PI3SO: a double-array gamma scanner for radwaste sorting *

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The PI3SO (Proximity Imaging System for Sort and Segregate Operations) project represents a cutting-edge advancement in the field of radiation detection and localization [1]. The system is able to identify and localize radioactive materials using a double-array scanner equipped with CsI(Tl) scintillators and Silicon Photo-Multipliers (SiPMs). Our evaluation highlights the system capability of detecting and quantifying radioactive sources, even in presence of shielding materials. The PI3SO system is composed of 128 CsI(Tl)+SiPM detectors organized in a double-array configuration, which provides extensive coverage and redundancy. Initial characterization tests of individual detector elements established a robust foundation for understanding the system's overall performance. The detectors underwent calibration with known radioactive sources, and their performance was evaluated based on energy resolution and peak detection capabilities.

In experimental trials, the system was tested with three distinct radioactive sources (^{137}Cs, ^{60}Co, and ^{22}Na) placed at predetermined positions. The system demonstrated identification of gamma sources, with results visually represented through imaging indicating the presence and intensity of radioactive materials. A notable achievement was the system ability to detect and localize a shielded ^{137}Cs source covered with a lead slab, underscoring its robustness in scenarios where materials may be partially or fully obscured. The system performed spectroscopic measurements to identify specific radioisotopes based on their characteristic gamma-ray spectra, confirming its capability of identifying gamma hot-spots and reconstructing the related energy spectrum.

The performance of the PI3SO system was further validated by evaluating its energy resolution and detection efficiency. The system achieved an energy resolution of approximately 9% FWHM at 662 keV (for ^{137}Cs), aligning with benchmark values for similar detectors. The capabilities of PI3SO system, even in the presence of shielding, make it an valid tool for nuclear decommissioning and radwaste sort & segregate operations. Our findings indicate that PI3SO system not only enhances safety and efficiency in handling radioactive materials but could also provide a robust solution for both routine monitoring and emergency response scenarios. Future research will focus on refining the system capabilities placing it at the forefront of radiation detection technology.

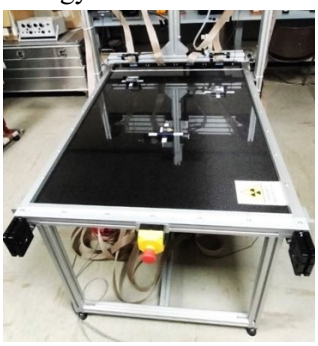

Figure 1- The PI3SO system: upper section.

References

[1] G. E. Poma et al., "Hot-spots finding with modular gamma-ray system for sort and segregate activities," in EPJ Web of Conferences, vol. 288, p. 06007, EDP Sciences, 2023.

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Enhancement and Modifications to a radiation detection instrument

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Abstract

The present paper addresses several key modifications to the BICRON radiation detection instrument to enhance its functionality and internal space optimization. Originally, the instrument had its analog display replaced by an LCD 2x16 display, with dimensions like the analog display, but not 100% exact. The replacement of the original Arduino Uno with a more compact Arduino Nano, along with the integration of a custom PCB, streamlined the internal arrangement, reducing cable clutter and improving module placement. The instrument's local storage capability was upgraded to fully utilize an SD card for recording measurement data, including timestamps, count values, GPS coordinates, and battery levels, all formatted into a CSV file for easy access. A NeoGPS 6M module was added to provide time and location data, though its performance is limited by satellite availability and requires an external antenna for optimal accuracy. Energy consumption was also addressed; the original analog design lacked an effective on/off switch, leading to continuous battery drain. The new system, powered by a rechargeable 9V battery, now includes an external on/off button to reduce power usage to around 2 hours of operation. These changes necessitated external modifications to the instrument's case to accommodate the GPS antenna and the new power switch.

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Promoting Diversity in Nuclear Security: The Role of the International Nuclear Security Educational Network (INSEN)

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Abstract

Promoting diversity in nuclear security is essential for cultivating an effective workforce capable of addressing the evolving global security challenges. This paper examines the role of the International Nuclear Security Educational Network (INSEN), a collaborative initiative under the auspices of the International Atomic Energy Agency (IAEA), in fostering diversity and gender parity within the nuclear security community. Established in 2010, INSEN serves as a platform for international cooperation among universities, research institutes, and other stakeholders to advance nuclear security education through innovative programs and collaborative partnerships. The network's mission is to enhance the global nuclear security regime by developing and promoting excellence in nuclear security education, including efforts to support gender balance. INSEN develops and reviews educational materials, curricula, and faculty development programs through its working groups, while also promoting nuclear education to a broad audience. It is known that women are underrepresented in the nuclear sector, and there are worldwide efforts to change this. By actively encouraging the participation of women and promoting inclusive policies and practices, INSEN aims to ensure that nuclear security education is accessible and equitable for all, contributing to a more resilient and comprehensive approach to global security. This paper provides an overview of INSEN's and highlights its efforts in promoting diversity and inclusion in nuclear security by advancing women and emphasizing their potential and expertise.

Characterization of the FOOT neutron detectors at the n_TOF facility

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The goal of the FOOT (FragmentatiOn Of Target) experiment, within the applied nuclear physics framework, is to perform high-precision cross section measurements of fragmentation reactions relevant for hadrontherapy and radiation protection in space. In fact, a thorough understanding of the physical and biological effects of nuclear fragments is highly relevant for developing efficient spacecraft shielding systems for long-term human missions in deep space, as well as for improving the planning of hadrontherapy treatments. However, there is currently a lack of available data in the literature to adequately model and calculate the behavior of nuclear fragments in these scenarios. This is especially true in the case of secondary neutron production, the impact of which is particularly challenging to estimate in radiation risk assessment studies.

The FOOT collaboration intends to carry out a series of studies using light ion beams, such as C and O, in the energy range of 100-800 MeV/n interacting with tissue-like and shielding material targets in order to fulfill the gaps in nuclear databases. By measuring the kinematic properties of the generated nuclear fragments, the FOOT experiment enables an accurate identification of them. The setup was initially designed for the detection of charged fragments and in 2021 the Collaboration started investigating potential solutions for neutron detectors.

There are two proposed detection systems that could be added to or upgraded from the current FOOT setup. The first system is based on BC-501A liquid scintillators that have the ability to discriminate between neutrons and γ. The other system is based on BGO crystals that operate in phoswich mode, and it may be a future upgrade of the FOOT calorimeter.

In 2022, a dedicated data acquisition campaign was carried out at the n_TOF facility at CERN in order to accurately assess the capabilities of the two systems. First, to study the neutron/γ discrimination efficiency of the BC-501A system several radioactive sources were used. Then, the two systems were placed in the n_TOF experimental area to study their neutron detection efficiency under a well characterized neutron beam. Since the n_TOF facility can produce a neutron beam with an energy spectrum spanning from thermal up to 1 GeV, it is especially well-suited for this measurement.

In this contribution, after an overview of the FOOT experiment, the first results on the characterization of the two potential neutron detectors are presented.

Geant4 Simulation of the CBM Silicon Strip Detector for Interaction Vertex Imaging

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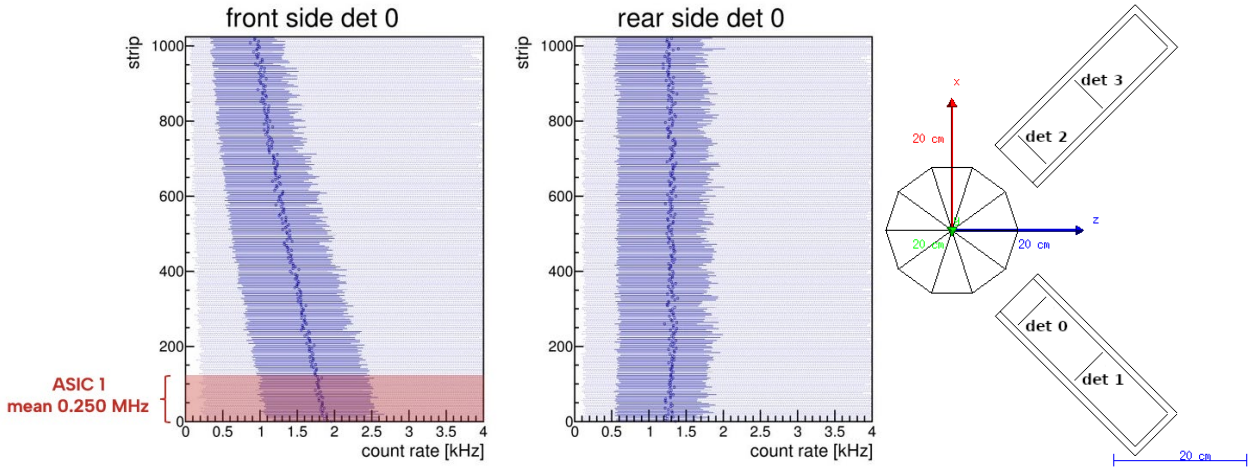
Interaction vertex imaging (IVI) is a method which can be used to determine relative range differences in Bragg peaks in heavy-ion therapy. Current treatment plans must account for uncertainties in Bragg peak position on the order of millimeters. The sub-millimeter precision of IVI reduces the overall treatment uncertainty and allows further reduction of dose to healthy tissue. Previous studies suggest that to achieve IVI under clinical conditions, large sensitive detectors will be required to operate at high event rates of order MHz [1]. One possible detection system uses the double-sided silicon strip detectors and fast readout electronics developed for the Compressed Baryonic Matter (CBM) experiment at GSI (Gesellschaft für Schwerionenforschung). To evaluate the suitability of this system, an IVI setup was simulated using the Geant4 Monte Carlo toolkit. The resultant event rates and cluster sizes, when compared to the capability of various readout configurations, are an order of magnitude lower than the limit of the CBM detection system. When energy cuts relevant for IVI are applied, the simulation shows that 98% of detected events correspond to particle species of interest, further demonstrating the suitability of this system for range monitoring in heavy-ion therapy under clinical conditions.



Left Figure: Simulated count rates per channel on detector 0; **Right Figure:** Simulation setup

References

[1] Hymers *et al.* 2021 Phys. Med. Biol. **66** 245022

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Soil radioactivity comparison in three different regions of Greece

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The present work focuses on comparing the natural radioactivity results obtained from samples taken from three different environments in Greece. In total,, 23 soil samples from urban parks of metropolitan areas of Athens, 10 soil samples from the remote areas of Pogoni and Zagori (Northwestern Epirus), and 50 coastal and inland samples from Lemnos Island (North Aegean Sea) were collected. All samples were prepared and measured with high-resolution gamma spectroscopy at the γSPEC station of the University of Athens. Bulk reference samples were used to calibrate the spectrometer. Specific activities for five naturally occurring (^{40}K, ^{214}Pb, ^{212}Pb, ^{208}Tl, and ^{214}Bi) and one artificial radioisotope (^{137}Cs) were deduced.

Based on the measurements of specific activities, the absorbed dosage and index of external hazard (H_{ex}) have been additionally calculated using UNSCEAR models. Additionally, the ^{137}Cs/^{40}K and U-series/Th-series ratios have been estimated. The specific activities of ^{40}K reach values up to 271(8) Bq/kg in Pogoni and Zagori, 331(37) Bq/kg in urban parks of Athens, and 1214(30) Bq/kg in Lemnos Island. All results are correlated to the geological background, as well as the geodynamics of each area.

A newly developed, openly available data repository has been created at the University of Athens to incorporate the present results using a state-of-the-art GIS platform. The repository will be upgraded to a risk-informational system in the near future.

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Utilizing the Natural Tracer 7Be for Optimizing Constructed Wetland Hydronynamics

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Abstract

Constructed wetlands (CWs) are increasingly recognized as sustainable solutions for wastewater treatment and water quality improvement. This study uses the natural radionuclide ^{7}Be as a tracer to examine and optimize the hydrodynamics of CWs, particularly after rainfall events. Simulations and analyses, highlight CWs' potential in sustainable water management and suggests strategies to enhance their efficiency using radioactive tracers. CWs mimic natural processes to manage wastewater and pollution effectively. Understanding their hydrodynamics is essential for optimizing their design and function. ^{7}Be, with a 53.3-day half-life, provides insights into water and contaminant movement within CWs. This study uses ^{7}Be, to assess hydrodynamic properties and optimal decontamination conditions, especially after rainfall, affecting water flow and contaminant distribution. Sediment samples are analyzed to measure ^{7}Be concentrations and evaluate water dynamics. Tools, like MODFLOW, are used to model CW hydrodynamics. The study confirms that CWs are effective, sustainable wastewater treatment systems and identifies ways to optimize their performance through simulations, especially using the NWT version of MODFLOW. The ^{7}Be tracer provides valuable data to improve CW design and efficiency. Combining simulations with tracer studies is a promising approach to advancing CW technology. Further research is recommended to enhance the use of radioactive tracers, ensuring CWs remain effective in sustainable water management.

Acknowledgment:
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Clustering Analysis of Relatively Elevated Radon Concentrations in Tap Water of the Mygdonia Basin in Macedonia

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The Mygdonia Basin in Northern Greece is of great interest for measuring radon in water due to its geological background and the reliance on boreholes for public water supply. In the present study, time series measurements of radon in tap water were systematically conducted and analyzed over the period 2018-2024 in seven villages within the broader Mygdonia Basin region, known for having relatively high radon activity concentrations in water (Bq/l). A previous study in this area showed that radon concentrations in drinking tap water ranged from background levels to 184 Bq/l [1]. Time series data are analyzed using various statistical techniques, such as classification, clustering, and anomaly detection. The present study focuses on clustering and periodicity. The aim is to determine whether the clusters and periods observed in radon-in-water time series measurements hold physical significance. Clustering analysis of the time series of radon in water was performed using several methods such as K-Means and Neighborhood-Contraction. Its simplicity is adequate for the limited number of variables involved in the analysis. The Elbow method and the Silhouette method were exploited for determining the ideal number of clusters of the measurements corresponded to each village.

Some variables related with the concentrations of radon-in-water are: (a) the time (b) the different borehole, (c) the supply percentage of each borehole to the tap water, (d) the rate of water consumption. The results of the clustering analysis yield significant and no-significant correlations of the measurements for the seven villages with the above-mentioned variables. For instance, the clustering in Fig. 1 reveals dependency on boreholes supply and time. The significance of clustering analysis on time-series measurements is explored.

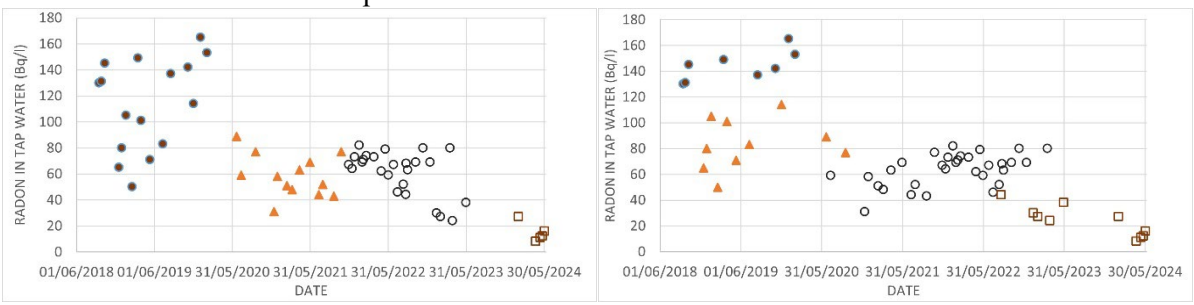

Figure 1 The identification of four clusters within the time series data of Askos village with K-Means (left) and Neighborhood-Contraction (right).

References

[1] M. Omirou et al Journal of the European Radon Association, Volume 3, (2022).

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Continuous measurement of radon progeny in atmospheric aerosol using a NaI(Tl) detector and a High Volume Air Sampler

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Radon and its short-lived progeny can be utilized as tracers for atmospheric processes, such as air masses transfer, air mixing, aerosols residence times etc. [1]. To this end, radon progeny activity fluctuation is being widely studied, revealing both a diurnal and seasonal variation [1] and the influence of meteorological phenomena such as precipitation events [2, 3]. Short-lived radon progeny monitoring is a challenging process and several studies report on methodologies for on-line measurements [4, 5]. At the Nuclear Engineering Laboratory of the National Technical University of Athens (NEL-NTUA), short-lived radon progeny outdoors are being monitored for years and a continuous effort is being made to improve the utilized techniques [6] and the recorded signal. In this work, an improved technique for the continuous measurement of radon progeny activity is presented.

The measurement set-up consists of a NaI(Tl) scintillation detector system [6] and a High Volume Air Sampler (Fig. 1a). During air sampling, radon progeny are accumulated on a 8"x10" glass-fibre filter and measured by the detector, positioned very close to the filter. Temperature and humidity are continuously monitored as well. Once a week the filter is replaced and analysed further using high resolution γ-spectrometry. With this technique, an increased count-rate and a higher peak-to-background (p-t-b) signal for radon progeny – focusing on ^{214}Bi – is recorded. The p-t-b ratio rises during the first 2 h of air sampling and, after equilibrium of radon progeny activity on the filter is established, stabilizes at a value ~4 times higher (Fig. 1b, 1c), with a much lower relative uncertainty. As a result, a more reliable signal for radon progeny existing in the air is provided. The technique presented in this work may prove of great value for on-line environmental monitoring.

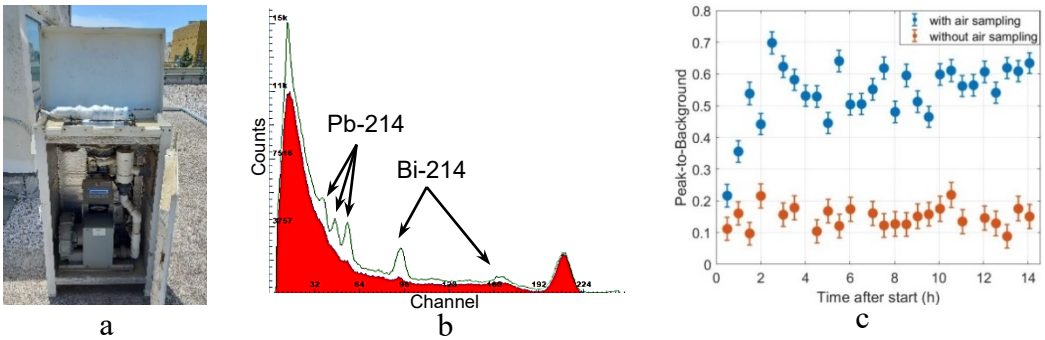

Figure 1- a) The measurement set-up. b) A gamma spectrum before (red area) and during (green line) air sampling. c) The Peak-to-Background ratio with air sampling (blue) compared to a typical value (orange).

References

[1] M. Baskaran, *Radon* (2016), doi: 10.1007/978-3-319-21329-3
[2] C. Bottardi *et al.*, Atm. Env. **238**, 117728, doi: 10.1016/j.atmosenv.2020.117728
[3] D. Patiris *et al.*, Act. Geoph. **71**, 2517-2533 (2023), doi: 10.1007/s11600-023-01090-9
[4] L. Zhang *et al.*, Rad. Prot. Dos. **173(1-3)**, 259-262 (2017), doi: 10.1093/rpd/ncw333
[5] D.A. Kremenchutskii, Env. Mon. Assess. **193**, 545 (2021), doi: 10.1007/s10661-021-09337-y
[6] K. Kanoutos *et al.*, *Monitoring Radon Progeny*, Poster presented at: 31st Hell. Nucl. Phys. Symp. (2023)
[7] A. Orphanou, *Monitoring Short-lived Radon Progeny Activity Variations*, Diploma thesis, NTUA (2023)

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Application of Greek Zeolites for the Removal of U and Cs from Aqueous Solutions*

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Natural microporous zeolites have been demonstrated to be effective in removing Cs as well as other radionuclides like U and Co from wastewaters and gained widespread attention in radioactive waste applications. They combine unique physical and chemical features such as special open structure and void space, cation exchange capacity, thermal stability, low cost and selectivity towards specific metal cations.

In this study sorption properties of Greek zeolites from Thrace, north-eastern Greece were investigated for the removal of U and Cs from aqueous solutions. The sorption experiments were undertaken using zeolites of different origin and grain size under different conditions (pH, metal concentration, temperature).

The pHpzc and CEC were determined and sorption isotherms were reproduced through mathematical models. The characterization of the materials before and after sorption was performed by XRD, FTIR, SEM-EDS. The results showed that the sorption capacities were affected by chemical composition and grain size and that these materials are promising candidates for environmental applications.

References

[1] A. Bambaiti *et al*., J Radioanal Nucl Chem. **303** (2014), doi: 10.1007/s10967-014-3796-4
[2] I. Dianellou *et al*., J Radioanal Nucl Chem. **332** (2023), doi: 10.1007/s10967-023-08857-w

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Management of low-level nuclear waste by application of recycling by-products*

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Radioactive contaminants in liquid waste, produced by various industries like nuclear plants, hospitals, mines, laboratories etc. pose significant threat to the environment and human health as they can contaminate water sources, soil, and air. These contaminants may include radioisotopes of uranium, thorium, cesium, cobalt, technetium, iodine, etc. which are highly toxic and can cause long-term health problems.

Recently the use of recycled by-products-biosorbents has been proven as an effective method for removal of contaminants from liquid waste. Biosorbents are materials which are derived from natural sources (agricultural by-products, sewage sludge) and have the ability to absorb and accumulate heavy metals, organic compounds, and radioactive pollutants from liquid waste.

In this work, the use of winery waste as well sewage sludge were studied, for removal of cationic (U(VI), Th(IV), Cs, Co(II)) and especially anionic species (TcO_4^- and I^-) from aqueous solutions. The materials were used in the initial form and after thermal modification for biochars production.

The results showed a significant adsorption capacity of the tested materials especially for technetium and iodine proving that it is possible to use them for environmental applications.

References

[1] S. P. Paredes *et al*., J Nucl Mater. **359** (2006), doi: 10.1016/j.jnucmat.2006.07.022
[2] A. J. Juhola, Carbon. **13** (1975), doi: 10.1016/0008-6223(75)90016-0
[3] J. J. Kipling *et al*., J Colloid Interface Sci. **21** (1966), doi: 10.1016/0095-8522(66)90019-5

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A study of natural radioactivity in thermal springs in Greece using gamma and alpha spectrometry*

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Thermal springs have a geographical distribution that is mostly shaped by major tectonic phenomena, such as volcanic events and extended fault zones. Thermal springs are known to exhibit elevated activities of natural radioisotopes, such as ^{226}Ra and ^{222}Rn. The present work aims to study the natural radioactivity in a few thermal springs in the Hellenic region.

Seven water samples were collected from thermal springs in Therma and Nigrita of Serres, and around the perimeter and underwater of the volcanic peninsula of Methana. After preparation, the samples were measured with a calibrated, high-resolution, high-purity germanium detector (HPGe) at the γSPEC station of the National and Kapodistrian University of Athens. Specific activities of natural radioisotopes of the ^{238}U and ^{232}Th series, as well as of ^{40}K were deduced.

The same samples were also measured with a factory-calibrated radon spectrometer RAD7 aiming at investigating the correlation of the specific activities obtained by alpha spectroscopy with those deduced by gamma-ray spectroscopy. The results show that such a correlation is clear.

In addition, the results extracted with gamma-ray spectroscopy agree well with the values of activities measured in thermal springs, as found in international literature. Further investigation of the correlation between the alpha and gamma spectroscopy in additional water samples, as well as other types of matrices is underway.

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Arsenic detection in sea water samples from Lavrion, using Neutron Activation Analysis

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Among the nuclear analytical techniques applied at the Nuclear Engineering Laboratory of the National Technical University of Athens (NEL-NTUA) is Neutron Activation Analysis (NAA), [1]. To this end a 10Ci Am-Be neutron source positioned inside an $1m^3$ water tank for neutron moderating and shielding is used, while the activated samples are analyzed using high resolution HPGe detectors.

Lavrion, a small city in the Southeastern part of Attica (Greece) is very close to an ex-mining area, where Silver and Lead have been extracted from ancient times till 19^{th} century. Lead and Arsenic pollution still exists nowadays, caused by open-air mining waste deposits. Pollutants are spread around by wind or leak when it is raining and end up in the sea via rain-water drainage system. Sediment samples from Lavrion coastline have been analyzed in the past at NEL-NTUA with NAA. This work focuses in the analysis of sea water samples collected from the region.

For the detection and quantification of Arsenic in sea water samples the precipitation method with $FeCl_3$ was used [2]. An extensive investigation to determine: the $FeCl_3$ mass that has to be added to the water sample, the procedure to collect the sediment produced, the way of sediment drying and the final sample preparation, was carried out. It concludes that a concentration of 200mg $FeCl_3$ /L of sea water, was enough to create -at the end of the procedure- a dry sample of 2.2ml volume.

For the efficiency calibration of the gamma spectroscopic analysis of the 2.2ml samples the NIST 2782 SRM (industrial sludge) was used. Based on the previous experience at NEL-NTUA, neutron activation and gamma spectroscopy analysis time was selected as follows: activation of standard and samples for 4 days, followed by gamma spectroscopic analysis for 3 days, [1]. This procedure was proved sufficient for the successful detection of ^{76}As. As the whole procedure is time consuming, only a few sea water samples have been processed and analysed, so far.

First results show that Arsenic is detected in sea water samples which were collected close to a coast where swimming is forbidden, but it was not detected in the sea water sample collected from a beach where swimming is allowed. However, additional work is required, especially for the accurate calibration of the whole procedure and the determination of the efficiency of the co-precipitation process of Arsenic with $FeCl_3$.

References

[1] T.K. Peppas, K.L. Karfopoulos, D.J. Karangelos, P.K. Rouni, M.J. Anagnostakis, S.E. Simopoulos, Radiological and instrumental neutron activation analysis determined characteristics of size-fractionated fly ash, Journal of Hazardous Materials, Volume 181, Issues 1–3, Pages 255-262, 2010, https://doi.org/10.1016/j.jhazmat.2010.05.005

[2] EPA USA, Proven Alternatives for Aboveground Treatment of Arsenic in Groundwater EPA-542-S-02-002, 68 pp, 2002.

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Analysis of elemental composition of atmospheric aerosols in Bratislava using Particle Induced X-ray Emission (PIXE) method with an external beam [*]

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In addition to the gaseous component, the atmosphere is full of small solid or liquid particles called aerosols. Interest in studying these particles arises because aerosols play an important role in environmental and climate change studies, and as pollutants they can adversely affect human health. The various properties of aerosols are being studied in laboratories around the world. In this work, attention is paid to the study of the elemental composition of aerosols using the PIXE technique.

The aerosol samples were collected at the meteorological station situated at the campus of the Faculty of Mathematics, Physics, and Informatics in Bratislava. Quartz microfiber filters are used to collect particulate matter, while approximately 1500 m^3 of air is pumped through each filter. This type of filter was selected because the samples were also used for the analysis of ^{14}C in aerosols. The filters are designed to retain particles larger than 0.3 μm. The samples were collected over one year between April 2023 and April 2024 in a two-week interval.

The total collected mass of aerosol and elemental composition was determined by gravimetric analysis and PIXE method, respectively. PIXE is a reliable and fast technique for multi-elemental analysis with sufficient sensitivity for most elements.

The Centre for Nuclear and Accelerator Technologies (CENTA) operates 3 MV Pelletron accelerator (NEC, USA), with the necessary infrastructure for production and extraction of the selected ion beams. In 2023, a new external beam line was set up with a SiPIN detector from AMPTEC Inc. (USA) for in-air PIXE analysis.

The PIXE analysis of filters identified nine elements in atmospheric aerosols, where Si, S, K, Ca, and Fe were the most abundant ones. Since the quartz filters are used for sampling and the silicon detector is used for the analysis, the observed Si concentration values are only indicative.

The homogeneity distribution of atmospheric aerosols retained on membrane filters was investigated for the most abundant elements in the samples. The difference in elemental concentration in different spots on the filters was less than 50%. Variations in the concentration of some elements over the year help to identify the source of aerosols and indicate how they are produced. For example, elements originating from soil dust tend to have lower concentrations during the winter season due to weather conditions.

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A new underwater nuclear detection system integrated in robotic vehicles for nuclear security maritime needs*

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The Marine Environmental Radioactivity Laboratory of the Hellenic Centre for Marine Research owns and maintains low and medium resolution underwater gamma-ray spectrometers such as the KATERINA [1, 2] and GeoMAREA [3] detection systems. The detection systems have been applied in the aquatic systems (from shallow water masses till the very deep water masses -2500m) in many areas of the world during the last twenty years. In this work, a new radioactivity system will be presented to bridge the gap for smart operational needs to identify dangerous nuclear objects. The new nuclear detection system is capable to be integrated in robotic vehicles. The data of a demonstration activity performed in controlled aquatic environment will be presented. To calibrate the system for dangerous objects identification under the hull of the ship, various reference sources and radioactive stimulants were utilized. The new system exhibits high performance in terms of buoyancy, maneuverability as well as for the stability, energy resolution and efficiency.

The underwater nuclear detection system together with a robotic vehicle will be applied for nuclear security needs and for identifying nuclear substances under the hull of the ships. The system will be applied in general inspection tasks performed in collaboration with the port authorities. Moreover, the integrated system (robot and nuclear detector) is requested by the private sector to identify potential leak detection in applications related to pipeline inspection where special radiotracers (gamma-ray emitters) are applied.

References

[1] C. Tsabaris *et al*., App. Rad.Iso **66**, 1419(2008), doi: 10.1016/j.apradiso.2008.02.064
[2] C. Tsabaris *et al*., App. Rad. Iso **142**, 100(2018), doi: 10.1016/j.apradiso.2018.08.024
[3] C. Tsabaris *et al*., Journal. Env. Radioac **204**, 12 (2019), doi: 10.1016/j.jenvrad.2019.03.021

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Techniques for Radiological Characterization of Metallic Waste from Nuclear Facility Decommissioning: An Innovative Non-Destructive γ-spectrometry Method for Validation of Scaling Factors

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For decommissioning of nuclear reactors, grouping and segregation of the metallic radioactive waste is necessary. Various methods are used for the detailed radiological characterization of nuclear facilities. However, full-scale measurements for activity determination of radionuclides in all metallic components are costly and hardly feasible.

For intermediate and high level waste, the neutron activation calculations are used mainly for determination of difficult-to-measure (DTM) radionuclides in scaling factors (SF) method. The SF method is a widely accepted technique for assessment of the concentrations of DTM nuclides from the concentrations of the ETM (easy-to-measure) radionuclides. Nevertheless, the accuracy of this technique depends on the composition and distribution of impurities in the materials, the flux and energy of neutrons, the nuclear data libraries, the methodology of the process and the simulation codes. For low and very low-level waste, the modelling of fission and corrosion products transport inside the primary cooling system is even more complicated and thus less accurate. Because of the modelling uncertainties, the theoretically determined SF by neutron activation or modelling of radionuclides transport is need to be validated/ corrected using experimental data.

Both the neutron activation and the surface contamination might be present and contribute to the metallic component activity. Their input to waste management activities and procedures vary depending on the reactor type, the operation history and the primary cooling system peculiarities.

Most of the long-lived DTM radionuclides are low energy gamma, pure beta or alpha emitters and require radiochemical methods to separate the various radionuclides for measurement. For successful application of the SF method, one needs to establish a correlation between ETM gamma emitters (key nuclides) and DTM nuclides. The activities of DTM nuclides are estimated by measuring the ETM gamma emitters and using the SF. The key radionuclides are usually ^{60}Co and ^{137}Cs, which can be determined by non-destructive γ-spectrometry. ^{60}Co is an activation product, while ^{137}Cs is mostly fission product and due to its high-water solubility is easily transported and settled on the surface of the components.

A non-destructive γ-spectrometry technique by using MCNP6.1 simulation is proposed for interpretation of the resulting γ-ray spectra of the radionuclides in activated components exhibiting contamination. In particular, spectra of a scintillation detector 3" × 3" NaI(Tl) and a HPGe of 20% efficiency are generated, based on defined activities of the main radionuclides in the activated components (i.e. spectra for activation as well as for surface contamination) and the results of MCNP6.1 simulation. The simulation spectra are compared with the experimental spectrum to determine the activation as well as the contamination of a specific component.

The proposed method could validate the SF for gamma emitters in surface contamination, as well as the results of neutron activation calculations in activated components exhibiting contamination.

Enhanced Micro-RBS Sensitivity for Spatial Distribution Analysis of Heavy Elements.

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This study presents a new experimental concept that combines heavy ion RBS with microbeam technology, employing a high-detection solid angle to measure the spatial distribution of heavy trace elements. The concept revolves around using a probing beam heavier than the major substrate's elements, aiming not only to increase the backscattering cross-section, similar to well established heavy element RBS, but also to eliminate pileup due to backscattering from substrate, which is essential for sensitive analysis. The choice and characteristics of the probing beam are important for ensuring precise and reliable measurements. Various aspects of the probing beam, such as brightness, spatial resolution, and beam halo, were thoroughly investigated to enhance result accuracy and precision.

A detection system with a total detection solid angle of approximately 1 sr was utilized in an unconventional geometry, where backscattering ions enter the detector at different angles resulting in longer distances in the passivation layer of the detectors. An examination into the effect of entrance angle on detector resolution was conducted, and a spectral analysis model was developed to address kinematic spread issues resulting from large detection solid angles based on Au reference thin films.

Examples of this approach include the use of focused 2.4 MeV Si^{2+} ions that were employed to scan the frontal or lateral surfaces of different silicon and SiC samples, enabling the measurement of both the areal concentrations and depth profiles of elements heavier than silicon. Tests were conducted on samples containing Au and Pt elements in concentration lavels of the 10^{12} to 10^{14} at/cm^3 levels. Additionally, Au implanted silicon samples were utilized to establish the detection limit of the new system. Subsequently, sensitivity of the areal distribution of elements has been determined to be down to 10^{10} at/cm^{2}levels, using focused Si ions with an approximately 10 μm spot size and up to 1 nA beam current range.

Abstract submitted to ANP2024

Enhanced Industrial Process Monitoring Using Gamma-Ray Spectrometry and Tomography for Column Scanning

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The application of gamma-ray spectrometry in industrial tomography presents a significant advancement in non-destructive testing and evaluation. This study explores the integration of gamma-ray spectrometry with ionizing radiation techniques for detailed column scanning in industrial processes. The methodology focuses on enhancing the accuracy of detecting material compositions and structural anomalies within industrial columns. By employing gamma-ray spectrometry, the research demonstrates improved resolution and reliability in imaging, contributing to more efficient monitoring and maintenance of industrial systems. The findings highlight the potential of this combined approach to optimize industrial operations, reduce downtime, and ensure the safety and integrity of critical infrastructure.

Keywords: gamma-ray spectrometry, tomography, ionizing radiation, industrial processes, column scanning

In-situ depth profiling of Aluminium during annealing of self-reporting Cr_2AlC

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Cr_2AlC MAX phase (M corresponds to an early transition metal, A to an A-group element, and X to either carbon or nitrogen) is a nanolaminated material that has drawn scientific interest over the past 20 years owing to its combination of advantageous/favorable properties. The mixture of both metallic and ceramic properties like high stiffness, damage tolerance, good machinability, good electrical conductivity and high-temperature oxidation resistance originate from the alternation of metallic-like layers (between M and A) and ceramic-like layers (between M and X). Moreover, it has been shown that phase changes in Cr_2AlC thin films can be detected by non-destructive resistivity measurements [1]. Materials with such unique properties are ideal potential candidates for applications in industry, mainly in the field of protective coatings. Thus, accurate chemical composition measurements are essential for enabling the tailoring of properties.

In the present work we investigate the system of Cr_2AlC in Elastic Backscattering Spectroscopy (EBS) experiments performed *in-situ* during annealing to shed further light on the interdependence of temperature exposure and composition. Experiments were performed at the SIGMA setup [2] at the 5-MV 15 SDH-2 Pelletron Tandem accelerator at Uppsala University using a primary beam of 3.042 MeV He^+ ions and employed the elastic $^{16}O(^4He, ^4He)$ resonance at an energy of ~3.037 MeV. The Si detector, mounted at 170°, was a passivated implanted planar silicon detector. The studied samples were two Cr_2AlC films of ~500 nm nominal thickness deposited using direct current magnetron sputtering on MgO substrates. We obtained the composition depth profile of the film as a function of the temperature (from room temperature to 1150 °C) in vacuum and in oxygen atmosphere. In vacuum, aluminium starts to migrate towards the surface at 1000 °C while the amount of oxygen remains the same. In oxygen atmosphere, we observe oxygen absorption starting from below 800 °C while aluminium again migrates towards the surface at 1000 °C. At 1150 °C, an alumina film has been formed on the surface.

References

[1] B. Stelzer *et al*., Scientific Reports **9**, 8266 (2019), https://doi.org/10.1038/s41598-019-44692-4
[2] K. Kantre et al., Nuclear Inst. And Methods in Phys. **B 463**, 96-100 (2020), https://doi.org/10.1016/j.nimb.2019.11.007

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First ^{129,127}Iodine Measurements at CologneAMS

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In the Atacama Desert, one of the driest places in the world, fog plays an important role in ensuring the survival of plants with its moisture. This fog contains an increased proportion of the unstable rare ^{129}I compared to ^{127}I due to nuclear bomb tests in the South Pacific. As part of the CRC1211 project "Evolution at the Dry Limit", research was carried out in the Atacama Desert on the so-called Tillandsia landbeckii plants. The AMS Iodine analysis of this Tillandsia landbeckii plants can be used to gain information about fog patterns and environmental conditions,

For this reason, the first Iodine measurements have been performed at the 6MV AMS system of CologneAMS. Samples covering the entire capabilities of the accelerator system were measured. ^{129}I/^{127}I ratios of down to 10^{-13} were achieved in this first measurement. During the measurement, a dependence of the iodine ratio and the ion current coming from the source became visible in samples with a high ^{129}I/^{127}I ratio. In addition, a memory effect was analyzed, which means the effect of a measured sample on the following sample.

In this contribution we will present the current progress and the results of the first Iodine measurements in Cologne.

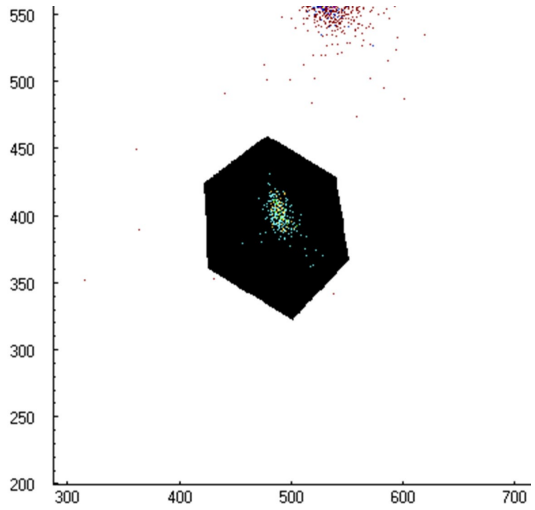

Figure: 2 dimensional representation of the ^{129}I counts in the gas ionization detector used. The gas ionization detector consists of 4 plate condensers, which are placed one behind the other. The graph shows the counts in the first two capacitors against those in the last two. This is done to distinguish ^{129}I from other ions and to suppress background, as these would be shown elsewhere in the graph. The region of interest in which the ^{129}I counts are located and counted is shown in black.

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Effect of Cu and Ag multi-energy ion implantation on polyimide and poly(methyl methacrylate) thin films

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Ion implantation has long demonstrated a positive impact on the modification of the electrical properties of polymers [1]. The ion implantation process induces chemical and physical changes that, through the formation of free radicals, reorganization of molecular chains, and the creation of new chemical functional groups, alter the internal structure of polymers and thus their mechanical and electrical properties [2,3]. This approach offers a promising alternative to produce new electronic components without the need for pure metals. Based on our research on multi-energy ion implantation of Au ions, conducted in our laboratory, we decided to further explore this technology [4]. Polyimide (PI) and polymethyl methacrylate (PMMA) thin films with a thickness of 50 μm were multi-energy implanted with Cu^+ and Ag^+ ions sequentially with energies of (2.8, 2.0, 1.2) MeV and with different ion fluences ($1x10^{12}$, $1x10^{13}$, $1x10^{14}$) at/cm². The ion energies were determined according to SRIM simulation to create continuous layers of ions in the polymer films that intersect in a Gaussian distribution at their end. Elemental changes in the layers were examined using RBS/ERDA, changes in chemical bonds using XPS, IR spectroscopy, and Raman spectroscopy, and finally, electrical properties were examined using EIS. The sheet resistivity of the implanted layers decreases with increasing ion fluence, indicating enhanced electrical conductivity of the material.

References

[1] M. C. Wintersgill et al., Nucl. Instrum. Methods Phys. Res. B 1, 595 (1984), doi: 10.1016/0168-583X(84)90129-0

[2] V. N. Popok, "High-Fluence Ion Implantation of Polymers: Evolution of Structure and Composition," in Radiation Effects in Polymeric Materials, 2019, pp. 69–111, doi: 10.1007/978-3-030-05770-1_3

[3] J.-E. Potaufeux et al., "A comprehensive review of the structures and properties of ionic polymeric materials," Polymer Chem. 11, 5914 (2020), doi: 10.1039/D0PY00770F

[4] P. Malinsky et al., EPJ Web of Conferences 261, 02006 (2022), doi: 10.1051/epjconf/202226102006

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Radiation response testing of Fe-Cr steels for nuclear applications*

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Ion irradiation is widely used to simulate damage caused by neutron irradiation across a broad range of temperatures and fluences. Due to accelerated damage rates, it serves as an effective screening tool for the development and qualification of materials for irradiation environments. In the last decade, nanoindentation of ion-irradiated materials has gained significant interest as it allows for the assessment of irradiation-induced hardening even in thin irradiated layers. However, the effects of experimental parameters such as ion type, ion energy, and dose rate have not yet been fully explored.

In the present study, T91 ferritic/martensitic and oxide dispersion strengthened Fe-20Cr-5Al steels were exposed to ion irradiation using protons, helium, and heavy ions (primarily iron) with varying energies, and dose rate. Nanoindentation was employed to determine the nanomechanical properties of both reference and ion-irradiated samples. The effects of ion type and energy on the irradiation hardening and microstructure of the two selected materials are discussed.

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Evolution of Zirconium Deuteride Under Ti Ion Implantation*

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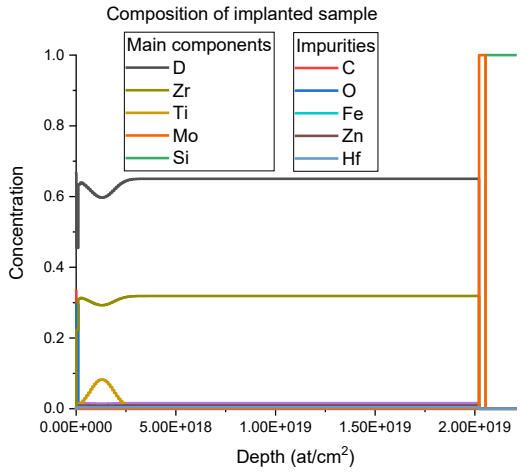
Zirconium (Zr) and titanium (Ti) are hydrogen storage metals. Their deuterides (ZrD_x and TiD_x) and tritides (ZrT_x and TiT_x) films are used for targets of fast neutron generators. To evaluate the irradiation hardness of the targets, ZrD_x films were prepared by magnetron sputtering on Mo/Si substrates, and then implanted by 240keV Ti^{2+} with fluences from 1×10^{15} ion/cm^{-2} to 1×10^{17} ion/cm^{-2}. The depth profiles of deuterium(D), Ti and Zr etc. elements were measured by Elastic Recoil Detection Analysis (ERDA) and Rutherford Back Scattering (RBS) respectively [Fig.1]. The surface morphologies, microstructures and phases were analysed by Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), Scanning Transmission Electron Microscopy (STEM) and X-ray Diffraction (XRD) etc. methods versus implantation fluences. The implanted Ti distributes in depth from 0 to 300 nm. A peak is found at 70nm, which just corresponds to the valleys in D and Zr depth profiles. It indicates that the implanted Ti replaced Zr and caused D concentration decreases. At the same time, TiD_x is formed in the film [Fig.2]. Both of ZrD_x and TiD_x are mixed inside film, but some lattice are changed by implanting. Deuterium concentration decreases in Ti^{2+}implanted region, but the most of D remains inside, which means the deuterides are rather stable after 1×10^{17} Ti^{2+}/cm^{-2} bombardment. No significant morphologic change has been observed on films surface up to a fluence of 1×10^{17} ions/cm^{-2}.



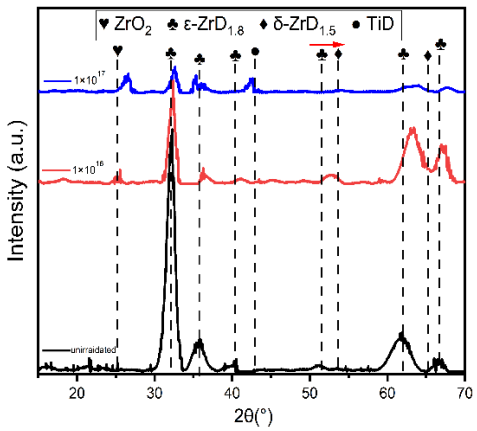


Fig.1 Depth distribution of elements in Ti^{2+} implanted ZrD_x *Fig.2 XRD pattern of original and implanted samples*

References

[1] A.G. Nikolaev et al., Technical Physics, 2017, 62(5): 701-707. DOI:10.1134/S1063784217050218.

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Upgrade of the new ToF – ERDA experimental setup at N.C.S.R. "Demokritos"

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Ion Beam Analysis (IBA) is a family of modern analytical techniques which are widely used for the analysis of different samples. Among them, the most promising and suitable one for surface analysis and characterization of thin foils is the Time of Flight – Elastic Recoil Detection Analysis (ToF-ERDA). The new ToF–ERDA spectrometer in the Tandem Laboratory of N.C.S.R. "Demokritos" consists of two timing (MPC) detectors for the determination of the time of flight of the recoiled particles and one Silicon Surface Barrier (SSB) detector for the recording of the total amount of their deposited energy. Thus, the *in-coincidence* data processing leads to a high accuracy mass separation and depth resolution regarding both light and heavier elements present in a sample.

The spectrometer detection efficiency varies with respect to the ion type and energy. This effect is more intense for light elements and occurs due to the different number of the emitted secondary electrons while the ions pass through the MCP foils[1]. In order to improve the detection efficiency of the setup, different materials such as carbon foils coated with LiF or Silicon Nitride thin films are used for the triggering of the timing detectors aiming at replacing the standard carbon foils. The results and the comparison between the different cases will be shown.

ToF-ERDA measurements of Li-doped ZnO targets, that are used as semiconductors, were conducted in order to reveal the presence and the concentration of lithium in the samples. The detection of lithium, as well as of several light elements is not easily directly obtained with other IBA techniques. The corresponding results reveal the high sensitivity and the low detection limit that can be achieved by the ToF-ERDA technique even for low mass elements, such as hydrogen present in a sample.

For the future upgrade of the setup, a new Gas Ionisation Detector (GID) will be built with the aim of replacing the SSB energy detector. GID detection chambers are more resistant to radiation damage and suitable for the specific application[2][3]. The first simulated results of the new detector will be presented.

References

[1] Y. Zhang *et al.*, "Detection efficiency of time-of-flight energy elastic recoil detection analysis systems," *Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms*, vol. 149, no. 4, pp. 477–489, Mar. 1999, doi: 10.1016/S0168-583X(98)00963-X.

[2] Z. Siketić, N. Skukan, and I. Bogdanović Radović, "A gas ionisation detector in the axial (Bragg) geometry used for the time-of-flight elastic recoil detection analysis," *Rev. Sci. Instrum.*, vol. 86, no. 8, Aug. 2015, doi: 10.1063/1.4927605/357185.

[3] J. Julin, M. Laitinen, and T. Sajavaara, "Time-of-flight ERD with a 200 mm2 Si3N4 window gas ionization chamber energy detector," *Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms*, vol. 332, pp. 271–274, Aug. 2014, doi: 10.1016/J.NIMB.2014.02.076.

Modulating the electronic properties of Ag/Au implanted 2D chalcogenide layer on polymers*

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The unique properties enable molybdenum disulfide (MoS_2) exhibit great potential applications in the fields of electronic and optoelectronic devices. MoS_2 is a typical two-dimensional (2D) layered material shows low band gap. MoS_2 was developed on polyethylene terephthalate (PET) substrate for the construction of flexible devices with Ion beam sputtering (IBS). These MoS_2/PET composites were enriched with Ag and Au using ion beam implantation with energy up to 1900 keV and ion fluences in the range of 5×10^{14} to 5×10^{15} cm^{-2}. In simple cases, only one kind of ion was implanted to the required depth (with the maximum in the depth of approximately 160 and 260 nm). In more complex cases, one ion and then another was implanted successively to achieve an independent structure (see Figure 1). The implantation energy was chosen according to the SRIM simulation program to achieve the required depth for both ion species. Thickness of the MoS_2 layer as well as Ag and Au depth profiles were examined using Rutherford backscattering method (RBS). Surface morphology before and after ion beam implantation was checked using Scanning electron microscopy (SEM). The electrical properties of prepared structures were characterized by 2-point configuration. Ion implantation has been shown to increase sheet resistance.

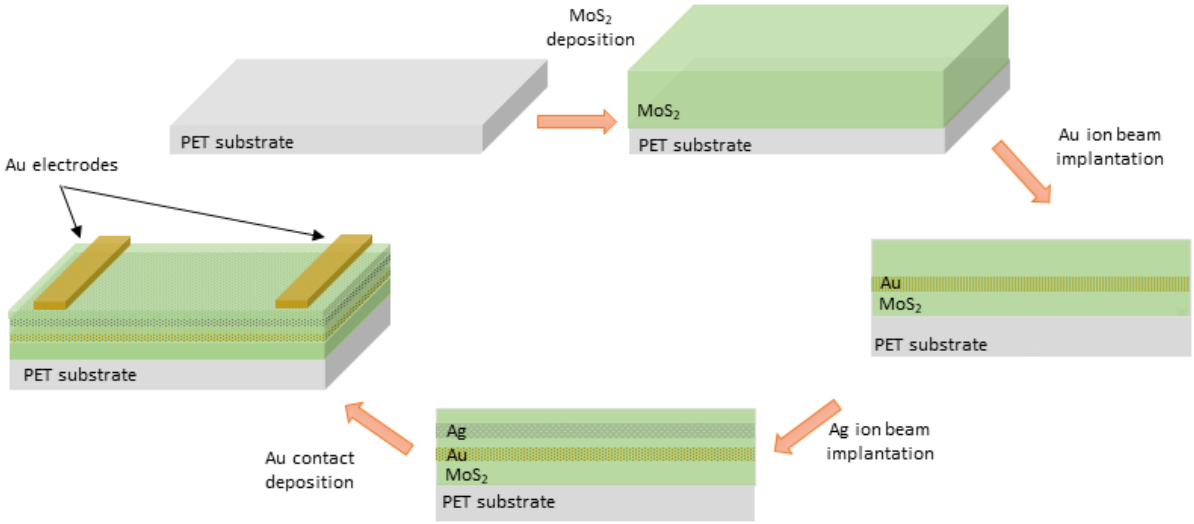

Figure 1- Structure preparation scheme with gradual implantation

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A Geant4 Monte Carlo simulation and Bayesian unfolding to estimate organ activities during MRT treatments

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Background: The precise estimation of dose absorbed by the tumor and healthy organs is essential to increase therapeutic effectiveness and optimize the treatment planning in Molecular Radiotherapy (MRT). To meet this need we proposed WIDMApp (Wearable Individual Dose Monitoring Apparatus), a multi-channel radiation detector and data processing system for in vivo patient measurement and collection of radiopharmaceutical biokinetic data [1]. The key components of WIDMApp are a Monte Carlo (MC) simulation and a deconvolution algorithm.

Material and Methods: The case under study is the prostate cancer treatment with 177Lu. Following the WIDMApp approach, a sensor is strategically placed on each organ to be monitored (i.e., tumor and Organ at Risk) after radiopharmaceutical administration, continuously collecting counts over time. We developed a Monte Carlo (MC) simulation, using the ICRP110 voxelized phantom to represent the patient' body, to model radiation propagation within the patient. The simulation provide the probability matrix that a primary particle generated within each active organ produces, directly or indirectly, a signal in each detector. We then applied a Bayesian deconvolution algorithm that, based on the signals detected by these sensors, can estimate the time-dependent activity in each organ without assuming any specific functional form.

Preliminary results: We will present preliminary results demonstrating the reconstruction of time-activity curves in organs during MRT using a Bayesian unfolding procedure over time. This study highlights the feasibility of reconstructing TAC, starting from measurements of the signals recorded by several detectors placed at selected positions on the patient's body. The proposed methodology exhibits significantly enhanced reconstruction accuracy compared to current state-of-the-art methods.

References

[1] S. Morganti et al.; Med Phys - ISSN 0094-2405. - 48:12(2021), pp. 8117-8126. [10.1002/mp.15311]
[2] C. Mancini-Terracciano, et al.; Phys Med Biol. 2023 Sep 25;68(19). [10.1088/1361-6560/acf910]

Neutron Activation Cross Section Measurement of the (n,2n), (n,3n) Reactions on ^{203}Tl at 17 and 20 MeV

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Studies of neutron-induced reactions are of great interest, for two main reasons: first, for their contribution to basic research in nuclear physics, and second, for their practical applications. Thallium has many uses in electronics, pharmaceuticals, fiber optics, infrared detectors and nuclear medicine. However, there is meagre information available for neutron induced reactions on Tl isotopes. On the one hand, there are many inconsistences among the existing experimental data on the (n,2n) reaction, especially in the energy region above ~14 MeV. On the other hand, there are too few data available on the (n,3n) reaction, resulting in severe discrepancies between the evaluation libraries.

The aim of the present work was to study the cross section of the (n,2n) and the (n,3n) reactions on ^{203}Tl, implementing the activation technique. That was accomplished by irradiating a natural TlCl pellet target with a quasi-monoenergetic neutron beam at 17 and 20 MeV. The cross sections of the ^{203}Tl(n,2n)^{202}Tl and ^{203}Tl(n,3n)^{201}Tl reactions were deduced with respect to the ^{197}Au(n,2n)^{196}Au, ^{27}Al(n,α)^{24}Na reference reactions. The quasi-monoenergetic neutron beam was generated in the 5.5 MV Tandem accelerator of NCSR Demokritos, using the ^{3}H(d, n)^{4}He reaction. The target and reference foil assembly was placed at approximately 1.5 cm from the tritiated titanium target, where the produced neutrons are practically isotropic and monoenergetic. The fluctuation of the neutron beam flux was monitored with a BF3 detector located at about 3 m from the neutron source. After the irradiation, the foils and pellet were placed in front of HPGe detectors, in such a way that the energies of the emitted gamma rays of the different isotopes did not coincide. The MCNP code has been used to perform Monte Carlo simulations to account for the gamma-ray self-absorption factor as well as replicating the neutron flux of the thallium chloride pellet.

Lastly, the nuclear reaction code EMPIRE was utilized for theoretical investigation, using the same parametrization implemented in the theoretical study of Ir [1] and Au [2] nuclei, which are in the same mass region as ^{203}Tl, and have an odd number of protons and an even number of neutrons.

References

[1] A. Kalamara et al., Phys. Rev. C 98, 034607 (2018).
[2] A. Kalamara et al., Phys. Rev. C 97, 034615 (2018).

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Measurements of the ^{234}U(n,f) cross section using quasi-monoenergetic neutron beam in the keV region and Micromegas detector setup

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In the current work, the reaction ^{7}Li(p,n) was studied and utilized to produce neutrons of energies in between 100keV to 900keV in order to measure the cross section of the ^{234}U in the respective region. Experimental data in the particular energy region appear to have significant discrepancies and deviations in the latest evaluated libraries and as such further and more precise measurements are needed to cover for the aforementioned data deficiencies.

The experimental procedure was carried out at the newly upgraded Tandem accelerator laboratory of Tandem van de Graaff 5.5MV at N.C.S.R. 'Demokritos' (Greece) with a quasi-monoenergetic neutron beam produced via the previously mentioned reaction, ^{7}Li(p,n). The goal of this experiment was to measure the ^{234}U cross section in reference to the ^{235}U cross section which is well known and studied. As such, the experimental setup included an aluminum chamber, in which the ^{234}U as well as the reference ^{235}U targets were placed in back to back positions. In order to detect the fission fragments created during the experiment, Micromegas detectors were placed in each side of the target setup. The aluminum chamber was also filled with a mixture of Ar and CO_2 gas, with the later acting as a quencher.

After the experimental process, the resulting spectra were analyzed and the yield of the fission fragments for 10 different neutron energies was extracted. However, before the final calculations, the yields had to be corrected for various effects like the detector dead time, the secondary neutrons produced due to the ^{7}Be first excited state, the shift to the effective measured energy due to the expected steep rise of the ^{234}U cross section in the particular energy region and others that will be thoroughly presented and discussed in this work along with the final results.

Measurement of the ^{235}U fission cross section relative to the standard ^{10}B(n,α) reaction at the CERN n_TOF facility*

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The neutron induced fission cross section of ^{235}U is a very important reaction for nuclear technology applications and the design of future systems to produce clean and safe energy. In addition, it is used as a reference reaction for neutron cross-section measurements. Thus, the cross section is needed with a very high accuracy over a wide energy range.

In this work, the measurement for the ^{235}U(n,f) reaction was carried out at the n_TOF facility located at CERN, at both experimental areas EAR-1 and EAR-2, taking into advantage the different neutron beam characteristics of each area. The standard ^{10}B(n,α) reaction was used as reference, while a setup based on the gaseous detectors Micromegas was implemented for the detection of the fission fragments and α-particles of the two reaction respectively.

In order to determine the thickness of the ^{10}B sample EBS and NRA measurements were carried out at the National Centre for Scientific Research "Demokritos". Both measurements provided consistent results for the target thickness within experimental errors.

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Efficient coupling and decoupling of a high intense laser with prolific AlO molecular anion beam

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Precise accelerator mass spectrometry (AMS) measurements have revealed crucial information for environmental sciences. To expand the list of measurable isotopes for AMS the Anion Laser Isobar Separator (ALIS) was installed at CologneAMS. The system uses elemental selective photo-detachment for the suppression of the high abundant isobars.

The process of laser isobar interaction requires the superposition of a high intense laser with the anion beam. For this purpose, usually magnetic deflectors or electrostatic deflectors, with a hole in the outer electrode, are used. A disadvantage of magnetic components in the injection beamline is the requirement of a complex and expensive fast-sequential injection setup and the disadvantage of holes in electrodes of electrostatic devices are unwanted field inhomogeneities. Therefore, we developed an additional correction electrode for electrostatic deflectors, that is able to correct the inhomogeneity. With this correction electrode the electrostatic deflector works as a precise energy filter without being affected by technical and geometrical circumstances.

The main focus of the ALIS setup is the measurement of environmental (^{90}Sr, ^{135}Cs), and cosmogenic isotopes (^{26}Al, ^{41}Ca). For the benchmark test of the new setup we want to compare the efficiency and level of detection of an isotope that is routinely measured at CologneAMS which can be improved for the users of the facility. Therefore, we aim to measure ^{26}Al by the prolific molecular injection (AlO^-) where the suppression of ^{26}Mg is required. We measured the anion extraction efficiency with the High Voltage Engineering SO-110 ion source, that will be compared to the National Electrostatic Corporation SNICS ion source, which is in operation at the ALIS setup.

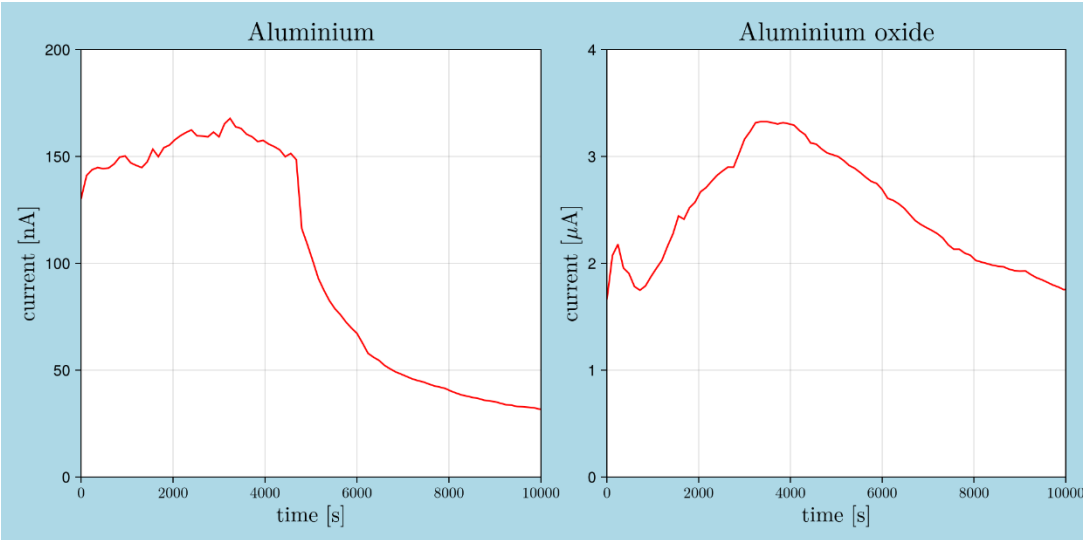

Figure: efficiency measurement of Al and AlO

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Constraining the ^{95}Zr(n,γ) cross section via the Oslo-method

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The neutron capture cross section of specific isotopes proves to be an important quantity for a wide variety of applications. In the case of unstable isotopes, measuring said cross section can however prove to be a challenge. Using the Oslo method we aim to constrain the neutron capture cross section of ^{95}Zr via the ^{96}Zr(p,p') reaction at the 10 MV FN-Tandem accelerator of the Institute for Nuclear Physics at the University of Cologne using the SONIC@HORUS detector array [1]. The ^{95}Zr(n,γ) cross section is of pivotal understanding for the slow neutron capture process (s-process) as the long-lived ^{95}Zr isotope is a branching point at which β-decay is in competition with the production of ^{96}Zr.

The SONIC@HORUS detector array consists of 14 HPGe γ-ray detectors arranged around the target under five distinct angles between 35° and 145° with respect to the beam line axis as well as 12 planar Silicon particle detectors covering the backwards angles hemisphere with respect to the beam line axis.

As target a 0.5 mg/cm^2 film of high purity ^{96}Zr was used for the main experiment. In addition, ^{90}Zr, ^{28}Si and ^{12}C foils were irradiated in order to perform background subtractions as well as calibrating the detector response for the statistical Oslo-type analysis. Initial tests were performed over the course of a week with the aim of determining the feasibility of using the preexisting setup of the Institute for Nuclear Physics at the University of Cologne for use in Oslo-method type measurements.

The preliminary results of these first measurements will be presented, along with a discussion of the impact of the achieved precision on our understanding of the s-process.

References

[1] Pickstone et al, 2017, Combining γ-ray and particle spectroscopy with SONIC@HORUS 10.1016/j.nima.2017.09.016

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Specific and Efficient Neutron Measurement Techniques for Nuclear Engineering Applications.

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Detecting neutron sources in real-time is imperative for nuclear engineering applications, demanding precise identification and quantification of neutron and gamma signatures. However, existing approaches encounter limitations in terms of speed, efficiency, and computational complexity. The present study addresses these challenges by developing advanced algorithms to improve the accuracy and speed of neutron detection in both fast and thermal energy ranges. The proposed techniques aim to overcome the limitations of current methods, enhancing the efficiency of neutron source identification in real time. The efficacy of algorithms was tested with different combinations of neutron-gamma sources and detectors. The initial phase of the research involves a comprehensive study of radiation detection and pulse shape discrimination (PSD) using various detectors and algorithms. The findings suggest stilbene as a viable alternative for combined neutron-gamma detection and reveal its linear response to neutrons below 5 MeV. Monte Carlo simulations using GEANT4 provide detailed analyses of various detector responses, particularly focusing on GAGG: Ce scintillation crystals' optimal thickness for thermal neutron absorption. The study also discusses using organic scintillation detectors for PSD, incorporating deep neural network (DNN) and other machine learning algorithms. This machine learning-based PSD algorithm discriminates between neutrons and γ rays across diverse data sets and source-detector setups. The research introduces a two-dimensional convolutional neural network (2D CNN) for neutron-gamma PSD, achieving comparable accuracy to traditional methods such as charge integration. The work also reports the development of novel PSD algorithms that eliminate the need for dedicated programmable hardware devices. The proposed algorithm, based on tail area and total area, demonstrates efficacy in pulse normalization, shaping, identification, and removal of multiple peaks, offering a cost-effective alternative without specialized hardware. Overall, the implications of these findings extend to nuclear security, neutron imaging, medical diagnostics, space applications, and the development of efficient and accurate detectors for identifying and distinguishing different types of radiation.

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