet fed animals. The elemental homeostasis was disturbed in all examined organs but the largest number of abnormalities was found for the liver. What is more, sex dependent differences were noticed in case of some of the observed anomalies.

Acknowledgements
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Applicability of electron spin resonance for detection of free radicals in different cellulose containing food samples

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Keywords: irradiated food, EPR (ESR) spectroscopy, detection of irradiated foodstuffs

Food irradiation includes exposure of food to controlled doses of ionizing radiation in order to increase its safety and quality by elimination of harmful microorganisms and reduction or replacement of chemicals. Development of the method leads to introduction of reliable tests capable of detecting radiation induced changes in food. Irradiation causes different changes in food, so different detection methods should be applied.

The aim of our study was to determine the applicability of electron paramagnetic resonance (EPR) / electron spin resonance (ESR) for detection of irradiation of different foodstuffs containing cellulose.

ESR is one of the physical methods which can identify radiation induced specific changes in food. It is based on detection of radicals as paramagnetic centres that may be due to irradiation. An intense external magnetic field is applied to the sample, producing a difference between energy levels of electron spins and leading to resonant absorption of an applied microwave beam in the spectrometer. ESR spectra are displayed as the first derivative of the absorption with respect to the applied magnetic field. The magnetic field and frequency values may be adjusted according to the experimental arrangements, while the g-factor value is an intrinsic characteristic of the paramagnetic centre and its local coordination.

Irradiation of food produces radicals that can be detected in solid and dry parts. Intensity of the produced signal increases with the concentration of paramagnetic compounds, thus the higher the applied dose, the greater their concentration. However, the stability of the ESR signal, which influences detectability of irradiation in food, depends on the time after irradiation and properties of food such as crystallinity of cellulosic component and humidity during irradiation and storage.

A representative number (45) of different plant origin food samples, considered as cellulose containing materials, was chosen for irradiation with 10 kGy in Gamma Chamber. Directly after irradiation samples were put in thin-wall EPR tubes. Measurement were performed on Magnettech Bench Top EPR/ESR Spectrometer, according to the standard EN 1787 Detection of irradiated food containing cellulose – Method by ESR spectroscopy. After the first measurement some samples were rejected from further studies due to their insensitivity to the method. For the selected foodstuffs measurements were done with more portions of each sample, including unirradiated and irradiated portions with doses of 1 kGy, 2 kGy and 5 kGy.

As a result, 45 plant origin food samples were classified in a view of their possibility to be analysed by ESR method according to EN 1787 standard. The classification includes detectability of radiation induced cellulosic ESR signal, it’s dose dependency and ESR signal stability during storage time.

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From TENORM to Superheavy Element Chemistry: Measurement of Alpha Emitters

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The measurement of radionuclides emitting alpha particles has been a tedious and time-consuming work but is necessary in many fields. The classical procedure foresees chemical separation steps followed by electrochemical deposition to prepare a sample to be measured in a vacuum chamber. Preparing a single sample requires many hours of working time for a radiochemical specialist. This method is utilised in many applications of which three will be illustrated.

1. Recovery valuable materials from Technically Enhanced Naturally Occuring Radioactive Materials (TENORM) requires adequate knowledge of the radionuclides present in the materials and chemical procedures for their removal. All steps of processing need to be controlled by suitable measurement techniques also of the alpha emitters. The measurement of large number of samples is a great challenge.
2. Alpha emitters are used more in more in individualized cancer therapies with radiolabeled antitumor agents e.g. antibodies. Before their application to a patients extensive pharmaceutical testing is required to assure the high quality of the radiopharmaceutical. This needs to be done quickly after preparation.
3. Experiments to investigate the chemical properties of superheavy elements, elements with atomic number >103, suffer from difficult side conditions: These elements are synthesized in large accelerator laboratories with low rates of formation ranging from a few atoms per hour to a few atoms per month. Their short half-live frequently prevents preparation if samples are to be measured with silicon detectors in a vacuum chamber. This holds even more when the experiments are not conducted in the gas phase but in aqueous solution. Therefore, such experiments could not be performed since ~ 25 years.

A new technology developed in our laboratory brings solutions to all these problems: coating silicon detectors with an ultrathin layer which can selectively bind an alpha-emitting radio-element provides a solution to all the problems described above.
Sample preparation and separation of the alpha-emitter can be done in a single step.

Perfusion cells have been constructed containing the detectors to bind the radioelement quickly to the detector surface while a solution is passing it. This allows to process short-lived radionuclides as well as a large number of samples when using arrays of these detectors.

The presentation will illustrate the working principle with many examples.

The temperature-dependent luminescence emission of $LiMgPO_4$: Tb,Tm crystals for radiation measurements

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Keywords: thermoluminescence, optically stimulated luminescence, crystal growth, $LiMgPO_4$, temperature dependence, Rare-earth elements

Among the radiation measurement technics, still one of the most popular are those based on luminescence phenomena, like thermo-(TL), optically-(OSL), cathodo-(CL), photo-(PL), luminescence etc.

In this work, the TL and OSL properties of $LiMgPO_4$:Tb,Tm (LMP:Tb,Tm) crystals have been studied. The crystals have been grown from the melt using novel micro-pulling down (μPD) method. The raw materials (in the form of powders) were prepared using up a solid state reaction between: monohydrate lithium hydroxide ($LiOH{\cdot}H_2O$), hexahydrate magnesium nitrate ($Mg(NO_3)_2{\cdot}6H_2O$ and ammonium dihydrogen phosphate ($NH_4H_2PO_4$). Tb_4O_7 and Tm_2O_3 oxides have been utilized for doping the nominally pure powders with Tb^{3+} and Tm^{3+} ions. The TL emission spectra have been also measured.

It was found, that the TL emission of LMP:Tb,Tm crystals is strongly dependent on the temperature. Namely, at lowest temperatures (up to around 290 °C) only the emission of Tm^{3+}ions is visible (no Tb^{3+} ions emission is visible). At higher temperature range (up to around 385 °C) the emission of Tb^{3+} ions starts to be visible with simultaneous decreasing of emission of Tm^{3+} ions emission. At the highest analyzed temperature range (above 400 °C) Tb^{3+} ions emission dominates the measured spectra, while the Tm^{3+} ions emission is practically not visible (see Fig. 1A). The same was also confirmed for cathodoluminescence and radioluminescence emission (see Fig. 1B)

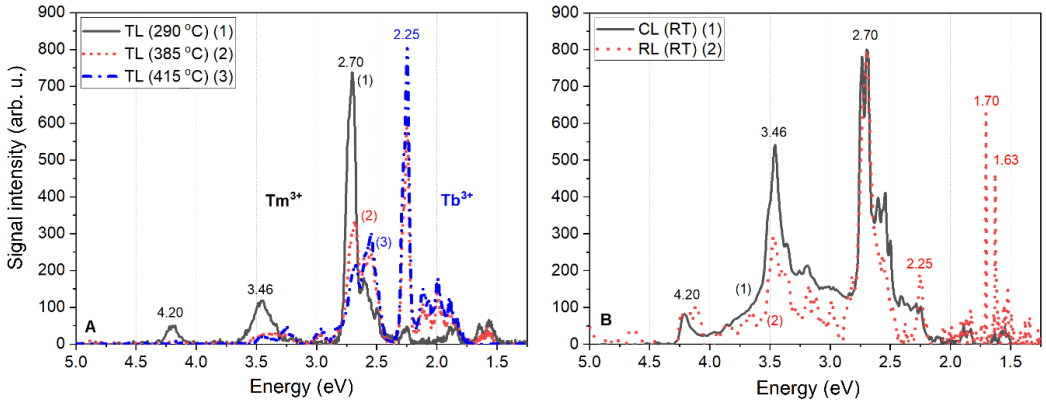

***Figure 1**. The temperature-dependent emission of $LiMgPO_4$:Tb,Tm crystals grown by MPD technique. Thermoluminescence (A), Cathodoluminescence and radioluminescence emissions (B)[1]*

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Comparison of performance of professional and popular dose-rate meters — experiences of a calibration laboratory

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Keywords: dosimetry, calibration, dose-rate meters

Laboratory for Calibration of Dosimetric Instruments at the Institute of Nuclear Physics in Kraków provides accredited calibration services for various radiation survey meters, monitors, and dosimeters since the year 2001. The accreditation scope comprises Cs-137 gamma-radiation, as well as alpha and beta surface emission. During over 20 years of operation, nearly 250 different types of various dosimetric instruments have been processed by the Laboratory.

In recent years we observe an increased number of simple and relatively inexpensive dose-rate meters in use. They show a very varied quality of performance. Most of them are probably intended for private use, rather than for professional application in radiation protection. Nevertheless, they are more and more often used also in this capacity.

This work will be mainly focused on investigating the performance of these popular dosimetric instruments. The analyses will be performed both by exploiting the database of the gathered calibration data and by conducting dedicated tests with the dose-rate meters under study. The results will be compared with those obtained for the more sophisticated, professional instruments.

LiF fluorescent nuclear track detectors appliedto cosmic radiation measurements

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Keywords: fluorescent nuclear track detectors, FNTD, lithium fluoride crystals, cosmic radiation

The fluorescent nuclear track detectors (FNTD) technique is a relatively new method of microscopic imaging of ionizing particle tracks. This new approach based on radiophotoluminescence has been recently applied for lithium fluoride single crystals [1, 2]. It was shown that this technique can be successfully used for measurements of heavy charged particles and neutron doses [3-5].

Those specific features of the LiF FNTDs technique, combined with the fact that such FNTDs are passive detectors resistant to external conditions, make them good candidate for application in cosmic ray measurements. This work will present the first analysis of the fluorescent track images registered during several space experiments performed at the Earth orbit (DOSIS 3D project) and during the recent Artemis I mission– flight to the lunar orbit.

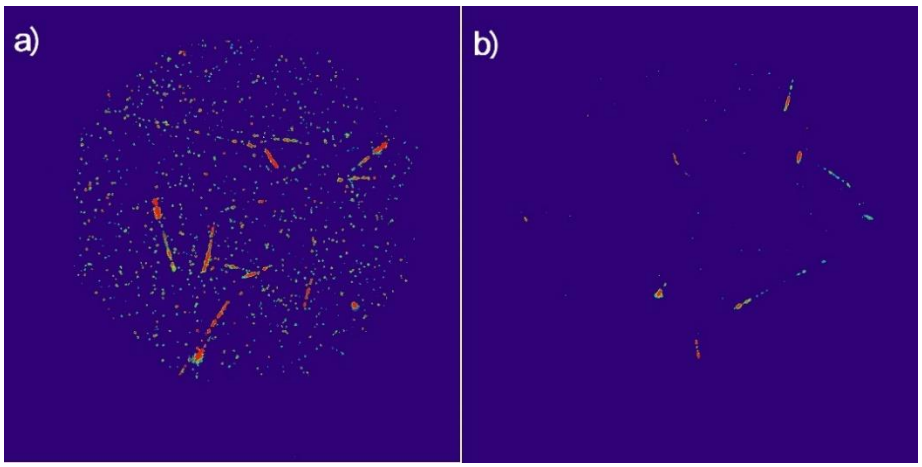

***Figure 1**. Examples of fluorescent track images registered in LiF crystals: a) 6 months exposure on the Earth orbit, b) during 25 days mission Artemis I to the Moon orbit*

Acknowledgments
This work was funded by the National Science Centre, Poland (grant No 2020/39/B/ST9/00459).

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Thermoluminescent dosimetry of cosmic radiation

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Keywords: dosimetry, cosmic radiation, TLD

Thermoluminescent detectors (TLD) have been applied for the dosimetry of cosmic radiation nearly since the beginning of the space age. The first reported application of TLDs in measurements on Earth's orbit is the Mercury-8 mission in 1962, which was the third US manned orbital spaceflight. Nowadays, in spite of the technical progress over the years, TLDs still remain an important tool of space dosimetry.

IFJ PAN participates in space dosimetric experiments for over 20 years, using always self-developed and manufactured TLDs: LiF:Mg,Ti and LiF:Mg,Cu,P [1]. The presentation will provide an overview of the main space-related projects: Matroshka (phantom measurements at the Earth orbit, years 2004-11) [2], DOSIS and DOSIS-3D (dose mapping at the International Space Station, years 2010-2023) [3], and the most recent MARE (phantom measurements during Artemis I flight to the Moon orbit, 2022).

***Figure 1**. Left – astronauts unpacking the Matroshka phantom at the ISS to dismount TLDs; Right – two phantoms with TLDs inside in the Orion spacecraft before the launch of Artemis I*

Acknowledgments
This work was funded by the National Science Centre, Poland (grant No 2020/39/B/ST9/00459).

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An interdisciplinary measuring station using an electron beam

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Department of Nuclear Equipment HITEC (ZdAJ) is a facility of the National Centre for Nuclear Research (NCBJ) dealing with the construction, production, sales and maintenance services of equipment applied in the industrial and medical sectors.

Currently, a station for interdisciplinary research with the use of electrons has been constructed. The stand is flexible - it enables irradiation with the use of electrons with a wide spectrum of energy (4-12 MeV) and power (5 Gy/min to even 350 Gy/s). Field size – 4-10 cm in diameter with beam profile symmetry less than 3% and homogeneity less than 5%. The station is adaptable, i.e. it can be adapted to the required measurements. Currently, it is possible to make measurements in a water phantom, in the air and in a solid phantom made of a material with a composition similar to water (RW3). Dedicated phantoms and holders were also made for alanine measurements and for irradiation of cells in bottles and multi-plate containers. The station can be used not only in the fields of electron field dosimetry (ionization chambers, diode, GAFCHROMIC films etc.), but also in radiochemistry, radiobiology and material research.

Testing and applying optimal modflow codes to study constructed wetlands hydrodynamics

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Keywords: modflow, groundwater, radioactive tracers, interaction

Constructed wetlands (CWs) constitutes an environmentally friendly method being used widely for wastewater treatment. CW are artificially engineered ecosystems and their performance is strongly dependent from the design and manipulation involving a number of multidisciplinary inputs, such as aquatic chemistry, biology, flow hydraulics and engineering hydrology (Fioreze and Mancuso 2019). Recent studies have been focused on the influencing factors such as manipulation configuration, size of porous media and inflow rate (Garcia et al., 2004; Song et al., 2014). Obviously, the simulation of the hydrodynamics of constructed wetlands constitutes a critical process for the conceptualization of the CWs. Radioactive tracer method is very competitive for validation of modelling and simulation, aiming the optimization of CWs.

In literature there are available several codes for the simulation of hydrodynamics of constructed wetlands. We have been determining and evaluating the suitability of several simulation codes for the study of the hydrodynamics of constructed wetlands. The optimal code for the simulation is strongly depended from the geometry, material, water quality and quantity of the constructed wetland.

Within this study selected simulation codes have been tested in theoretical constructed wetlands under different scenarios. The MODFLOW code and the versions of 2005, NWT and USG has been used for the simulation of the hydrodynamics of constructed wetlands. The NWT version is the most promissing for the optimization of the CW. The use of radioactive tracer constitutes a challenging approach to test the efficiency of CW and will be the next step of the simulation process.

On balance, the simulation should be also use data from existing CW which use radioactive tracers in order to verify the theoretical results of the modeling.

Acknowledgments
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Influence of the reader on the reading of thermoluminescent detectors

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Keywords: TLD, thermoluminescent reader, dosimetry

The thermoluminescent detectors (TLD) are commonly used in individual and environmental dosimetry. Among others, TLD based on lithium fluoride are characterized by: high sensitivity, tissue equivalence and the ability to use in various radiation fields. To ensure the reliability of the measurements, proper preparation and reading must be applied.

The main goal of the study was to evaluate the differences in the results (e.g. number of counts, dose) obtained from TLD for different readers (RA'94 and RA'04 produced by Microlab and lexygresearch produced by FREIBERG INSTRUMENTS GMBH). The comparative analysis was carried out in terms of repeatability of the received doses, regardless of the choice of device.

In this study 40 thermoluminescent detectors LiF: Mg, Cu, P type, commercially known as MCP-N (produced by IFJ PAN Krakow), were used. TLD were divided into 5 equinumerous groups. In order to eliminate the dependence on the properties of individual detectors, their individual response factors (IRF) were determined. Calibration curve was performed. The measurements were made in two operating modes: READER and ANALYSER. Ten measurement series were carried out. Each of them consisted of pre-exposure annealing, exposure, post-exposure annealing, and readout in the selected mode. Based on the obtained results (namely: number of counts (READER); area under the peak (ANALYSER-AREA) and the amplitude (ANALYSER-AMPL)), doses were estimated. Average values were calculated for each cycle. To determine the statistical significance of differences between the readers, the non-parametric *U* Mann-Whitney was used.

The obtained results suggest that the RA'04 reader worked stably while RA'94 reader was characterized by a lack of repeatability of readings and a significant underestimation of the dose. In addition, READER mode has been shown to provide the higher accuracy of readings. The obtained average dose values ranged from: 0,9573 ± 0,0068 mGy - 0,9935 ± 0,0071 mGy (RA'04 READER), 0,596 ± 0,018 mGy - 0,874± 0,021 mGy (RA'94 READER), 0,935 ± 0,052 mGy - 0,981 ± 0,055 mGy (RA'04 ANALYSER-AREA), 0,433 ± 0,011 mGy - 0,690 ± 0,031 mGy (RA'94 ANALYSER-AREA), 0,965 ± 0,013 mGy - 0,998 ± 0,0097 mGy (RA'04 ANALYSER- AMPL), 0,5239 ± 0,0063 mGy - 0,791 ± 0,011 mGy, (RA'94 ANALYSER- AMPL). The results were addiotionally compared with readouts provided by lexygresearch.The performed statistical test confirmed the above conclusions and indicated statistically significant differences in the results obtained in individual reading modes on both readers. For each of performed tests, the average dose values were higher for the RA'04 reader. (READER $p<0,01$, ANALYSER (AREA) $p<0,01$, ANALYSER (AMPL) $p<0,01$). Thus, the choice of the reader can have a significant impact on the accuracy of the obtained results.

Double- and triple-coincidence positron annihilation lifetime spectroscopy based on fast pulse digitizers

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Keywords: positron annihilation spectroscopy, nuclear and irradiated materials

Positron annihilation lifetime spectroscopy (PALS) is a well-established nuclear physics based analysis tool targeting the nano-scale region in a broad spectrum of different, technologically high important materials [1]. Of particular interest are defects in nuclear and irradiated materials important for future fission and fusion energy systems [2].

Historically, PALS setups have been usually based on classical, analog electronics which was used for the extraction of timing information from the registered two gamma rays from positron annihilation in the investigated sample, see e.g. [3]. Additional information, especially concerning contributions of three gamma annihilations, can be obtained by acquiring the energy information of the annihilated gamma rays [4]. The appearance of high-performance fast pulse digitizers has enabled a new approach in PALS measurements with substantial reduction on the hardware side, but with more demanding data analysis, see e.g. [5].

This approach also offers more flexibility in measurements. We have assembled a PALS system that consists of three cylindrical 1 inch x 1 inch BaF_2 detectors with XP2020URQ PMTs which are coupled to DRS4 evaluation board [6] with four input channels which enables registration of the entire detector signal pulses with the sampling rate which can be selected in the interval 0.7-5 GS/s. Appropriate algorithms in CERN Root software for timing and energy determination from the registered pulses have been developed. For timing determination, the emulation of the constant fraction method was applied, and fraction had been varied until the best time resolution was obtained. Recorded pulses enabled usage of both photo-peak and Compton gamma rays in the analysis, a procedure which increases statistics of useful events, and which is not possible with classical analog electronics. By using gammas from photo-peak the timing resolution of 146 ps was obtained and using both gammas from photo-peak and Compton gammas the resolution of 155 ps was obtained. For the energy determination an integration of the whole signal pulse was used and clear separation of photo-peak and Compton gammas can be done.

With the setup standard double coincidence PALS measurements with ^{22}Na source by choosing 1.28 MeV gamma as start and 0.51 MeV annihilation gamma as stop signal can be performed. Triple coincidence measurements can be done by demanding coincidences between 1.28 MeV gamma acting as a start signal in one of the detectors and two annihilation gammas as stop signals in the remaining detectors. The setup is suitable for the determination of contribution of three gamma annihilations, which can be of special interest for investigations of various materials with large vacancies.

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Susceptibity to I-SCC of Zircaloy Nuclear Fuel Cladding: Assessment of iodine critical thresholds

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Keywords: I-SCC, PCI, iodine, zircaloy, corrosion, failure, threshold

Pellet-Cladding Interaction (PCI) can potentially lead to clad failures in Light Water Reactors (LWR) under specific reactor operating conditions, such as fast power transients, according to a mechanism of Iodine induced Stress Corrosion Cracking (I-SCC) [1]. Adjustments of the reactor protection thresholds and Operating Technical Specifications are implemented to prevent efficiently PCI/SCC failures.

The present study is an attempt to establish a chemical model of the iodine corrosion of Zircaloy cladding consistent with the thermodynamics of the Zr-O-I system and experimental observations. The model is then applied to some published data [2] in order to assess the chemical parameters that determine the critical iodine thresholds causing cracking of Zircaloy nuclear fuel claddings.

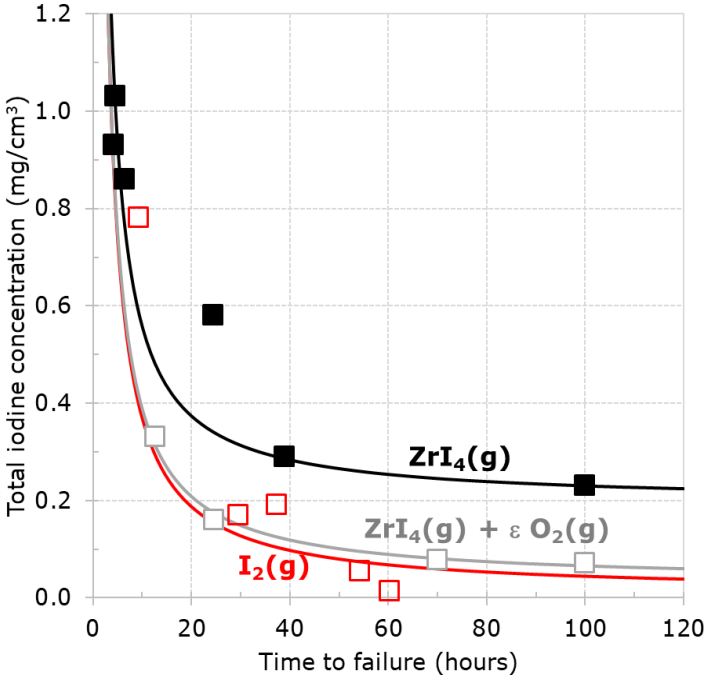

***Figure 1**. Stress Corrosion Cracking of Zircaloy: time to failure versus total iodine concentration (data from [2])*

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Diffuse Scattering of aged (U,Pu,Am)O_2 single-crystals

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Keywords: MOX, alpha-decay, self-irradiated, helium, neutron diffraction, diffuse scattering

Neutron diffuse scattering was used in order to study short range order in 20 years aged (U,Pu)O_2 single-crystals. Since their fabrication[1] these samples had not undergone any thermal treatment, they thus contain both their original elements as well as radiogenic helium and an extra amount of Am due to ^{241}Pu alpha-decay. The signal scattered between Bragg peaks contains information related to short-range order. These elements all show a diffusion length for neutrons which is of the same order of magnitude making it possible to study the contribution of the actinide cations, O^{2-} anion and He.

The diffraction study was carried out in Léon Brillouin Laboratory, on 5C2 beamline, with a four-circle diffractometer. This latter allows to determine crystal structures of single crystals.

The 3D intensity map was fitted by means of DISCUS[2] software.

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Radioactivity Characteristics of Turkey Coals: Case Study of Zonguldak, Konya and Antalya

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Keywords: coal, radioactivity, lignite, hard coal, HPGe, Türkiye

Coal, which is one of the fossil-based energy sources in the world, is important because it is more accessible and versatile than petroleum. Turkey has a total of 20.8 billion tons of coal resources, including 1.5 billion tons of hard coal and 19.3 billion tons of lignite [1]. This amount constitutes 1.8% of the world's coal reserves. Therefore, the size of Turkey's lignite resources is 7.1% of the world's reserves [2]. In our country, coals are produced in the form of underground and open pit mining operations, and lignites are of low rank and are generally used in thermal power plants. Most of the lignite basins of our country are located in the Western Anatolia, Central Anatolia. A significant part of the hard coal fields in our country are located in the Zonguldak Basin. In this study, radioactivity contents of lignites from Konya-Karapınar (Central Anatolia) basin and hard coal from Zonguldak-Kozlu (North Anatolia) and Antalya-Pamucakyayla (South Anatolia) basins were evaluated.

In this study, the radioactivity contents of Carboniferous Zonguldak-Kozlu hard coals, Carboniferous Antalya-Pamucakyayla hard coals and Pliocene Konya-Karapınar lignites were determined, compared with the limit values determined by the authorized institutions and their hazard indexes were determined. The measured activity concentrations were ranged from 16.2 to 227.6 Bq kg-1 for ^{238}U, 20.6 to 67.5 Bq kg-1 for ^{232}Th and from 211.9 to 515.5 Bq kg-1 for ^{40}K. The calculated mean absorbed gamma dose rate (D), radium equivalent activity (Raeq) and annual equivalent dose (AED) were 105.7 nGyh-1, 227.9 Bq kg-1 and 129.6 μSv h-1, respectively.

^{238}U and ^{232}Th radionuclide activity concentrations are comparable to literature values, but ^{40}K activity concentrations were around three or four times higher than that of UNSCEAR (2000) reports [3]. Due to the fact that it poses a radiological risk, it is necessary to take the necessary precautions to reduce the negative effects on the environment and human health in the use of coals from Konya-Karapınar, Antalya-Pamucakyayla regions and to burn in a controlled manner.

Acknowledgments
This work supported by the IAEA-RER1023 Project

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Portable Multichannel Spectrometry System and methods applied for sedimentology studies

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Keywords: sediment dynamics, natural radioactivity, radiotracer, gamma-ray spectroscopy

For the radiological assessment of ecosystems, measurements of natural radioactivity have been conducted (1). Sediment dynamics in coastal locations, such as beaches and river mouths, can also be estimated using the natural radionuclide activity concentration readings. Researchers have been using the natural radionuclides ^{226}Ra, ^{228}Ac, and ^{40}K as tracers to examine erosion and accretion processes on sandy beaches. Traditional radioactivity measurement studies are carried out with laboratory-based measurement systems such as NaI and HPGe detectors connected to nuclear instrument modules. Studies in this system consist of site selection, sampling planning, sampling and preparation, radiometric measurements and spectrum analysis. For these studies, firstly, sampling locations are determined by making a grid on the study area. Samples are taken from each sampling point with appropriate equipment and transported to the laboratory. Samples are then subjected to a series of physical processes, such as drying, sieving, grinding, and holding to reach secular equilibrium, in order to be ready for measurements. Each sample is then measured in the gamma spectrometric system for approximately one day (sometimes longer) and the spectra are analyzed to obtain a very detailed radioactivity characteristic of the study site. On the other hand, with in situ measurement systems, most of these steps are not required. In these systems, the portable measurement system (consisting of detector, battery, minicomputer and GPS) is taken to the site and the study area (grid) is completely scanned horizontally and vertically. Measurements are made in such a way that the height of the detector from the ground varies between 15-100 cm, the measurement time varies between 10-30s and the forward speed varies between 0.5 - 1.0 m/s. Finally, the general radioactivity characteristic of the study area is determined by analyzing the spectra. When these two systems are compared, it is clear that both systems have advantages and disadvantages. In studies carried out with traditional methods, a significant amount of manpower, time in the order of months and a significant amount of budget are needed to determine the detailed radioactivity characteristics of an area, while the general radioactivity characteristics of a site can be determined economically and with relatively little labor in a few hours with in-situ measurement systems. As a result, the general radioactivity characteristic of a study area of interest can be determined quickly and economically with portable measurement systems, if detailed results are needed, traditional measurement systems can be preferred.

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Investigation of DIY plastic scintillators made from polyepoxydes and high loads of commercial liquid scintillation cocktails

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Keywords: polyepoxydes, liquid scintillators, plastic scintillators, radiation detection

Polyepoxydes are obtained by mixing a prepolymer and a curing agent. These, once mixed, give a cross-linked network, which can be easily cast and harden into complex shapes. Most such polyepoxydes are used as good clear glues; their main application in radiation detection is as an optical glue. However, there is success building on their advantages: (a) light transparency, (b) limited shrinkage on polymerization, (c) small exothermic hardening, (d) easy handling and (f) inherent fluorescence capabilities. Plastic scintillators produced using polyepoxydes are dimensionally stable, resist temperature and chemical attacks and do not tend to crack or craze. On the other hand, there are limitations: low UV transmission and poor solubility of scintillating agents [1]. Further, the available plastic scintillators are costly per unit volume. However, development of new polyepoxydes and of stable scintillation cocktails and available inorganic fluors, tempt towards investigating their mixtures as plastic scintillators. The results of experiments in our Lab are promising: (i) transparent "liquid glass" seems to be most suitable, (ii) significant loading of liquid glass with liquid scintillators (> 30%) does not seem to interfere with curing, (iii) integration of the ZnS(Ag) fluor is homogeneous, (iv) 48 h curing and (iv) minimum temperature, shrinkage and bubbles at mixing and curing. From the detection side, photomultiplier tests show that the produced scintillators are both total -γ and total -β sensitive. Since the scintillator cocktail mass is severely increased, the scintillation process relies on the cocktail and not on the cross-linked matrix. However, for a 1" thick plastic detector interacting with radiation the produced light is mainly at the fluorescent spectrum and only partly UV_A. Testing such detectors with a photomultiplier showed small part of this light resonating with the UV_A length suitable for its photocathode. Thus, the efficiency achieved through a 0.5 mm thick aluminum light shield for a Sr-90 point source is close to 5%, while the efficiency for a Cs-137 point source is estimated around 2%. On going work is to: (1) test more polyepoxydes, (2) maximize cocktail load, (3) optimally add ZnS(Ag) fluor, (4) minimize the detector volume to 4 - 5 cm diameter disks and volume of 3 cm^3 to counter UV quenching, (5) minimize thickness of light shield, (6) optimize efficiency and estimate spectroscopic capabilities. ZnS(Ag) dilluted within a polyepoxyde is expected to enhance -β detection and promote the discrimination of total -β from total -γ activity; Future work could investigate extrusion of the suggested plastic scintillators mixtures. Such approaches for similar mixtures are already being investigated. Film plastic scintillators testing is another field, in which development is in progress but has not engaged polyepoxydes yet. Finally, it seems to our team, that the liquid organic nature of polyepoxydes may lead to affordably 3D printing any detector geometry.

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Application of gamma ray attenuation technique in assessment of bubble column reactor

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Keywords: bubble column, gamma ray attenuation, void fraction

Bubble column fluid dynamics needs proper understanding for the purpose of improved design, scale up, safe operation and better performance of bubble column reactors. In this study, gamma ray attenuation technique was used to assess the performance of a first generation bubble column experimental facility which has been newly designed, constructed and installed. The objectives were to (i) establish or otherwise the suitability of the facility for multiphase flow research, (ii) generate data for validation of models and testing of computational fluid dynamics codes, (iii) enhance multiphase flow research, training, education and development in Ghana. Being a first generation facility, the data collection technique used for the assessment was carefully selected so that there would be no deficiency in the technique which could affect the actual performance of the facility. In this regard, gamma ray attenuation technique, which has numerous advantages of which all cannot be found in any other single technique, was selected for the investigations in this study. The test section is 3 inches internal diameter transparent pipe which enables visual monitoring of the flow field. The facility was operated at atmospheric pressure and temperature of 28^{o}C with air and water as the working fluid. The fluid superficial velocities were varied from 0.95 to 7.56 cm/s for the air (J_g) and 0 to 8.51 cm/s for the water (J_L). For each flow condition, the gamma counts were recorded with thallium activated sodium iodide gamma ray detector which was connected to a laptop installed with Caeser 12 data acquisition software. The main parameter use for the verification and validation of the facility is the void fraction (VF) due to its importance in gas-liquid two-phase flow. A total of 270 flow conditions were investigated and the void fraction calculated from the gamma counts recorded by the detector. The experimental results were compared with models of Premoli, Lochart-Martineli and Kanizawa for validation. Overall, analysis of the results indicated a trend which is in agreement with bubble column fluid dynamics as reported in literature. Based on the recomendation of other investigators, the standard deviation (SD) was used as the statistical parameter to estimate the variation of the experimetal results from those of the reference models. The minimun percentage SD was 2.1% (from the model of Kanizawa) and the maximum was 9.6% (from the model of Lochart-Martineli). Figure 1 shows a sample result.

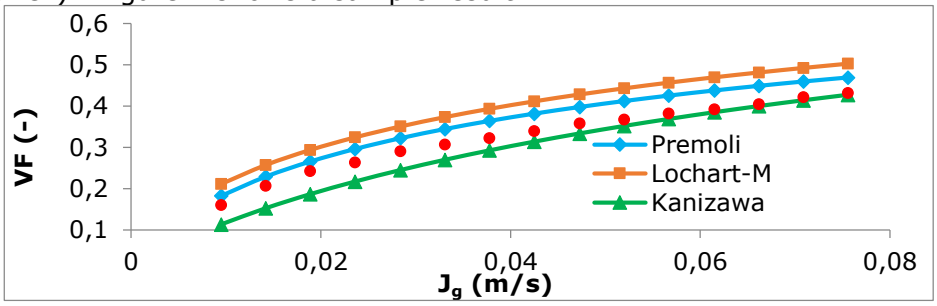

Figure 1. *Comparison of experimental void fraction with models*

Use of natural dolomite mineral as an adsorbent for cobalt-60 radionuclide from aqueous solutions

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Keywords: adsorption, dolomite, cobalt-60, liquid radioactive waste

Dolomite, a natural adsorbent, has been used for removal of cobalt ions from aqueous solution (1-2). Türkiye has a substantial number of dolomite deposits. The authors identified a lack of research in this area because no studies on the cobalt-60 radionuclide adsorption potential of natural dolomite material from Türkiye have been done. This was the motivation to investigate the adsorption properties of the dolomite mineral obtained from Thrace region in Türkiye for its use as a low-cost natural sorbent. In this study, cobalt-60 radiotracer was obtained by irradiating the cobalt chloride compound in the ITU TRIGA Mark II research reactor. Different concentrations of solutions containing the radioactive compound were prepared to simulate a wastewater media. Adsorption parameters including solid/liquid ratio, concentration and contact time have been investigated by determination of the cobalt-60 activities in the solutions by gamma-ray spectrometry with NaI(Tl) scintillation detector. Equilibrium isotherm data were analyzed using Langmuir and Freundlich isotherm models (Figure 1). Maximum adsorption capacity of cobalt was 2.5 mg/g at room temperature. The adsorption kinetics were studied at the determined optimum conditions pH 6, cobalt concentration 128 mg/L, adsorbent concentration 20 g/L and room temperature. The equilibrium was attained after 120 min of contact time. As a conclusion, it was found that natural Turkish dolomite mineral is suitable to be used to remove cobalt-60 radionuclide from aqueous solutions as a potential low-cost natural sorbent.

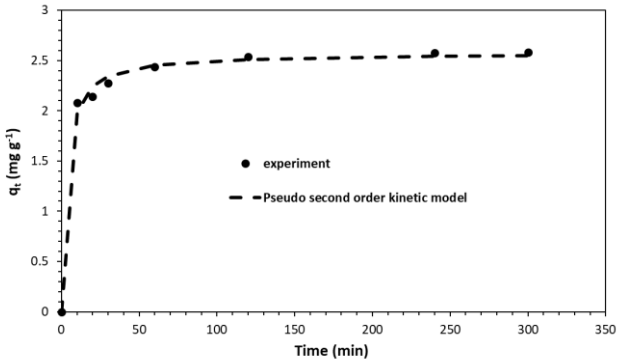

Figure 1. *Pseudo-second-order kinetic model for Co(II) adsorption onto dolomite*

Acknowledgments
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Possible use of Resadiye natural bentonite mineral as engineering barrier material for gamma radiation shielding

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Keywords: bentonite, gamma-ray, attenuation, Geant4, XCOM

Nowadays, a variety of industries, including the energy sector, the medical field, and nuclear research, create and use radioactive materials. Consequently, one of the key application areas of nuclear technology is radiation shielding. In this study, it is aimed to determine gamma-ray shielding capabilities of Resadiye bentonite for low and medium gamma-ray energy range, whose radionuclide adsorption properties have been studied before (1,2). In the experiments, the sodium bentonite obtained from Reşadiye (Tokat City, Türkiye), which is one of the largest sodium bentonite deposits in the world (3), was used. Gamma transmission properties of the bentonite at various thicknesses were investigated with standard gamma point sources experimentally and theoretically by XCOM and Geant4 softwares. The attenuation coefficients of bentonite were determined at 59.5 keV energy of ^{241}Am, 81.0 keV and 356.0 keV energies of ^{133}Ba, and 661.7 keV energy of ^{137}Cs by gamma-ray spectrometry with NaI(Tl) scintillation detector. The theoretical and the experimental calculations of mass attenuation coefficients were found to be in good agreement (Figure 1).

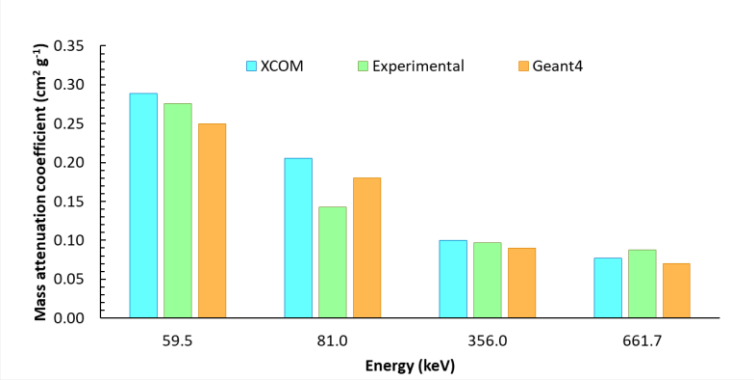

***Figure 1**. Mass attenuation coefficient at different energies*

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SMRs III & IV generation candidates for the decarburization of energy sector in Poland

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Keywords: SMR, nuclear reactors, decarburization

Small Modular Reactors (SMRs) have gained significant attention as potential candidates for decarbonizing the energy sector in various countries, including Poland. SMRs offer several advantages over traditional large-scale nuclear reactors, such as increased safety, scalability, and flexibility. While specific candidates for SMRs in Poland may evolve over time, There are many SMR designs from the third and fourth generations that are currently being considered globally. Each of them offers some specific or unique solutions. It's important to note that the suitability of SMRs for decarbonizing Poland's energy sector would depend on various factors, including regulatory considerations, public acceptance, and specific energy needs. Technical considerations, such as the power of the reactor, the temperature of the steam produced, and the characteristics of the fuel, are crucial when selecting nuclear technology as well. The selection of an SMR design would require careful assessment and evaluation of these factors in the Polish context. In this presentation advantages and disadvantages of different SMR technologies will be presented. Some of the most interesting III & IV generation SMRs candidates for the decarburization of the Polish energy sector will be presented.

Acknowledgments
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Optimization of Conditions for Topaz Irradiation in the WWR-K Reactor

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Keywords: radiation treatment, research reactor, topaz, NAA, tantalum, neutron irradiation, fast neutrons

When semi-precious stones, topazes, are irradiated with thermal neutrons, impurities are activated in them (induced radioactivity occurs), which complicates their further handling. This leads to the need for their long exposure for safe use. The Institute of Nuclear Physics (Kazakhstan) is conducting R&D to develop a method for the effective formation of color centers in topaz during their irradiation in the WWR-K reactor. An irradiation capsule design has been developed in which optimized conditions for irradiating stones in the neutron field of the reactor are formed [1]. The capsule uses shielding materials made of boron carbide and tantalum to cut off thermal neutrons, resulting in a reduction in induced radioactivity in topaz. The effectiveness of the irradiation capsule was tested in the core of the critical facility. As a result, it was shown that when using a sandwich screen made of boron carbide and tantalum, the thermal neutron flux density decreases by 5.7 times, and the fast neutron flux density is insignificant (by 7%). The induced activity of the tantalum monitor is reduced by 2.2. The results of gamma-spectrometric analysis of irradiated topazes showed that the induced activity of Ga-72, Na-24 and Ta-182 radioisotopes decreases by at least 2 times. The results of gamma-spectrometric analysis of irradiated topazes showed that the induced activity of Ga-72, Na-24 and Ta-182 radioisotopes decreases by at least 2 times.

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Dosimetry for Low Energy Electron Beam Applications at Fraunhofer FEP

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Keywords: radiochromic film, optically stimulated luminescence, dosimetry, electron beam

Accelerating electrons to achieve chemical and biological effects is a well-established competence of Fraunhofer FEP. Today there is a large variety of established low-energy electron beam applications, ranging from seed dressing over inactivation of viruses for vaccines, to sterilization of medical devices. Moreover, there are new emerging technologies like stimulation of biological systems, electron beam sustained synthesis of chemical energy carriers, as well as the treatment of wastewater or exhaust gases with low-energy electrons. This spectrum of applications comes with a range of absorbed doses and calls for reliable, sensitive, and flexible methods for dosimetry.

Due to the limited penetration depths of electrons with energies of 300 keV and below, thin radiochromic films are suitable tools to measure electron dose distributions for the characterization and quality control of Fraunhofer FEP's irradiation facilities. Risø B3 radiochromic film from DTU Health Tech [1], the dosimeter of choice at FEP, reliably detects doses in the range of 10-100 kGy. However, with new upcoming applications, like bio-stimulation or wastewater treatment, doses in the single digit kGy range and even lower come to the fore. Hence, the palette of dosimeters at FEP must be extended. Gafchromic's HD-V2 radiochromic film is a welcome complement and widens the accessible dose range down to 10 Gy [2]. Using a UV-VIS spectroscope for read-out of the films and custom analysis algorithms further increase the sensitivity of the dosimetric setup. Additionally, dosimeters based on the optically stimulated luminescence of beryllium oxide [3] offer a wide dose range and very high sensitivity. They have been used to measure doses induced by X-ray components to gain more information about a specific radiation field. The work gives an overview of the dosimetric toolbox at Fraunhofer FEP and the efforts to implement new methods of detection for low-dose applications and X-ray dosimetry.

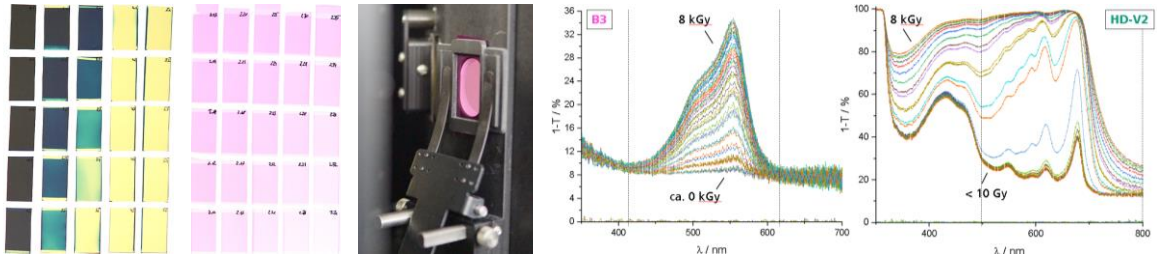

***Figure 1**. Irradiated radiochromic films (left), spectrometer read out (middle) and spectra (right)*

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Determination of krypton and xenon radionuclides in the air - preliminary research

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Keywords: radionuclides, krypton, xenon, gas chromatography, gamma spectrometry, nuclear activities, cryogenic enrichment method, air monitoring

Air pollution is currently one of the most important issues in the modern world. The main air pollutants are particulate matter, but equally dangerous to health are possible contamination with radionuclides (including noble gases, xenon and krypton). Radioactive isotopes of krypton and xenon are the most volatile fission products of uranium-235 and plutonium-239, the main components of nuclear fuel in power plants. Therefore, they are the main component of radioactive substances emitted from nuclear power plants, during normal operation of reactors as well as accidents. ^{85}Kr is released in significant amounts in nuclear fuel processing plants. Therefore, monitoring of noble gas radioisotopes can serve as an information on the ongoing activity of nuclear reactors, as well as undeclared nuclear activity (contrary to the CTBT-Comprehensive Nuclear-Test-Ban Treaty).

Energy Policy of Poland until 2040 (PEP2040) assumes the commissioning of the first block (with a capacity of approx. 1-1.6 GW) of the first nuclear power plant in 2033. The next ones will be launched every 2-3 years - the entire nuclear program assumes the construction of 6 units by 2043 [1]. Therefore, in addition to controlling the level of particulate pollution, it is important to monitor the level of radiation pollution.

Due to the very low activities of the noble gas isotopes in the air, krypton and xenon radionuclide measurement systems used in the world consist of complex enrichment and purification systems [2,3]. Activity concentration in air for ^{85}Kr, with a half-life of 10.756 years, is approx. 1.45 Bq/m^3, and for ^{133}Xe, with a half-life of 5.247 days, ranges from approx. 0.1 mBq/m^3 to approx. 140 mBq/m^3. In our research we plan to use enrichment system consisting of the cold trap filled with activated charcoal. Separation and purification will be carried out using gas chromatography and titanium pomp. Measurements will be performed using gamma spectrometry. First experiments were carried out for a self-prepared gas standard of krypton and xenon in helium using two Shimadzu gas chromatographs. First GC 2014 gas chromatograph equipped with three packed columns filled with molecular sieve 5A and activated charcoal and the thermal conductivity detector TCD. The second GC-17A with 30m capillary column filled with molecular sieve 5A and TCD detector. Both experiments gave good results with LOD limits for Kr and Xe at the air concentration levels.

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Treatment of Contaminated Ground Water from Uranium Using Adsorption Technology by Novel Mesoporous-silica Nanoparticles

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Keywords: uranium removal, mesoporous-silica nanoparticles, adsorption, ground water, ground water treatment, uranium recycling, decontamination

Contamination of underground water by uranium (U) and other heavy metals is a growing environmental concern. Mesoporous silica nanoparticles (MSNs) have emerged as promising adsorbent materials for heavy metal removal. In this study, we present the synthesis of novel MSNs, namely phosphate-MSNs (A) and poly-phosphate-MSNs (B), with enhanced adsorption properties for uranium removal from aqueous solutions. To modify the surface properties of the MSNs, we employed the surface-initiated atom transfer radical polymerization (SI-ATRP) technique. Additionally, we reduced the particle size to the range of 150-340 nm to maximize adsorption efficiency. The successful synthesis and modification of MSNs were confirmed through Fourier transform infrared characterization and thermo-gravimetric analysis. Through comprehensive evaluations under various conditions, we observed that the MSN adsorbent exhibited exceptional effectiveness in removing uranium. At 120 minutes, the MSNs achieved a removal rate of 85.35%. Notably, temperature played a significant role, with the highest removal rate of 96.7% obtained at 25°C and a uranium concentration of 10 ppm. Moreover, a pH of 6 and a uranium concentration of 50 ppm yielded the highest removal rate of 91.89%. Furthermore, at room temperature for 60 minutes, a uranium concentration of 50 ppm with 25 mg of MSNs resulted in the highest removal rate of 95.16%. Importantly, the MSNs also exhibited a substantial removal rate of 58.27% in a mixture solution under the same conditions. This study demonstrates the novelty and effectiveness of our phosphate-modified MSNs synthesized via SI-ATRP for uranium removal under various conditions. The introduced modifications and comprehensive evaluation provide valuable insights into the development of advanced adsorbent materials for combating uranium contamination in underground water.

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Liquid Dosimeter with kGy Sensitivity for the Characterization of a New Module for Wastewater Treatment

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Keywords: liquid dosimetry, radiochromic effects, micropollutants, wastewater treatment

The increasing use of antibiotics, X-ray contrast agents, hormones and hormonally active chemicals in hospitals, pharmaceuticals and many aspects of daily life has led to a rise in concentration of these highly persistent micropollutants in hospital and municipal effluents. In contrast to conventional wastewater treatment techniques, advanced oxidation processes show promising capability of removing selected micropollutants from the wastewater [1]. However, treatments to simultaneously and reliably eliminate the majority of emerging micropollutants in the presence of traditional pollutants have not yet been established. A new method, the treatment by low-energy electron-beam irradiation, is currently investigated at Fraunhofer FEP. The approach benefits from the superior energy conversion efficiency of low-energy electrons interacting with the wastewater and the high reactivity of the produced radicals while putting low demands on radiation protection and power consumption. This allows for a compact, flexible treatment module, which could be integrated in existing treatment plants or operated as a decentralized system at point emitters. To play into the main advantages of this technology and keep it economically viable, it is necessary to achieve the desired degradation of the micropollutants at an absorbed dose as low as possible. This calls for a liquid dosimeter which is sensitive at single digit kGy and below. An extract from natural Roselle has been reported to show a radiochromic effect in this dose range [2]. In the present work, Roselle dye solutions were closely investigated and optimized to characterize low energy electron beam applications in fluids. Calibration and read-out regimes were established, and the dosimeter was tested with the functional model of a wastewater treatment module, installed at FEP's laboratory facility REAMODE, under different operation parameters.

***Figure 1**. Experimental setup (left) and radiochromic effect of liquid roselle dosimeter (right)*

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Evaluation of the impact of the accuracy of the Ra-226 activity determination method in water on the estimation of radiation hazard of patients in sanatoriums using radium water balneology

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Keywords: ^{226}Ra, radium water, balneology

The aim of the reported study was to evaluate the uncertainty of the applied method for determining the concentration of Radium-226 in water and its radiation hazard to patients undergoing balneology treatment. The Central Laboratory for Radiological Protection (CLRP) is a leading laboratory in Poland that specializes in radiation protection, occupational hazards, and other issues related to radiation in everyday life. The expert approach to radiation at CLRP is based on 15 accredited procedures and several methodologies concerning ionizing radiation. Among the accredited procedures, there are some that were employed in the conducted research.

The methods used were as follows: (1) γ spectrometry with a medium-resolution, high-efficiency HPGe detector; (2) γ spectrometry with a medium-resolution, medium-efficiency HPGe detector; (3) Emanation method; and (4) Liquid scintillation method.

In the case of γ spectrometry, three additional approaches were utilized, including energy-efficiency calibration of HPGe detectors using both a calibration source and mathematical methods, as well as numerical simulation through commercially available software (LabSOCS, Geometry Composer) based on the MCNP method.

After acquiring γ spectra, Ra-226 activity concentration in water was estimated using three spectrum analysis methods: (1) An analytical method in Genie software; (2) Method based on net count in 186.2 keV peak and photon registration efficiency; and (3) Method based on peaks of short-lived progeny of Rn-222, namely Pb-214 and Bi-214.

The Reference Man model was adopted for calculating the radiation hazard. Since the effective dose is linearly dependent on the Ra-226 concentration in water, the method uncertainty also represents the uncertainty of dose prediction. All analyses were conducted with the assumption that radioactive equilibrium is fulfilled.

***Table 1**. Results*

Measurement Method	Energy efficiency calibration	Calculation Method	Radioactivity concentration [Bq/l]	Uncertainty [%]
Gamma spectrometry with medium efficiency HPGe detector	Calibration source	Genie2000	55.0	5.0
		Evaluation of 186.2 keV peak	65.6	5.0
		Evaluation of Pb-214 and Bi214	51.1	5.0
	LabSOCS	Genie2000	49.5	4.0
		Evaluation of 186.2 keV peak	65.8	4.0
		Evaluation of Pb-214 and Bi214	51.1	4.0
Gamma spectrometry with hight efficiency HPGe detector	Calibration source	Genie2000	68.0	4.3
		Evaluation of 186.2 keV peak	71.2	4.2
		Evaluation of Pb-214 and Bi214	59.0	2.8
	LabSOCS	Genie2000	65.8	3.4
		Evaluation of 186.2 keV peak	68.9	4.2
		Evaluation of Pb-214 and Bi214	56.8	2.6
Liquid scintillation			57.9	10.4
Emanation method			51.1	16.3

Radiation impact of ashes from the combustion of bottom sediments in a municipal sewage treatment plant

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Keywords: radioactivity, fly ashes, sewage sludge combustion, radiation safety

The aim of the research was to determine the radioactive activity of fly ashes produced as a result of sewage sludge combustion in the sludge thermal utilization station in Warsaw. In the period from April 2022 to April 2023, 16 representative samples of fly ashes, weighing approx. 1 kg each, were collected, resulting from the combustion of sewage sludge. The method of collecting, homogenizing, and transferring ashes was in accordance with the IAEA guidelines. Each test was performed for 458 grams of fly ash.

The radiometry of ash samples was performed using a high-efficiency, high-resolution HPGe spectrometer manufactured by Canberra. The detector, enclosed in an ORTEC shielding, was electronically cooled and equipped with numerical features for energy efficiency calibration. The calibration process involved the application of the Monte Carlo method and LabSOCS software. Numerical methods for calibrating gamma spectrometry are widely acknowledged. The calibration of the Marinelli baker demonstrated compatibility within 0.1%.

The ashes were enclosed in a gas-tight Marinelli chamber to prevent the release of ^{222}Rn, a gaseous progeny of ^{226}Ra, thereby maintaining the radioactive equilibrium during measurement of parent and progeny radionuclides. Qualitative and limited-scale quantitative analysis were performed using the Genie2000 software. However, most quantitative analyses depended on specific full energy absorption peaks (FEAP) for interference.

^{238}U radioactivity was determined via the progeny radionuclides ^{234}Th and ^{234m}Pa. ^{235}U activity was determined from its other FEAPs (e.g.: Eγ=143.765 keV, Pγ=10.93%; Eγ=163.357 keV, Pγ=5.07% where Pγ intensity of particular transition) because FEAP with energy Eγ=185,72, Pγ=57% interfered with ^{226}Ra FEAP (Eγ=186,21 keV, Pγ=3,56%). Thus, the impact to the net peak area of both interfering radionuclide was calculated and subsequently the activity of ^{226}Ra was deducted. Determining the ^{210}Pb concentration was done directly via the FEAP at the comparatively low energy (Eγ=46,54keV, Pγ=4,25%). Radioactivity of other radionuclides meat in sample were calculated indirectly based on radiation equilibrium assumption fulfilling. In the samples were detected radionuclides from three natural decay chains i.e., ^{208}Tl, ^{210}Pb, ^{212}Bi, ^{212}Pb, ^{214}Bi, ^{214}Pb, ^{222}Rn, ^{226}Ra, ^{228}Ac, ^{231}Th, ^{232}Th, ^{234}U, ^{235}U. Apart from the above mentioned, the natural radionuclide ^{40}K, cosmogenic ^{7}Be, and artificial ^{137}Cs were detected. ^{7}Be is made on a recent timescale in the solar system by spallation while ^{137}Cs as the fission product was present in the global fallout in result of nuclear tests as well as disasters of nuclear reactors (in: Windscale, Three Mile Island, Chernobyl, Fukushima). The radioactivity of particular radionuclides changes from hundredth part of Bq/g to a few Bq/g. The expected dispersion of activity between the samples was up to several dozen percent.

Thus, one can make assumption that radiation hazard due to utilizations of ashes in result of burning bottom sediments from treatment plants can be neglected.

Dosimetry for 60 MeV proton FLASH beam at IFJ PAN

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Keywords: proton, flash, high intensity, dosimetry, radiotherapy

The wide range of applications of the proton beam in medicine requires maximizing safety and quality. Radiobiological and clinical studies have shown the potential effectiveness of proton radiotherapy at very high dose rates, the so-called FLASH radiotherapy [1]. It involves providing the whole prescribed therapeutic dose of ionization radiation without fractionation in less than 1 s with doserate over 40 Gy/s. This method can spare healthy tissues while remaining an effective way to cure cancers. The introduction of the FLASH technique to proton radiotherapy requires the development of appropriate dosimetric methods and conducting in-depth radiobiological studies. The aim of this work is to verify capabilities of producing ultra-high intensity beam from the AIC - 144 isochronous cyclotron at the Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN) and to elaborate dosimetric method which can be used with FLASH proton beams.

The research was carried out on 60 MeV horizontal proton beam irradiation facility. The radiation field size was verified using Gafchromic EBT3 films. The dose measurements were carried out with using both passive and active detectors such as alanine pellets, Gafchromic EBT3 films, ionization chambers, diamond detector, Faraday cups and innovative radioluminescence crystals. A newly-produced (at crystal growth laboratory at IFJ PAN) crystals of LiF and $LiMgPO_4$ connected via optic fiber to filters and the photomultiplier tube, called PORTOS [2], were applied. These system allows to read out radioluminescence signal up to a million times per second.

Measurements confirmed capability of the AIC - 144 cyclotron to produce 60 MeV proton beam with high intensity required to FLASH irradiation. The beam shows a double structure: micro-pulses (related to the RF cyclotron frequency) are grouped into macro-pulse with a length of 0.5 ms. Macro-pulses are repeating with frequency of 50 Hz. Dosimetric measurements showed that the average doserate can exceed 60 Gy/s which corresponds to 2400 Gy/s in macro-pulse. Radioluminescence crystals have shown potential to be used in dose measurements.

The facility at the AIC-144 cyclotron is ready for hosting of FLASH irradiation of biological cells, tissues and small animals. We also offer reliable, active and passive methods for FLASH dosimetry.

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Lithium fluoride based fluorescent nuclear tracks detectors for detection of low-dose gamma radiation

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Keywords: FNTD, lithium fluoride, nuclear particle, particle tracks, dosimetry

Lithium fluoride (LiF) is a well-known luminescent and optical material broadly used for dosimetric purposes. It became possible to measure under fluorescence microscopy the photoluminescence (PL) emission from a single densely ionizing particle in LiF crystals grown at IFJ PAN by Czochralski method [1]. Radiation-induced fluorescence in LiF crystals arises mainly from F_2 and F_3^+ anion vacancies, with maximum intensity on 670 nm wavelength with 440 nm excitation light [2]. The anion vacancy creation energy is much lower than band gap energy [3], therefore LiF detectors provide very high response to irradiation.

The method has been applied to measure radiation tracks induced by densely ionizing radiation such as alpha particles, protons, neutrons etc. [4, 5, 6]. Even when the principal physical phenomenon leading to these effects is known, the specific properties exhibited by the fluorescent tracks raise several questions waiting to be answered. Surprisingly, some "flashing points" of approximately 1 μm size were also observed after low-LET, low-dose of gamma-rays from Cs-137 source.

Within the work the dose-response for Cs-137 gamma-ray has been investigated. Preliminary results will be shown – including normalised-to-kerma signal: "flashing points" number. The paper will discuss the possible physical mechanisms of this phenomenon, including microdosimetric overlapping of gamma-rays induced secondary electrons.

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Lifetime Extension of the Loviisa NPP in Finland

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Keywords: lifetime extension, nuclear power plant, nuclear energy

Fortum is a Finnish power company with long roots in the field of nuclear power as an owner, operator and service provider. Fortum owns and operates two nuclear units at the Loviisa nuclear power plant. The units, Loviisa 1 and Loviisa 2, have been operational since 1977 and 1980. Fortum applied for the lifetime extension for both units in March 2022, and lifetime extension until the year 2050 was granted by Finnish Government in February 2023. The lifetime extension was also granted for the Loviisa's final disposal facility for low- and intermediate-level waste.

In this presentation, a short overview of the Finnish process for the application of a new operating license for operating nuclear power plant is presented. This process includes for example Environmental impact assessment as well as Periodic safety reviews for an operating power plant. In addition, the outcome of this process in case of the Loviisa NPP is discussed, including plans for intended investments in the coming years.

Updating the μRate application for trapped charge dating calculations

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Keywords: luminescence dating, dose rate, environmental dose rate, Monte Carlo, Sobol sensitivity analysis, web application

The μRate application is used for dose rate calculations in trapped charge dating. The software has been updated with two major additions. The first update incorporates new attenuation of β radiation factors in granular matrices proposed by Cunnigham et al. (2022). The second update includes dose rates induced by disequilibrium in ^{238}U decay series.

The project was conducted in collaboration between the Division of Geochronology and Environmental Isotope at the Silesian University of Technology, the University of Salzburg, and Heidelberg University.

Once the new calculation models were deemed satisfactory, they were integrated into the μRate application. The implementation process involved careful consideration of the existing codebase to ensure seamless integration without compromising the overall functionality of the application. The updated version of the application was thoroughly tested to verify its performance and accuracy.

The successful completion of the project resulted in an updated version of the μRate application that incorporates the latest corrections for imbalances in the radioactive series and beta ray attenuation of 238U. This update enhances the accuracy and reliability of ionizing radiation dose rate calculations in dosimetry dating. Researchers and practitioners in the field can now utilize the improved application to obtain more precise results in their dating analyses.

Overall, this project exemplifies the collaboration between academic institutions and the advancements made in the field of dosimetry dating. The updated μRate application serves as a valuable tool for researchers and contributes to the ongoing progress in understanding geological and archaeological timelines.

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Investigation of thermo-hydraulic and neutronics related effects following the voiding of the nuclear core during LOCA transients

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Keywords: nuclear safety, thermo-hydraulics, neutronics, nuclear system codes

This work presents the use of CATHARE and SMART codes for LOCA transient simulations. The main focus is given on the investigation of the thermo-hydraulic and neutronics coupled effects. CATHARE is a thermo-hydraulic code for simulation of multiphase flow dynamics in system-scale problems. It was developed by CEA, EDF, Framatome and IRSN for more than 40 years (starting at 1979). It is used mostly for nuclear reactor design and nuclear safety studies [1]. SMART is the computer code developed and used by Framatome for the core neutronic calculations. It solves the deterministic equation of neutron kinetics for a given nuclear core, under defined physical conditions and fuel loading. By using SMART data, it is possible to obtain, in CATHARE computation for intermediate break (IB) or a small break (SB) loss of coolant accident (LOCA) transient, a realistic evolution of power decay accounting for the heterogeneous core voiding. For study of the thermo-hydraulic/neutronic related effects, parametrized transient calculations by CATHARE were performed by penalizing progressively the moderator anti-reactivity feedback resulting from SMART calculations. One of the main criteria used for quantification of conservatism is the impact on peak cladding temperature (PCT) during the simulated transients. Work shows that even when significant penalization is applied to the models, the clever design of the nuclear core and safety systems ensures that the PCT safety criteria is met. Additionally, study shows that differences introduced in the energy stored in the nuclear fuel, due to the penalization of neutronic effects in the initial seconds of the transient, are highly impacting thermo-hydraulic behavior after dozen seconds later. At that time the fission power has become very weak due to core emptying and control rod drop, so temperature changes can be related mostly to transient history. One example is higher cladding temperature at the beginning of adiabatic heating of the rods which results in higher PCT value. Such behavior highlights the importance of the core neutronic history for simulations of system-scale thermo-hydraulics.

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The PCB toxicity of factory waste channel sediments after radiation decontamination

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Keywords: polychlorinated biphenyls, radiation degradation, co-solvents, electron beam, toxicity

The PCBs (PolyChlorinated Biphenyls) are a serious environmental problem in eastern Slovakia. According to 15 years of monitoring, the locality with an area of 3000 km^2 and 200,000 inhabitants near former factory Chemko Strazske (producing the PCBs in 80-ties) is considered as one of the most PCB contaminated territories in Europe and whole world. The PCB concentration of sediments from the factory waste canal sampled during years 2000 – 2020 exceeds the legal limit of 0.8 mg/kg for the sum of seven indicator PCB congeners 10- up to 100-times [1,2].

The sediments from the waste canal were treated by 5 MeV electron radiation of 100 and 200 kGy dose. Two co-solvents, 2-propanol and K_2CO_3, were combined to compare the effectivity of radiolythic dechlorination as well as the toxicity reduction. The concentration of indicator PCB congeners exceeding the Slovak low limit 10-times, dropped by 73% when K_2CO_3 co-solvent was used, regardless 100 or 200 kGy applied. On the other hand, the PCB toxicity of treated samples was affected by the dose and co-solvent. It was shown that the PCB toxicity of canal sediments linearly depends on the concentration of the PCB-126 congener in all analysed samples regardless its radiation treatment, heat treatment or no treatment at all. The analysis of the content of the PCB-126 congener can very precisely predict the toxicity of PCB contaminated sediment in samples from Strazske factory area.

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High Temperature Reactor for Decarbonizing Energy-Intensive Industry: The European Project GEMINI for Zero Emission

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Keywords: nuclear cogeneration, poly-generation, decarbonization, high temperature reactor

Europe's decarbonization objectives necessitate addressing also emissions from sectors other than electricity generation, particularly industry and transport, which account for a significant portion of CO_2 emissions. These sectors rely on fossil fuels, posing challenges to European competitiveness and energy security, especially in light of volatile oil and gas prices. The previous GEMINI+ project has already demonstrated that nuclear High Temperature Reactor (HTR) systems can offer a promising and safe solution for CO_2-free cogeneration of process heat and electricity at large scale, addressing fundamental needs of industry. However, many industrial processes require not only heat but also substantial amounts of hydrogen or other energy products. GEMINI4.0 aims to extend the capabilities of the GEMINI+ system beyond process heat, showcasing its potential for comprehensive decarbonization of industrial activities. GEMINI4.0 will confirm that this novel form of poly-generation, encompassing multiple energy products, has no adverse impact on the safety of the integrated plant, but on the contrary, improves its versatility, efficiency and market opportunities.

GEMINI4.0 pursues the following objectives:

- Prove safety of the GEMINI+ system and assess readiness for licensing in poly-generation
- Assess and enhance effectiveness for poly-generation, ensuring its industrial viability
- Develop a roadmap for a European HTR fuel cycle
- Implement proactive communication with the public, industry and political stakeholders.

We emphasize poly-generation, which presents a significant market opportunity for HTRs. The unique capability of HTRs to deliver high-temperature heat positions them as a key technology for decarbonizing energy-intensive sectors. With exceptional safety features and advantageous performance, HTRs offer an attractive alternative to fossil fuel based heat sources. GEMINI4.0 will propose realistic solutions by determining viable flowsheets of hybrid energy systems, their economic viability and technology readiness. We will highlight the conditions and pathway to establish an independent European HTR fuel supply chain as a critical contribution to energy security, technology sovereignty and many energy policy targets. This would help addressing some of the concerns of the HTR development program in Poland. This strengthens European competitiveness and ensures a stable long-term fuel supply, mitigating potential disruptions caused by geopolitical factors or market uncertainties.

GEMINI4.0 is engaging with stakeholders, policymakers, and industry players, but also with investors in a meaningful dialogue and help them assess nuclear options for their businesses.

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Conversion of fast neutrons for neutron radiography with TPX2 detector

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Keywords: hybrid pixel detector, Timepix2, neutron conversion, neutron radiography

The non-destructive analysis is an important technique for inspection of critical components in industry such as compact new-class heat exchangers, the printed circuit heat exchanger (PCHE) [1] applicable in Generation IV nuclear reactors or solar power plants. The PCHE behaves as a single metal block, with etched holes running through it, withstanding high-pressure differences between primary and secondary coolant sides accompanied with compact size and high thermal efficiency, up to 98 % [2]. To reduce the time and cost associated with the maintenance tasks of future energy systems, technicians need to quickly identify the potential defects by the non-destructive techniques. Due to metal composition of the PCHE, the neutron radiography with fast neutrons is the most suitable.

For neutron radiography, the neutrons produced via the $D(d,n)^3He$ nuclear reaction (Q = 3.269 MeV) will be used producing the quasi-monoenergetic neutrons with energies in the range of 2 – 5 MeV depending on initial beam energy. The neutrons will be registered by Timepix2 detector with 500 μm thick silicon sensor after penetration of the PCHE experimental model. To enhance the detection efficiency of the Timepix2 silicon detector, conversion layers were applied to its surface.

This paper deals with the effectiveness of chosen conversion layers for fast neutrons: the Polyethylene layer of 50 μm, 100 μm and 150 μm thickness, the 10 μm Kapton polyimide film, all utilizing the elastic scattering of neutrons on hydrogen. And finally, the nitrogen and silicon conversion layers, utilizing the nuclear reactions of neutrons, were evaluated. The MCNP simulation results were compared to the experimental results obtained with fast neutrons of energies in the range of 3-16 MeV.

Acknowledgments
This study has been financially supported by FEEIT STU through the project NERAKO. This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

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Analysis of hydrogen behavior within containments of AP-1000 and APR-1400 nuclear reactors

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Keywords: AP-1000, APR-1400, containment, hydrogen, simulations

Fukushima Dai-ichi Nuclear Power Plant accident in 2011 clearly shown how destructive could be hydrogen in a nuclear reactor system. Analysis of hydrogen behavior in a containment building falls into thermal-hydraulic analyses, and, for obvious reasons, is performed by means of mathematical modeling and numerical simulations.

AP-1000 and APR-1400 reactors have been pointed as choices for Polish nuclear power plants. The first reactor is an example of a revolutionary approach for designing of safety systems, while APR-1400 is an evolutionary approach. Those designs are similar in term of hydrogen mitigation features.

This work deals with thermal-hydraulic analyses of hydrogen behavior in containment buildings of the considered nuclear reactors. The analyses were realized by applying an in-house computer code HEPCAL. The code is based on a lumped parameter approach, and it includes possibility of simulating the hydrogen removal system work, having the form of passive autocatalytic recombiners and hydrogen igniters. Design basis loss-of-coolant accidents (DBA LOCA), as well as beyond design basis LOCA (BDBA LOCA) scenarios were investigated.

Results shown that hydrogen mitigation systems enable keeping the hydrogen concentration below the flammability limits during DBA LOCA. BDBA LOCA scenarios analyses shown that flammability limits, as well as detonation limits, may be crossed. Full assessment of hydrogen combustion needs considering actual composition of a three component mixture of air, steam, and hydrogen. This was done for the considered systems and accident scenarios.

Finally, limitations concerning the use of the lumped parameter approach were identified and considered in an overall assessment of hydrogen combustion risk.

Acknowledgments
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Fast neutron spectrometer based on neutron-proton conversion

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Keywords: fast neutron spectrometer, neutron-proton conversion, proton energy spectrum deconvolution

A neutron spectrometer with neutron-proton conversion is designed for more detailed, up to point, energy spectrum mapping of more-intense sources of fast neutrons (in the neutron energy range from 1 to 20 MeV).

The efficiency of the conversion of monoenergetic neutrons to protons via (n,p) nuclear reaction in various filters: Cl, Ni, Si, Ti, S and Pd, in the geometry according to Fig.1., was calculated by Monte Carlo simulations (MCNPX code).

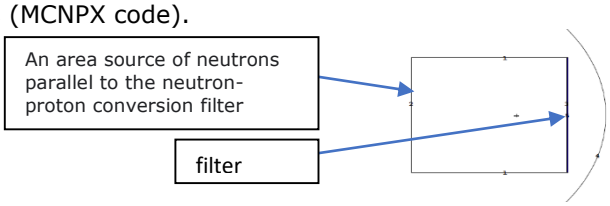

***Figure 1**. Geometry of MC simulation by MCNPX code*

The efficiency of the conversion of monoenergetic neutrons in individual filters, shown as a spectrum of proton flow energies (in lethargy units) is shown in Fig. 2.

The proposed spectrometer produces the highest proton fluxes in the range of proton energies of 4 to 6 MeV, while the shapes of the energy dependence of proton fluxes with energy above 6 MeV are not significantly different, which testifies to the higher fitness of the efficiency matrix constructed on the basis of the dependencies in Fig.2.

A lower fitness number can be expected in the construction of the efficiency matrix from the dependence of the production efficiency of the flow of protons during (n,p) reactions of monoenergetic neutrons in a filter made of Ni material, as shown in Fig. 3.

Deconvolution of the integral responses of the proton fluxes measured by the fast neutron spectrometer using Ni filter neutron conversion was performed with the SAND-II iteration code.

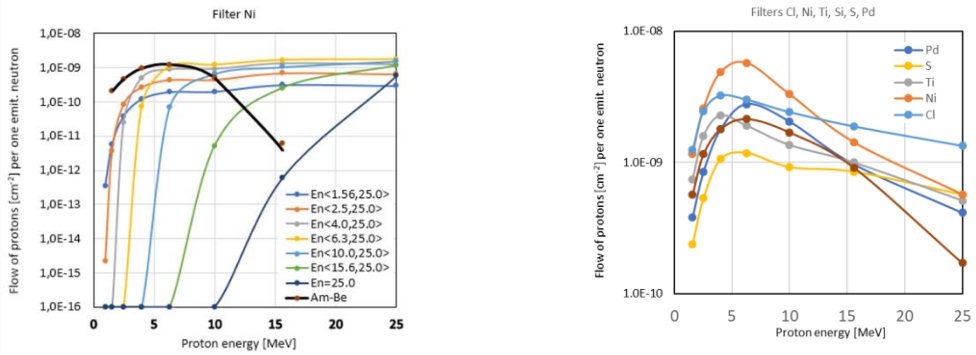

***Figure 2**. Energy spectra of proton flow after conversion of neutrons with energies of 1.56, 2.5, 4.0, 6.3, 10.0, 15.6 and 25 MeV (in lethargy units) simulated by MCNPX*

***Figure 3**. Simulated proton energy spectra after conversion of monoenergetic neutrons with energies of 1.56, 2.5, 4.0, 6.3, 10.0, 15.6 and 25 MeV and proton energy spectrum after conversion of Am-Be source neutrons with a Ni filter*

Acknowledgments

This study has been financially supported by FEEIT STU through the project NERAKO and it received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

Environmental application of the nuclear techniques- Irradiation of vegetal resin for characterization and improvement purposes

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Keywords: vegetal resin, preservationist actions, irradiation technology, characterization

A resilient and sustainable development in the context of current harmful climate changes must be the sharing of knowledge and effective preservationist actions. The promotion of the various production chains is essential for the development and enhancement of the standing, managed, conserved and protected forest, in addition to ensuring the adequate and equitable sharing of the benefits arising from the use of biodiversity.Many trees, particularly native trees, also support complex food webs, providing habitats for a diversity of faunal species. Furthermore, when native trees are preserved or reintroduced into deforested areas, they contribute to carbon sequestration, helping to mitigate climate change by absorbing and storing significant amounts of carbon dioxide.Natural resins are extractive substances secreted by plants, it is formed in the trunk of the tree from the sap elaborated through a plant defense reaction. It occurs in species of the *Burseraceae* family, and its power is recognized by the original population, who consider it a sacred resin. Most natural resins are composed of terpenes, which are macromolecules derived from isoprene (2-methyl-1,3-butadiene). It was possible to verify that the resin *Protium heptaphyllum (Aubl.) March* presents as an alternative source for obtaining α and β-amyrin in significant amounts [1].Irradiation with cobalt-60 has been explored as a means of improving the physical characteristics of plant material, in addition to moderate doses of irradiation reducing fungal,bacterial contamination and delaying aging processes. In this work, different irradiation doses were applied to *Protium heptaphyllum* resin, for characterization and possible improvement purposes.Irradiated and non-irradiated resin was physical and chemical characterizated using Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM) and thermogravimetric analysis (TG/DTG).The TG/DTG curves of the irradiated resin samples showed characteristic endothermic events of evaporation of adsorbed substances and thermal decomposition and suggest the occurrence of phase transitions, such as melting between 180 and 200 °C, which can be attributed to the melting of the resin's major constituents, such as α and β-amyrins.

Acknowledgments
The authors would like to thank the technicians and professors responsible for the CETER-IPEN labs. CNPQ and CAPES.

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Radioluminescence and radioisotope thermoelectric generator as a use of spent nuclear fuel

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Keywords: spent nuclear fuel, nuclear battery, radioluminescence, decay energy, RTG, microsources of electricity

The article will discuss radioisotopes produced during nuclear reactor operation and the problem in determining the composition of spent nuclear fuel. Possible options for using this material as a power supply for micro sources of electricity such as nuclear batteries or a radioisotope thermoelectric generator will be presented.

Battery technology uses semiconductors to convert radioactive decay energy into electricity. In this way, they are able to power devices continuously for up to 100 years, while they are characterized by low power of the order of μW/cm3. A luminescent layer between the semiconductor and the radiation source can increase the efficiency of this device. On the other hand, another limitation is the intensity of the radiation-induced luminescence effect. It is often attempted to solve this problem without interfering with the chemical composition of the luminophore.

The aim of this work is to increase the phosphorescence effect by inducing inhibition radiation. The measurements will be carried out using a designed test station, which will be made using 3D printing technology. The most important elements of the test station are shown in Figs. 1 – 4. The article, in its concept, is to compare the electrical power obtained with a nuclear battery model without a luminescent layer and a radioluminescent battery.

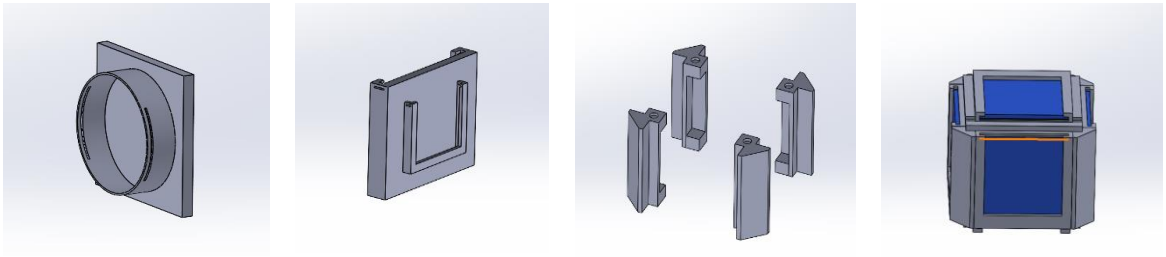

***Figure 1-4**. Test station*

Consideration of Quantitative Risk Reduction and Risk Achievement Measures in Safe NPP Design

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Keywords: nuclear power plant, probabilistic safety assessment, risk importance measures

Risk importance measures obtained from probabilistic safety assessments (PSAs) of the nuclear power plants (NPPs), [1], are integral elements of consideration in many cases, including solutions for safe NPP design. In PSA models and applications associated with NPPs the risk importance of a particular feature (e.g., function, system, component, failure mode or operator action) can be, most generally, divided into two categories: importance with respect to risk increase potential and importance with respect to risk decrease potential. The representative of the first category, as used for practical purposes, is Risk Achievement Worth (RAW). Representative of the second category, as mentioned in consideration of risk importance, is Risk Reduction Worth (RRW). It can be shown, [2], [3], that the two risk importance measures, RAW and RRW, are dependent on each other. The only parameter in this mutual dependency is probability of failure of the considered feature. Presentation discusses the relation between RAW and RRW and some of its implications, including those on the general strategies for the reduction of risk associated with particular NPP design. In NPP PSA models, risk is usually quantitatively expressed via the metrics such as reactor core damage frequency (CDF) and frequencies of events with large and early radioactivity releases. Two general risk reduction strategies considered in the discussion are: Strategy I - risk reduction while keeping the failure probability of the considered feature at the same level; and Strategy II - risk reduction by decreasing the failure probability of the considered feature (both illustrated in Figure 1).

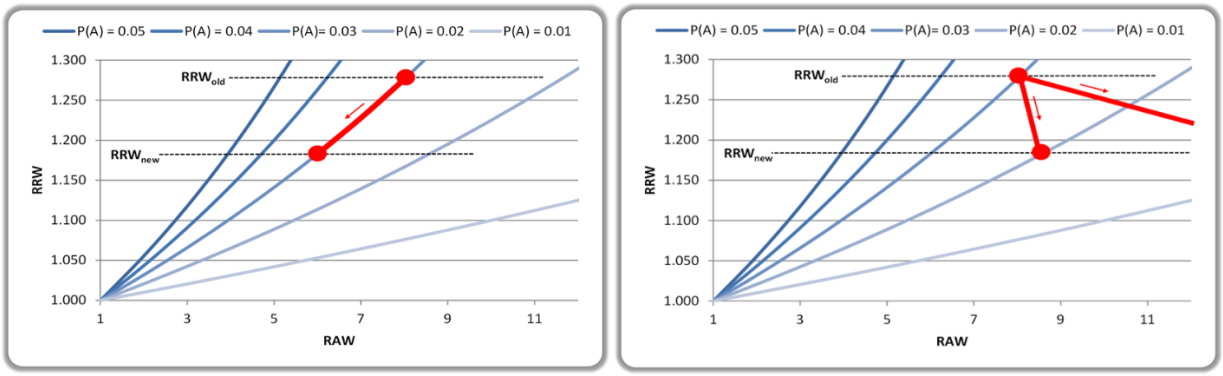

***Figure 1**. Illustration of Strategy I (Left) and Strategy II (Right)*

Simple example is provided to illustrate the differences between two strategies and point to main issues and conclusions.

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Environmental and safety aspects of introducing small modular reactors to industrial power and CHP stations

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Keywords: small modular reactors, NuScale, BWRX-300, emission of pollutants, radioactive waste, nuclear safety

The Polish Nuclear Energy Program assumes the installation of electric power of 6-9 GW in two or three commercial nuclear power plants, which will be based on the technology of large-scale pressurized water reactors. These activities are intended to reduce the emission of harmful substances into the environment and reduce the negative impact of the energy sector on the environment. These plans result from the current legal conditions in this respect. However, legal regulations also cover industrial energy installations. The nuclear option is of interest to the Polish industry, but it is planned to use small modular nuclear reactors in this regard. The most energy-intensive industrial companies even indicated specific technological solutions: the NuScale reactor based on PWR technology and the BWRX-300 reactor, which is a boiling water reactor.

As part of this work, an estimated analysis of the reduction of environmental pollution associated with the replacement of existing power plants and industrial CHP plants in four locations with the use of nuclear reactors mentioned earlier was carried out. At the same time, the potential amount of radioactive waste (including spent nuclear fuel) that would be associated with the operation of nuclear units was estimated. Some problems resulting from the inability to provide technological heat at the appropriate temperature level were also indicated.

The analyzed SMR reactor designs are characterized by interesting safety solutions. The paper characterizes the most important safety systems and conducts their comparative assessment in relation to the solutions used in large nuclear reactors. A security assessment was also carried out in relation to the applicable regulations in this regard. Particular attention was also paid to the issues of locating nuclear units in the immediate vicinity of industrial plants, but also densely populated areas.

Acknowledgments
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Monitoring of radioactivity in atmospheric precipitation in Krakow

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Keywords: precipitation, gamma-emitters, radioactivity of air

Two high volume aerosol sampling stations type ASS-500 work at the Institute of Nuclear Physics (IFJ PAN) in Krakow. This station, produced by Polish Central Laboratory for Radiation Protection (CLOR) is an aerosol sampler used for routine air radioactivity monitoring since 1990. Additionally, precipitation samples (rain and snow) have been collected monthly from 2005 to now. The samples were gathered in a fallout funnel , which was standalone station having an area of 2.28 m2.The rainwater together with dry precipitation were collected in plastic barrels with a volume of 160 L. Precipitation were acidified with 50 mL nitric acid to prevent any loss of radionuclides by adsorption to the surface of the vessel used. All the rainwater samples were evaporated into stainless steel vessel of 10 L volume. At the end of each procedure, rainwater samples were transferred to plastic vessel (5 cm diameter, 120 mL volume) and were evaporated to dryness under infrared lamp. The samples were analyzed using a low background gamma spectrometry. The absolute efficiencies of the detector were determined using calibrated with mix multi-gamma sources produced by Polatom, Świerk, with the same geometry. While analyzing the measurements reported here, our laboratory participated in gamma-spectrometric intercalibrations organized by the IAEA, PAA and the results were approved. The laboratory works in ISO—17025 accreditation regime. The research over 18 years on monthly basis revealed clear signals from:

1. Fukushima accident [1],
2. Still a bit mysterious presence on ^{106}Ru staring from October 2017 [2,3]
3. Numerous event of forest fires in Chernobyl zone [4]

The presented on poster measurements refers to recent time, were collected over 2.5 years (January 2021 to June 2023). The results for activity concentration of ^{7}Be and ^{22}Na, ^{137}Cs and ^{40}K obtained monthly show seasonal variations.

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Analysis of Polish coal-fired power plants from perspective of modernization potential with nuclear reactors, including SMRs

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Keywords: nuclear reactors, DEsire project, coal-to-nuclear retrofit, small modular reactors, decarbonization, coal-fired power plants

The progressive decarbonization of electricity generation is a phenomenon that is particularly relevant to the Polish energy-mix, where coal-fired power plants are still a very important component. In recent years, the share of renewable energy sources in the Polish energy-mix has increased significantly. However, the current technical and economic conditions do not allow the power system to be completely based on this type of power plants. Forecasts indicate that in the coming years, the role of power plants based on the combustion of natural gas and probably based on nuclear reactors will increase in Poland. As part of this work, the potential synergy between the declining share of coal-fired power plants and the projected increasing share of nuclear power plants (including small nuclear reactors) was analyzed.

In order to assess existing coal-fired power plants in terms of retrofit with nuclear reactors, in the first stage, a methodology for quantifying parameters was proposed for 107 power units which are parts of 23 Polish power plants (or combined heat and power plants). For this purpose six assessment areas were selected:

- technical parameters of power units,
- electricity infrastructure,
- transport infrastructure,
- availability of cooling water,
- the date and area of availability of the required site,
- demand for district heat.

For each area, a quantifying parameter and a materiality criterion in the final assessment were adopted. A distinction was made between evaluation criteria depending on whether a retrofit of generation III or IV reactors was considered. In the case of the retrofit with IV generation reactors, it was assumed that the parameters of live and secondary steam produced by the reactor fit with the parameters of steam supplied to steam turbines, currently operating within coal-fired units. Such a scenario potentially limits retrofit capital expenditures, as it allows to use of a significant part of the technical infrastructure of existing coal-fired units. Finally, a ranking was created of the power units and power plants whose parameters were considered most favorable for conversion from coal combustion to sources based on nuclear reactors.

Acknowledgments
The paper was created as a result of the project: "Plan of decarbonization of the domestic power industry through modernization with the use of nuclear reactors", financed by the National Center for Research and Development under the Program "Social and economic development of Poland in conditions of globalizing markets" GOSPOSTRATEG (Contract No.: Gospostrateg VI/0032/2021-00 dated March 15, 2022).

Coal-to-Nuclear decarbonization pathway - a case study

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Keywords: nuclear reactor, decarbonization, energy transformation, steam island

The research presented here focuses on a transformation of an existing power grid with a dominating share of coal-fueled power generating units and replace them with nuclear power plants. The main assumption is that a large part of existing installations may be used in nuclear systems. This includes mostly the steam turbines cycles, which are far from their lifetime limits. The Coal-to-Nuclear approach is considered in the report of the US Department of Energy [1] and in technical publications, for example [2].

The proposed transformation includes the application of the fourth generation nuclear reactors, which may provide the heat necessary to generate the steam for the turbines [3]. The reactors are currently under the development and the expected years of their start of the operation are 2028-2030 [4].

The Coal-to-Nuclear approach requires a coupling of an existing steam cycle with a sufficient number of nuclear reactors. The steam turbines are expected to operate in off-design conditions to satisfy the required parameters at the inputs and the outputs of the reactors systems. The presented research involved a numerical modelling of a steam island and the optimization of its parameters to achieve the best coupling with a nuclear reactor in terms of the efficiency criterion. The numerical model allows to verify different operating conditions.

The obtained results indicate that the analyzed steam cycle must be expanded to include additional components. This is due to the difference between the current and the required temperature of the steam and the feed water. The live and the reheat steam temperature must be reduced, while the feed water temperature must be increased. The research provided a list of modifications to the steam cycle that guarantee the highest power generation efficiency.

Acknowledgments
The paper was created as a result of the project: "Plan of decarbonization of the domestic power industry through modernization with the use of nuclear reactors", financed by the National Center for Research and Development under the Program "Social and economic development of Poland in conditions of globalizing markets" GOSPOSTRATEG(Contract No.: Gospostrateg VI/0032/2021-00 dated March 15, 2022).

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Eye lens dosimetry as consequence of eye lens dose limit reduction. Analysis of $H_p(3)$ measurements based on the experience of LADIS at the IFJ PAN

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Keywords: eye lens dosimetry, eye lens dose

The purpose of this study is to analyze results of eye lens dose measurements performed by the Laboratory of Individual and Environmental Dosimetry (LADIS) at the Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN) and compare it to the valid eye lens dose limit. The laboratory LADIS conducts regular and accredited dose measurements for nearly 12,000 entities in Poland and abroad using the thermoluminescent materials, mainly MTS-N (LiF: Mg, Ti) and MCP-N (LiF: Mg, Cu, P) detectors. The most accurate method of monitoring the dose to the lens of the eye is to measure the individual dose equivalent $H_p(3)$ with a dedicated dosimeter worn as close to the eye as possible.

In the presentation we analyse results of almost 20 000 $H_p(3)$ measurements performed by LADIS in 2014-2022. An increase in the number of performed $H_p(3)$ measurements have been observed since the introduction of a new dose limit to the Polish law in 2019 and by ICRP recommendation to reduce the dose limit for the eye-lens from 150 mSv /year to 20 mSv /year.

Most of the $H_p(3)$ values are at the level of natural background but still quite high $H_p(3)$ values are recorded. The fact that most of the measured values are at the background level indicates that appropriate measures of radiation protection of staff working with ionizing radiation are undertaken. However the $H_p(3)$ values that exceed the yearly dose limit support the need of constant dose monitoring of employees working with ionizing radiation.

Use of gamma spectrometry synthetic data in the training of neural networks for activity measurements

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Keywords: gamma spectrometry, machine learning, computational physics

The work presents a gamma spectrometry synthetic data-generating method for a gamma spectrometer based on given device calibration data and sample definition. The shape of the gamma spectrum registered from a radioactive sample depends on detector characteristics, measurement geometry, and environmental conditions, apart from the desired changes related to gamma rays emitted by the radionuclides. In the case of in-situ gamma spectrometry measurements, the energy calibration varies on the detector temperature which causes the drift of the full energy peaks on the spectrum [1]. Additionally, the efficiency calibration differs between devices, measurement geometries, sample materials, and absorbers if present. Thus, the neural networks (NN) applied for gamma spectrometry data analysis need to be trained on large volumes of data to decrease uncertainties and mitigate false positive errors [2].

This study presents a set of procedures for the generation of synthetic data for the training of the NN. Then, the use of a convolutional NN is presented for activity estimation based on gamma spectrometry measurement. The use of synthetic data limits the difficulty in the accessibility of representative experimental data for NN training and opens the possibility of the development of more sophisticated machine-learning tools for gamma spectrometry.

Acknowledgments
I like to thank my colleagues from the Central Laboratory of Radiological Protection in Poland for the exchange of knowledge and help in making this work possible.

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Thorium fuel cycle research potential at AGH University of Krakow

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Keywords: thorium, thorium assembly, MCB

Thorium is a naturally occurring element that is considered as an alternative nuclear fuel material for energy production. Thorium itself cannot undergo nuclear fission reaction but serves as a so-called fertile material. Thorium-232 after capturing a neutron become thorium-233 and through double beta decay becomes a fissile uranium-233.

For many years, thorium fuel cycle development has been marginalized, mainly because of sufficient uranium resources. However, the interest in thorium utilization has been renewed and is gaining increasing attention due to some beneficial physical and chemical properties compared to uranium. Among those benefits can be mentioned: superior abundance, lower waste radiotoxicity, ThO_2 chemical stability and better thermo-physical properties, the intrinsic proliferation resistance of thorium-based fuel, possibility of plutonium incineration without its production [1].

At AGH University of Krakow there is located a thorium-lead assembly. The core of the assembly consists of ThO_2 fuel rods manufactured in Bhabha Atomic research Centre (BARC) India surrounded by metallic lead rods manufactured at AGH University. [2]. The design of the individual elements allows for their different arrangements depending on the planned irradiation experiment. Lead partially replacement and/or use of other materials, like graphite or polythene can be considered, as well.

Before any experiment would be carried out, detailed numerical calculations should be performed. It is necessary to find the optimal irradiation geometry depending on planned research. To do so, the Monte Carlo Continuous Energy Burnup Code – MCB, a code developed at AGH University can be used [2].

The work will present the possibilities and potential of conducting research related to thorium fuel cycle at AGH University. Nowadays, the only works which can be performed are the numerical simulation one. However, taking into account the development of Polish nuclear program, radiometry laboratory located at university and equipped with such a unique experimental setup, would be a great place both for scientific research and future expert education.

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Plan of decarbonisation of the domestic coal power industry with the use of nuclear reactors - goals and objectives of the DEsire project

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Keywords: nuclear energy, power industry decarbonisation

In 2022 the DEsire project was launched. Its main aim is a complex preparation of domestic power industry decarbonization plan by means of modernization with use of generation III/III+ and IV nuclear reactors. The project is implemented by a consortium established by five entities: the Silesian University of Technology, the Ministry of Climate and Environment, Energoprojekt-Katowice SA, the Institute of Nuclear Chemistry and Technology and the Sobieski Institute. Funding of the project was obtained under 6th competition of the National Centre of Research and Development „GOSPOSTRATEG".

The implementation of nuclear power in the power sector decarbonising process is a response both to the impending need to replace aging coal-fired power plants and to the necessity to increase the stability and flexibility of energy system. The process of replacing carbon sources will be a long-term process. The technologies that will be selected for applications in individual places of the current coal-fired units operation should be selected based on an in-depth technical and economic analysis, taking into account also environmental and social aspects.

Regardless of the age of the country coal power generation systems, each location appropriate for these systems is potentially beneficial in the context of investment processes aimed at continuing energy activity after the end of coal units operation.
It is connected with the high human potential in the area of large power generation systems management and servicing, generally irrespective of the provided technology. Maintaining jobs in areas where coal units activity is being phased out, including the very often operations of coal mines coexisting with production systems, is beneficial in the social context, but also results in higher acceptability for planned investor actions. The location of the investment close to the coal-fired unit may also lead to a significant reduction in investment costs, which may be related to the use of some of the existing technical and construction infrastructure in case of the new energy source.

The DEsire project undertakes to assess the technical and economic potential, the level of social acceptability and the human resources preparation, and on the basis of this, create a plan for the modernization of national power units in accordance with the idea of Coal-to-Nuclear transformation. An important cognitive aspect is the assessment of the possibility of using the existing coal-fired units infrastructure as part of nuclear investments, both for the use of generation III / III + and generation IV reactors.

Acknowledgments
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Isotopic changes in nuclear fuel during first cycle of APR1400 reactor

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Keywords: APR1400, PWR, Monte Carlo, numerical model, burnup

The study considers Monte Carlo modeling of the neutron transport and isotopic changes in nuclear fuel during first reactor cycle of the Korean APR1400 PWR reactor. The analysis was performed using the continuous energy Monte Carlo Burnup code – MCB. The detailed 3D numerical model at the level of the reactor vessel was developed for numerical modelling – Fig. 1. The nuclear fuel was divided into 11 uniform axial burnup zones and 22 radial burnup zones to obtain core burnup distribution [1]. The radial burnup zones corresponds to the specific fuel assemblies envisage for the first reactor cycle.

In the simulation the isotopic changes in nuclear fuel in each burnup zone were investigated [2,3]. Additionally, the reactivity control systems were included in the simulation, especially chemical shim adjustment and burnout of the Gd_2O_3 burnable absorber. The control rods are placed above the active core in the model but they are not used for reactivity control according to the assumption of the first reactor cycle.

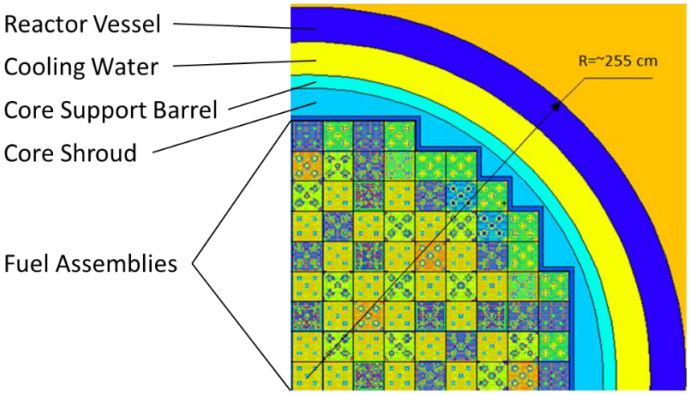

***Figure 1**. Cross-section of the ¼ APR1400 numerical model developed for the Monte Carlo simulations*

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CPL Interference in ROA Spectra of Chiral Lanthanide Complexes with L- and D-Alanine

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Keywords: chiral lanthanide complexes; alanine; Raman; ROA; lanthanide contraction effect

Our interest in lanthanide complexes stems from the relevance of the effective separation of lanthanides from actinides recovered from spent nuclear fuel. Lanthanides pose a problem in fuel reprocessing because they are chemically similar to long-lived, highly radioactive minor actinides. Hence, we are investigating new properties and looking for unique spectroscopic features of lanthanide complexes. The chirality of the compounds makes it possible to use modern chiral optical techniques, for their characterization.

Circularly polarized luminescence (CPL) and Raman optical activity (ROA) are optical spectroscopy tools for studying chiral molecules' structure and interactions. ROA is the chiral version of Raman spectroscopy which measures the optical activity of a chiral system using either scattered circular polarization. On the other hand, the CPL method enables the investigation of chiral interactions of luminescent molecular systems like lanthanide coordination complexes. Photophysical and CPL properties of lanthanides can be used for identifying, monitoring, or imaging various biomolecules.

In this study, CPL and ROA several chiral lanthanide complexes with L- and D-alanine [1] were simultaneously registered in a single spectroscopic experiment. In these complexes, the metal ion is coordinated by four water and four alanine molecules. Their CPL properties are due to high magnetic dipole moments of the f→f electronic transitions, whose excitation energies reach the mid-infrared range and thus can be registered in ROA experiments (*Figure 1a*). The CPL signal intensity was exceptionally high for the Eu^{3+} and Sm^{3+} complexes because their excitation energies are close to the 532 nm excitation line used in the ROA spectrometer. Moreover, the Raman spectra of lanthanide complexes (but Pm) in the solid state were registered using 488, 532, 633, and 1064 nm excitation lines which strongly modified the spectral pattern (*Figure 1b, c*).

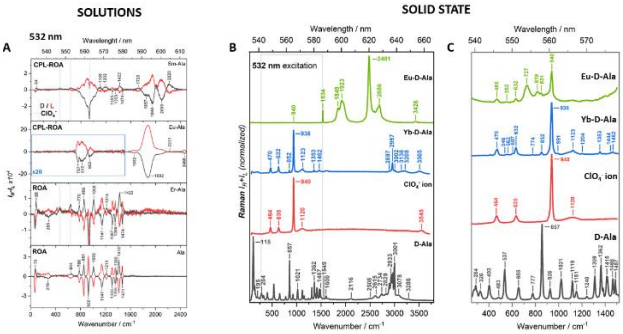

Figure 1. *ROA (A) and Raman (B,C) spectra of Ln complexes with and without presence of CPL*

Acknowledgments
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Removal of Microplastics from Sewage Sludge

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Keywords: electron beam treatment, water radiolysis, microplastics removal, advanced oxidation

Sewage sludge treatment plants are known to be an important entrance route for microplastics (MPs) into the aquatic environment. Although methods exist for the removal of MPs from sludge, these are currently inefficient. The possibility of using electron beam treatment for the removal of microplastics from wastewater and sewage sludge has been investigated. Six types of plastics in daily use were treated at a range of doses in tap water and in sewage sludge, taken both before and after anaerobic digestion. The electrons were found to significantly increase the sedimentation of four out of six of the types of MP in both water and sludge, while the other two largely remain floating. Density separation techniques of the treated samples have then demonstrated high removal efficiencies for the MPs at reasonable EB doses. This potentially provides a route to high efficiency removal from sludge.

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International Trends in Irradiation Technologies and Markets

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Keywords: gamma, electron beam, x-ray

Irradiation is a well established global industry that continues to evolve. At its core irradiation is used for bioburden reduction and in the modification of polymers but today irradiation is offers solutions to many challenges with core applications benefitting the health and wellbeing of a large proportion of the global population.

Increasingly the development and evolution of irradiation technologies and applications is influenced by external factors that either encourage or restrict applications and support or inhibit technological evolution and scientific research.

This presentation will review the leading commercial applications irradiation technologies, applications that have not been widely adopted and novel applications that offer solutions to current global challenges. The presentation will highlight why gamma, which is closely connected with the nuclear sector, will remain important for the foreseeable future and what scientific research could encourage increased adoption of accelerators for new and expanding applications. The presentation will consider the impact of geopolitical, business, climate and environmental issues on the likely evolution of irradiation technologies and applications.

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Influence of the type of fuel used on the content of gamma radionuclides in the soot from the smoke ducts of the home furnaces

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Keywords: gamma radionuclides, soot, PCA

The article presents the results of measurements of radioactive gamma isotopes in soot samples from 15 different chimneys from home furnaces fired with various types of solid fuels. Soot samples were collected by the chimney sweep during the mandatory periodic cleaning of chimneys. Based on the testimonies of users, it was found that the fuels used were hard coal, eco-pea coal, wood pellets, various types of wood and, in one case, plywood and chipboard. The following gamma radioisotopes were determined: ^{137}Cs, ^{40}K, ^{228}Th, ^{226}Ra, ^{210}Pb. Measurements were made using a gamma spectrometer with an HPGe detector (BE3830 Canberra/Mirion) with a relative efficiency of 34%, and low background lead shields. A principal components analysis was performed for 15 studied cases and 6 variables (an additional variable was soot density). Two principal components were extracted, because only they had eigenvalues greater than 1. The cumulative eigenvalue of the first two principal components was almost 4.4 and they explain 73.3% of the observed variance. The PCA (Fig. 1) carried out on the obtained results allowed for an almost perfect division of the tested soot due to the combusted fuel from which they were produced. One of the exceptions was soot from one type of eco-pea coal, where its density reached 1.32 g·cm^{-1} (the average for other soot was 0.47 g·cm^{-1}).

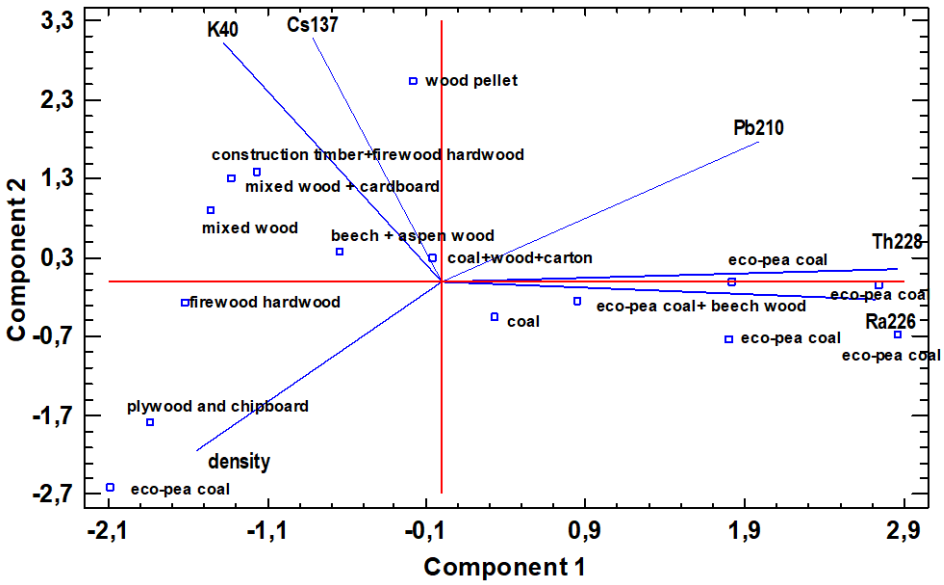

***Figure 1**. Principal component analysis of the measurements results*

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Spatial distribution of natural and artificial radionuclides in protected areas of Małopolska voivodeship

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Keywords: radionuclides, radioecology, environmental dosimetry

Naturally occurring radionuclides of terrestrial origin and artificial radioactive contaminants are present in almost all environmental media. There are many different radioisotopes, but in practical terms, only a few have sufficient abundance and radiological importance. Most research on naturally occurring radionuclides in soils has focused on primordial ^{40}K, ^{238}U, and ^{232}Th. On the other hand, assessment of anthropogenic radionuclides is usually limited to the most scattered isotope – ^{137}Cs. Research carried out in this area is mainly concerned with the assessment of radiation dose to populations or analyzing the mechanisms that determine the spatial distribution of radionuclides. To support research in the discipline, a spatial data layer has been created to provide the content of selected radionuclides in the protected areas of Małopolska voivodeship, taking into account the subdivision into macroregions.

The goal of this work was to compile the results from long-term research conducted by the Laboratory of Radiochemical Analytics and Radioactivity in the Environment. This allowed the creation of a broad-use database, provided in the form of geographic information system data.

The data was generated from 120 measurement points located in the Małopolska voivodeship. The samples were taken as a surface soil layer, to a depth of about 10cm. Soil was taken with a standardized sampler, with a known area, where each profile slice was further divided into 3 layers. To determine the radioactivity, a technique of gamma radiation spectrometry was involved, with the use of a high-purity germanium (HPGe) semiconductor detector (Canberra model BE3830).

The results were recalculated, obtaining the radioactivity concentration per unit of mass ($Bq \cdot kg^{-1}$) and area ($Bq \cdot m^{-2}$). In addition, the rate of the absorbed dose and annual effective dose were calculated. The collected data was processed using ArcGIS software, developed by ESRI. The structure of the data was prepared according to the latest cartographic study of Polish macroregions [1]. Maps were also generated, allowing a presentation of the spatial distribution of the calculated parameters in macroregions.

The created GIS data layer allows for a wide range of applications within the framework of the GIS software. It can be combined with other GIS data, e.g. layer of geological formation, climatic factors, or air quality. For future work in the field, it can be an interesting and helpful tool.

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Radionuclides and heavy metals as indicators of contamination of Rybnik reservoir

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Keywords: radionuclides, metals, sources, contamination, risk assessment

Sediments are an important component of water ecosystems and a valuable source of information on the aquatic ecosystem [1]. Among sediment contaminants, a significant role is played by heavy metals and radionuclides, especially of artificial origin such as ^{137}Cs [2].

The aim of the study was to evaluate the level of the presence and contamination of sediments collected from the Rybnik reservoir. The results of determination of radionuclides (^{137}Cs, ^{30}K, ^{228}Th, ^{228}Ra, ^{226}Ra, ^{210}Pb) and heavy metals (Zn, Cd, Pb, Cu, Cr, Ni) were presented.

The Rybnik reservoir is located in the Silesian Voivodeship, in the centre of the Rybnik Coal Area, which is one of the main industrial regions in southern Poland. This region is a highly urbanised, which mainly involves hard coal mining, power generation, metallurgy and transport. The samples were collected from 9 stations at a depth of 0-15 cm using an Eckman sampler. The radioactivity of selected radionuclides in sediment samples was determined by gamma spectrometry [1]. The heavy metal content was analysed using an inductively coupled plasma optical emission spectrophotometer (ICP-OES) [2].

The radioactivity of ^{226}Ra, ^{228}Ra and ^{228}Th was around 10Bq·kg^{-1} with the highest being 19.9 Bq·kg^{-1}. The level of ^{40}K was in the range from 124.8 to 266.9 Bq·kg^{-1} and ^{210}Pb from 10.8 to 109.9 Bq·kg^{-1}. The content of artificial radionuclide ^{137}Cs in most samples was less than 10 Bq·kg^{-1} with the highest concentration of 44.73 Bq·kg^{-1}, which indicated a good quality index. The average content of heavy metals was as follows: Cd < Cr < Pb < Ni < Cu < Zn < Mn < Fe. The results show that Cu and Ni were mainly responsible for sediment contamination.

The geochemical indicators and the contents of artificial radionuclide can be used as a determinant of the level of anthropopressure in the area of the reservoir in Rybnik.

Acknowledgements
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Use of alpha spectrometry in estimation the radiotoxicity of coffee beans

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Keywords: polonium, radiotoxicity, risk assessment, coffee

Coffee is the fruit of a shrub of the Rubiaceae family, the genus Coffea. The plant is difficult to cultivate, and optimal conditions for its development occur in the tropics. The coffee tree is cultivated in more than 75 countries, and plantations cover 11 million acres of land. The coffee plant absorbs minerals and trace elements from the soil, including pollutants such as radioisotopes. The coffee plant can also take up radioisotopes from the air as a result of dry and wet deposition [1].

The aim of this study was to develop a procedure for the determination of an alpha radionuclide ^{210}Po in coffee samples and to compare the radionuclide content in beans from different regions of the world. On the basis of the obtained results, the effective doses of coffee for an adult of the general population were estimated.

The researched materials consist of: green coffee beans from a coffee roasting plant near Krakow and commercial black coffee purchased in a grocery store. Green coffee beans are varieties of Arabica and Robusta originating in North America (Honduras, Guatemala, El Salvador) and South America (Brazil, Peru, Colombia), Africa (Uganda, Ethiopia) and Asia (India). Additionally commercial black coffee Lavaza Qualità Oro and MK Cafe Premium were used. Radiochemical analysis was used in order to determine ^{210}Po in coffee. The samples were first ground, homogenised, digested, evaporated with 2MHCl and the radioactive source was prepared. ^{210}Po was measured in alpha spectrometry and the results were calculated using Genie-2000 software and the law of radioactive decay.

The highest concentration of polonium was obtained in green coffee beans for the Robusta Cherry scr AA coffee and India Monsooned Malabor AA coffee from India, and the lowest for the Peru MCA. For commercial black coffee, Lavazza Oro has the lowest concentration of ^{210}Po and MK Cafe coffee has the highest concentration of this radionuclide. The concentration of polonium in the MK Cafe coffee machine infusion (0.432 Bq·kg^{-1}) is almost five times higher than in the traditional brewing infusion (0.089 Bq·kg^{-1}).

The assumed effective dose from drinking coffee or eating the beans (e.g. in chocolate) is irrelevant from radiological point of view.

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Preliminary studies on the radioactivity of ^{210}Po in selected tobacco products

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Keywords: polonium ^{210}Po, tobacco, tobacco products, alpha spectrometry

Tobacco as a plant, due to its biological characteristics, is more vulnerable to the deposition of products from the atmosphere or soil. Also as a crop, it increases this risk through agrotechnical treatments [1]. Radionuclides are also extensively accumulated in tobacco leaves, resulting in significant radiological exposure to cigarette smokers. Especially attention should be paid to ^{210}Po. It is a highly radiotoxic radionuclide and can re-enter the environment when tobacco is burnt in tobacco products.

The purpose of this study was to determine the concentration of ^{210}Po in selected tobacco products.

The research was carried out in several stages. The process started with the digestion of the weighed tobacco samples in the presence of concentrated acids, the concentration of the samples under heating lamps, and the preparation of a radioactive source in the deposition process. Then measuring polonium with an alpha spectrometer, collating the results and performing calculations for determining radioactivity.

The overall concentration of radioactive ^{210}Po of the tobacco products tested was between 16.4 ± 1.9 and 38.2 ± 3.9 [Bq·kg^{-1}]. Considering the ^{210}Po radioactivity due to the origin of tobacco from a given parcel, the amounts vary slightly. Also considered was whether there are differences between unburned and burnt tobacco cartridges. For most of the samples tested, an increase in ^{210}Po concentration was observed in burnt cartridges compared to those without burns. Determining whether the flavour affects the ^{210}Po concentration in tobacco products requires more research because there is currently a visible difference, but it also occurs between the same flavours studied, so the influence may not be the flavour introduced in the cartridge, but the origin of the tobacco, which is currently unknown. Drawing conclusions about the comparison of the level of radioactivity in traditional cigarettes in relation to the heaters used, requires continued research.

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Mobile Medium Energy eBeam Platform for Environmental Applications at Texas A&M University

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One of the emerging applications for both gamma and eBeam includes environmental remediation. By promoting and developing the eBeam approach to remediation there will be global access to alternatives to radioisotope-based irradiation technology. To accomplish this mission, Pacific Northwest National Laboratory and Texas A&M University are partnering with technology providers in the area of eBeam technology to design and build a mobile eBeam system that can be used in the field for environmental cleanup. Given that mobile eBeam platforms have been developed in the past for low dose applications such as wastewater and drinking water treatment, the primary objective of the Texas A&M University mobile eBeam project is to focus on the remediation of PFAS-impacted environmental media including sewage sludges, soils, groundwater and drinking water. Studies in our group have shown that very high doses (between 500 kGy and 2000 kGy) must employed to achieve complete degradation of PFAS. There are specific design criteria including, 1) the treatment will have to focus on solids as well as liquid or semi-solids, 2) the product handling and product conveyance system will have to be designed for either continuous treatment or batch treatment, 3) the mobile system will have to be designed with all the necessary and required utility connections, ozone abatement and other critical infrastructure needs. Specifically, the mobile system needs to be designed to meet the exacting requirements for environmental remediation of PFAS-impacted soils, groundwater, and similar matrices. The accelerator should have a beam energy between 2 MeV and 3 MeV with a maximum power to be able to treat a 50-gallon drum of media per day. The shielding should consider the vertical/horizontal configuration of the accelerator and should also take into consideration weight, cost, time to fabricate, time to set up at field site, etc. The design should consider access to the material handling system beneath the beam window for the remediation purpose; access to repair/replace parts; the need for beam window cooling and ozone abatement. The current design involves the use of a 3 MeV, 13 kW to allow a meaningful remediation treatment and material throughput.

IAEA Perspective on Radiation Science and Technology: Current and Future Plans

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The mission of the International Atomic Energy Agency (IAEA) is to accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world. This includes supporting the development and implementation of radiation science and technology in Member States, through all IAEA existing mechanisms. This support involves initiatives at national, regional, and global level for implementing proven industrial applications that lead to socio-economic benefits and strengthen capacity building in Member States.

Numerous innovations and accomplishments in the field of radiation sciences have been already acknowledged, however there is always space to take a comprehensive look at their status in academia and industry, as well as their ability to meet future challenges. IAEA is supporting Radiation scientists in addressing issues related to those areas in which radiation technology might have a positive impact: clean our environment (wastewater treatment, sludge disinfection, flue gases, plastic pollution – NUTEC plastics); enhance life and health quality (sterilization of medical devices and tissue allografts/tissue engineering); develop advanced materials (bio and nano materials, functionalized materials, etc); and preserve our past (cultural heritage preservation). Besides radiation processing applications, there are other radiation technologies, such as the use of radiotracers to improve and optimize the performance of industrial process operations (petroleum refineries, mining and ore processing wastewater treatment plants etc), to study and understand the dynamics of environmental processes such as sedimentation and erosion of coastal infrastructure, and to control the quality of products. Radiation technologists and radiotracer technologists in industry, on the other hand, are faced with other challenges, such as ensuring the safe and reliable operation of radiation facilities, developing, and implementing requisite international standards for process control.

The International Atomic Energy Agency (IAEA), working in close partnership with its Member States as well as with professional scientific bodies and the industry, has striven to maximize the contribution of radiation sciences and technologies towards the achievement of the Member States' development priorities in a safe manner.

How to use advanced simulations for the design of nuclear power plants

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Keywords: simulation, FEA, seismic analysis, severe accident events, ageing

Advanced simulation plays an important role for the design of nuclear power plants. In order to analyze the complex loading situations that building structures at nuclear power plants are exposed to and to show that the demands on the structures from such actions can be handled, simulations play a key role.

In this presentation there will be shown various examples of how simulation, with the Finite Element Analysis (FEA) method, of both normal operation condition and extreme load events can be utilized in the design phase. Special focus of is on actions that are crucial for the structural design of buildings at nuclear power plants, e.g. seismic and other severe accident loads.

Simulation also plays an important role as part of ageing management of building structures at nuclear power plants. Experiences from participation in research projects within this field will also be discussed.

Use of radiation indicator tag as dosimetry method

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Keywords: polymer irradiation, electron beam applications, beam dosimetry

Industrial electron accelerators are widely employed for various applications including sterilization of medical products, cross-linking of polymers, and treatment of surfaces. Accurate dosimetry is critical to ensure the quality and safety of these processes. This paper presents a fast and reliable method of beam dosimetry for industrial electron accelerators.

The work shows the fundamental principles underlying electron accelerator operation and the generation of high-energy electron beams. Subsequently, it explores the importance of accurate beam dosimetry in industrial applications, highlighting the challenges posed by the unique characteristics of electron beams such as their energy distribution, dose rate, and spatial distribution.

A review of conventional dosimetry methods is provided, encompassing techniques like ionization chambers, film dosimetry, and radiochromic film dosimetry. Limitations associated with these methods, such as sensitivity to radiation energy, dose rate, and dependence on beam direction, are discussed.

The core focus of this paper is on the use of radiation tags as a dosimetry technique to address the specific challenge of beam uniformity rather than absolute product dose deposition of industrial electron accelerators.

Also, a portable dose reader is presented to facilitate beam profiling and to indicate the need for equipment repair, as in the case of wide curtain type industrial electron accelerators.

To demonstrate the applicability of these advancements, case studies are presented wherein the newly developed dosimetry methods were employed to optimize electron beam processes in an ebeam curable printing line. The results showcase improved process efficiency, enhanced product quality, and increased operational safety.

In conclusion, this paper highlights the critical role of accurate beam dosimetry in industrial electron accelerator applications. It underscores the need for advanced dosimetry techniques to address the unique challenges posed by electron beams. By harnessing these recent innovations, industrial processes can be optimized for better productivity and reliability, thereby contributing to advancements across diverse sectors.

Electron beam mediated thermally enhanced radiolysis responsible for PFAS degradation in soils

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Per- and polyfluoroalkyl substances (PFASs) are a diverse group of man-made chemicals extensively used in consumer and industrial products. They have a broad range of applications in products such as food packaging, textiles, surface coatings, pesticides, carpet treatment, and fire-fighting foams. Ionizing technology such as eBeam and gamma irradiation have now been shown to have superior properties in terms of their ability to break down complex organic pollutants. Studies in our laboratory have shown that eBeam technology at relatively very high doses is able to complete degrade PFAS such as PFOA and PFOS. We have identified 2000 kGy as the dose required for complete degradation of PFAS in soils and sewage sludges containing less than 10% water content. At this dose, the moisture in the samples get vaporized and condensates tend to accumulate. When soil and sludge samples are exposed to 2000 kGy, the samples experience temperature increases in the 600^{o}C to 700^{o}C. The behavior of radiolytic species in terms of environmental remediation at elevated temperature needs deeper study. We have shown that when the sample is exposed to 2000 kGy incrementally (in multiple passes under the eBeam scan horn) the PFOS degradation is only partial. We have observed a significant difference in the efficiency of PFAS breakdown depending on whether the high dose is delivered incrementally or whether in a single dosing. The difference can be attributed to the elevated temperature that would occur during the single dosing. We hypothesize that during high dose eBeam treatment, "thermally enhanced radiolysis" of PFAS compounds occurs which does not occur during incremental (ambient temperature) exposure to eBeam doses. We, therefore, propose that at elevated temperatures, the breakdown of the PFAS compounds occur as a result of direct bond breakage, indirect radiolysis and the effects of high temperatures.

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