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Editorial

Special issue: applications of radiation in science and technology

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Abstract This special issue presents a selection of papers dealing with various aspects relevant for applications of radiation in science and technology. The topics include radiation measurement and detectors, radiation protection, applications in medicine, applications in environmental studies, and industrial application and neutron radiation. The selection illustrates a wide breath of uses of radiation and the multidisciplinary nature of studies in this area.

1 Introduction

Owing to its potentially harmful effects, ionizing radiation is often and much feared by the general population. Contributing to this are catastrophic historical events, e.g., Hiroshima, Chernobyl, and Fukushima, to name but a few. However, when properly controlled, radiation can be extremely useful in various fields of science and technology relevant for everyday life.

The International Conference of Radiation Applications (RAP) provides a forum for researchers and professionals involved with the applications of ionizing radiation and other connected areas, to exchange and discuss their findings and experiences. The conference topics cover various fields of physics, chemistry, biology, medical sciences, engineering, and environmental sciences. This special issue presents a selection of papers based on contributions to the 2022 edition of RAP, held in Thessaloniki, Greece, in early June 2022.

The papers are organized by subtopic into five sections: radiation measurement and detectors (six papers, [1–6]), radiation protection (three papers, [7–9]), applications in medicine (three papers, [10–12]), applications in environmental studies (six papers, [13–17]), and industrial application and neutron radiation (five papers, [18–22]). The following paragraphs briefly describe the contents of the papers. The readers should note the wide variety of radiation uses and the multidisciplinary nature of the presented studies.

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2 Radiation measurement and detectors

Radiation detectors are essential tools used in various fields, including nuclear power, medicine, industrial applications, and scientific research. They are designed to detect, measure, and quantify different types of radiation, such as alpha particles, beta particles, gamma rays, and X-rays. These detectors play a crucial role in ensuring radiation safety, monitoring environmental radiation levels, and conducting experiments or diagnostic procedures. There are five contributions in this topic in this special issue, mainly devoted to the evaluation of radiation detection systems.

Kuca et al. [1] present the bGeigie Nano detector within the SAFECAST.org project. The project was motivated by distrust of people affected by consequences of the Fukushima accident in the perceived biased information provided by Japanese authorities about the radiation situation. A group of enthusiasts developed a simple device for dose rate measurements and established a web platform for collecting and presenting data on the radiation situation, freely available to the public, which has rapidly expanded worldwide since. In this work, authors perform a dosimetric characterization of the detector itself (a thin-window Geiger–Müller counter) in terms of internal signal background and variability among detector units. Some limitations of system calibration and signal interpretation are also pointed out.

In a similar way, Polo et al. [2] assess the performance of a NaIL detector in the framework of the EU-funded CLEANDEM project for safely decommissioning and dismantling nuclear facilities. The study consists of characterizing a 2″ × 2″ NaIL detector in terms of energy resolution, full-energy peak gamma efficiency, thermal neutron/gamma discrimination capability, neutron efficiency, and gamma rejection ratio (at high counting rate). This experimental characterization is successfully combined with Monte Carlo simulations. These results can be used as a starting point for future developments, enabling the use of the instrumentation in places where decommissioning of nuclear power plants occurs.

Abbene et al. [3] describe the tests performed with a quasi-hemispherical CdZnTe detector by the SIDDHARTA-2 collaboration at the DAΦNE collider. The detector was installed for the first time in an accelerator environment to perform tests on the background rejection capabilities, which were achieved by exploiting the SIDDHARTA-2 luminosity monitor. The background suppression factor, which turned out to be of the order of 10^{5-6}, opens the possibility to plan for future kaonic atom measurements with CdZnTe detectors.

Lüley et al. [4] have developed a CR-39 detector-based radon dosimetry system with improved measurement capability by using a novel custom diffusion chamber. The proposed system operates in the self-decay mode, thus several measurements have been carried out to determine an optimal condition for conversion factor verification. However, large internal volume and penetration area can be the source of larger standard deviations, indicating the need for a more compact design with optimized penetration windows.

Lastovicka-Medin et al. [5] focus on two characterization techniques of detector interpixel/interstrip (IP) measurements that enable three-dimensional (3D) microscopy of volumes in microstrips or pixeled low-gain avalanche diode (LGAD)-based detectors for beam and dose delivery in hadron therapy. Both methods are depth profiling techniques for testing charge transport in micron-sized sensitive volumes. This work presents positive and negative aspects of both procedures, and the authors argue that there is a lack of comprehensive studies on systematic uncertainties resulting from the characterization methodology itself.

3 Radiation protection

Radiation protection refers to the practices and measures taken to minimize the harmful effects of ionizing radiation on human health and the environment. It involves a combination of techniques and strategies aimed at reducing radiation exposure and ensuring safety in various settings, including nuclear facilities, medical facilities, industrial applications, and even natural radiation sources. Three research groups have contributed to this topic.

Prifti et al. [6] evaluate the Albanian alarm system for detecting illicit trafficking and smuggling of nuclear materials in transit through its territory and borders. To do that, institutions responsible for nuclear security and radiation safety are described as well as the radiation detection infrastructure. In this regard, the Tool for Radiation Alarm and Commodity Evaluation application (TRACE) is presented, providing detailed information to help assess radiation instrument alarms. Finally, standard operation procedures at customs border points are detailed.

The failure modes and effects analysis (FMEA) method is developed for the risk evaluation of common practices. In their work, Kaissas et al. [7] exploit FMEA for radiological risk assessment in practices using radioactive materials. In addition, the radiological hazard of fire is studied, to classify its severity for different examples of radioactive materials inventories during interim storage. The severity of the hazard and the likelihood and detectability of its occurrence are used to classify the associated risk. Scenarios of external exposure, skin contamination, and inhalation are investigated to estimate the received doses, for workers and members of the public.

Food sterilization with ionizing radiation is a well-established technology and is constantly expanding due to its numerous advantages. Kazakis et al. [8] present data regarding the luminescence properties of glass containers of two widely known baby foods to explore their efficiency as dosimeters for the detection of irradiated baby food. A linear dose response is evident over the entire dose range studied (50–3000 Gy), while the use of the containers as dosimetric probes is validated by conducting dose recovery tests. Their findings are promising towards the use of glass containers for the identification of baby food sterilized with ionizing radiation since they would be equally and jointly exposed to the ionizing radiation during the sterilization process.

4 Applications in medicine

Radiation has found useful applications in healthcare, for both therapeutic and diagnostic purposes. For example, high-energy X-rays are used in radiotherapy, one of the three main modalities of cancer treatment, along with surgery and chemotherapy. Lower.energy X-rays are used in medical imaging (e.g., computed tomography (CT)), and positron emission tomography (PET) employs radionuclides for highly accurate cancer diagnostics. In this topic, we present three papers, two on radiotherapy and one on PET-related radiochemistry.

The study by Penev et al. [9] investigates the effect of dose uncertainty per fraction during radiotherapy on the tumor control probability (TCP). Different timing schemes and doses per fraction are considered, namely a standard (conventional) fractionation and stereotactic body radiotherapy (hypofractionation). By using a MATLAB code that simulates tumor irradiation with different parameters, and a ZaiderMinerbo–Stavreva TCP model for the calculations, as well as a linear–quadratic model of cell killing, histograms of the tumor control probability are obtained for different treatment regimens. The results indicate that dose uncertainty plays a significant role in treatment outcome and that, the smaller the fractions and the larger the doses, the greater the impact of dose uncertainty on TCP.

Determining the dose of scattered radiation absorbed by specific body organs and tissues in radiotherapy is very important. Zivkovic et al. [10] choose the humerus to determine the absorbed dose in female breast cancer patients who have undergone postoperative 3D conformal radiation therapy (CRT). The results of the comparison of the calculated dose in the tumor and humerus using modified FOTELP code (FOTELP-VOX) simulations show that the bulk dose to the humerus did not exceed the set expected maximums. However, clinicians must be aware of the risk in order to expose the humerus as little as possible.

The [^{18}F]-fluorodeoxyglucose ([^{18}F]FDG) is a universal PET radiopharmaceutical routinely applied in, e.g., oncology, cardiology, and neurology and widely produced by medical cyclotrons in nuclear medicine clinics. A current trend in medicine is personalization, and new types of therapeutic and diagnostic radiopharmaceuticals are being applied involving a pretargeting strategy. Simeonova et al. [11] investigate conjugation between [^{18}F]FDG and aminooxy-functionalized tetrazine by chemoselective oxime bond formation. They develop a method for direct labeling of a tetrazine derivative (clickable with trans cyclooctene moieties) with [^{18}F]FDG using a standard clinical laboratory setting.

5 Applications in environmental studies

Ionizing radiation and measuring techniques are very often used nowadays in environmental studies of different processes. Radiation itself and numerous possibilities of detection have proven to be very important in different aspects of environment study. This subtopic of the special issue is related to radiation applications in environmental studies. Six papers are presented, some of them related to the study of water, groundwater, marine sediments, and fish, and the others to the study of indoor radon.

Robert-Csaba Begy et al. [12] present research related to the radiological and elemental composition of spring water from Harghita County, Romania. This research is interesting since the study area has volcanic geology. The authors explore the radioactive properties of 48 carbonated water samples from the springs frequently used by the local population. Gross alpha/beta measurements are performed with the use of the liquid scintillation counting (LSC) technique, and specific radionuclides are determined by LSC, alpha spectrometry, and gamma spectrometry. Besides that, radioactivity element content analysis is conducted by using the X-ray fluorescence (XRF) technique. The authors register significantly higher activity concentrations of some of the measured radionuclides and raise the importance of monitoring spring water used for drinking in different areas.

Fatih Ozmen et al. [13] explore natural and artificial radioactivity and trace elements in marine biota (fish and invertebrate species) of the northeastern Mediterranean Sea with an estimation of the radiological risk. Trace element analyses are performed by atomic absorption spectrophotometry, and radionuclide activity concentrations are measured by gamma spectrometry. The overall conclusion is that the current state of the environmental doses in the study area does not pose any significant radiological risk for biota.

The radioactivity content of geothermal waters and dose estimation is the topic of the paper by Codrin-Fabian Savin et al. [14]. Balneotherapy is very popular in Romania, and the authors conduct a radiological survey of 25 geothermal water samples collected from different bays and spa centers in the western and northwestern parts of Romania. According to the results obtained, the authors conclude that it is important to establish limits for balneotherapy treatments, especially for practitioners and employees, to protect public health.

The accident at the Chernobyl nuclear power plant (NPP) made a significant contribution to the artificial radioactivity in the environment. Christina Ganzha et al. [15] deal with skeletal abnormalities in juveniles of common roach (*Rutilus rutilus*) and common rudd (*Scardinius erythrophthalmus*) from the cooling pond of the Chernobyl NPP. The authors observe up to 29 abnormalities per individual, a very high number compared with the 5 abnormalities in the control sample. The results suggest a very strong effect of radioactive contamination on fish growing and development in the Chernobyl NPP cooling pond.

Natural radioactive radon-222 gas is a popular research topic. Continuous diurnal radon measurements in Bulgarian caves and dose assessment are presented in the paper by Kunovska et al. [16]. The aim of this study was continuous measurement of the radon-222 concentration in six popular Bulgarian tourist caves and analysis of diurnal variations. According to the results, the estimated effective dose for workers in caves varies from 1.2 to 12.7 mSv per year and for visitors from 0.8 to 6.7 μSv per year. The authors conclude that it is necessary to introduce radiation protection measures in the caves in which high doses have been estimated for workers.

Another article dealing with radon-222 is written by Kolovou et al. [17]. They present a correlation between variations of indoor radon activity and the year of construction of dwellings in Greece. The main observation points out that the radon concentration decreases substantially as the focus moves from the oldest dwellings to those constructed in the 1970s, while dwellings built from 1970 to 2000 show no trend. Although high indoor radon concentrations in old dwellings can be attributed to structural problems, the newly built dwellings tend to show an increase in radon concentration, mainly due to the new Energy Efficiency of Buildings regulation, established in Greece in the last decade.

6 Industrial and neutron radiation

This section deals with the industrial use of radiation (one paper) and neutron radiation (four papers). One of the interesting industrial uses is food irradiation, where irradiation improves the safety and shelf life of foods by reducing or eliminating microorganisms and insects. On the other hand, neutrons are a product of nuclear reactions, e.g., in nuclear power facilities or accelerators. Neutrons are a great health hazard but have also found use in the structural analysis of materials and cargoes.

Irradiation of different materials with high-energy (typically up to 10 MeV) electrons is used in different industries, including medicine, sterilization of medical supplies, wastewater treatment, etc. Studenikin et al. [18] focus on the food industry, but describe a general method of electron beam modification with the use of aluminum modifier plates of different thicknesses, which enables a higher dose uniformity for the objects treated with the beam. They show by modeling and confirm by experiments on two types of industrial accelerator that adding aluminum plates with thickness ranging from 0.5 to 5 mm results in an increase of dose uniformity to up to 0.97.

High-capacity rechargeable batteries play an important role in integrating and optimizing the consumption of energy from renewable sources. Metal–air batteries, and among them zinc–air batteries, are considered to be very promising for this application. Khrezov et al. [19] propose a novel air electrode design involving perovskites and employ sensitive techniques, such as neutron and X-ray diffraction combined with scanning electron microscopy, to gain understanding of material properties relevant to the rechargeability. They show that the new design results in better electrochemical performance of the battery.

Nondestructive testing is capable of detecting defects in important components whose failure could pose a significant hazard and cause severe economic losses. Currently, imaging techniques utilizing gamma or X-ray sources are mainly used, but typically allow examination only of small items (up to tens of centimeters). The utilization of fast neutrons in radiography is a promising alternative, especially for industrial applications that require on-site inspection of large objects. Vrban et al. [20] present newly developed neutronic models of an important industrial component, printed circuit heat exchangers, where the specific ruptures are defined. They perform neutron transport simulations to investigate optimum irradiation geometries, neutron sources, and back-fill materials to access the principal detectability of the ruptures in an industrial environment.

Neutron shielding materials are generally made of a polymeric base containing a neutron absorption additive material, e.g., boron. Rahimi et al. [21] study the optimization of the additive neutron absorption material and the minimization of the thickness of the polymeric base. The response surface methodology (RSM) is used to investigate the simultaneous effect of these parameters on the radiation shielding efficiency of the polymer composite.

A research team from the Slovak University of Technology is involved in the development of new radiation shielding experimental workplaces for code verification and demonstration of radiation shielding principles. One of these activities is the so-called Mini Labyrinth experiment, a simple neutron and gamma shielding benchmark, modeled on a larger Labyrinth experiment developed at the Russian Institute of High Energy Physics. The paper by Cerba et al. [22] presents the results of the first measurements performed on the V3-50-R measurement geometry and their comparison with simulations using the Monaco code from the SCALE 6 system.

References

1. P. Kuča, J. Helebrant, P. Bossew, Characterization of the "bGeigie Nano" instrument used in citizen science dose rate monitoring. Eur. Phys. J. Special Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00877-7
2. M. Polo, F. Pino, J.C. Alvarez Delgado, D. Fabris, S. Moretto, Assessment of a NaIL detector performance for radiation monitoring applications. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00896-4
3. L. Abbene, M. Bettelli, A. Buttacavoli, F. Principato, A. Zappettini, C. Amsler, M. Bazzi, D. Bosnar, M. Bragadireanu, M. Cargnelli, M. Carminati, A. Clozza, G. Deda, L. De Paolis, R. Del Grande, L. Fabbietti, C. Fiorini, I. Friščić, C. Guaraldo, M. Iliescu, M. Iwasaki, A. Khreptak, S. Manti, J. Marton, M. Miliucci, P. Moskal, F. Napolitano, S. Niedźwiecki, H. Ohnishi, K. Piscicchia, Y. Sada, F. Sgaramella, H. Shi, M. Silarski, D.L. Sirghi, F. Sirghi, M. Skurzok, A. Spallone, K. Toho, M. Tüchler, O. Vazquez Doce, C. Yoshida, J. Zmeskal, A. Scordo, C. Curceanu, New opportunities for kaonic atoms measurements from CdZnTe detectors. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00881-x
4. J. Lüley, V. Filova, P. Blahušiak, B. Vrban, Š Čerba, I. Bonková, V. Nečas, CR-39 detector-based Radon dosimetry system calibration in the self-decay mode. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00876-8
5. G. Laštovička-Medin, M. Rebarz, G. Kramberger, M. Manojlović, T. Laštovička, J. Andreasson, Femtosecond laser based TCT-TPA and IBIC microscopy: two very powerful characterisation tools for testing micron-sized sensitive volumes in micro-strips or pixeled detectors and microdosimeters in microbeam and hadron therapy. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00892-8
6. D. Prifti, K. Tushe, C. Massey, E. Bylyku, B. Daci, Norm alarm assessment safety issues in Albania. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00878-6
7. I. Kaissas, C.J. Hourdakis, D. Mitrakos, Radiological risk assessment method for the interim storage of

radioactive materials. Eur. Phys. J. Special Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00897-3
8. N.A. Kazakis, Ch. Betsou, Detection of baby food sterilized with ionizing radiation using thermoluminescence. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00875-9
9. D. Penev, P. Stavrev, N. Stavreva, D. Pressyanov, Influence of dose uncertainty on TCP estimates: a model study. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00880-y
10. M. Živković, T.B. Miladinović, D. Krstić, N. Milosavljević, M. Živković-Radojević, A. Miladinović, Humerus absorbed dose in breast cancer postoperative radiotherapy. Humerus absorbed dose in breast cancer postoperative radiotherapy, simulated by FOTELP-VOX code, compared with values calculated by treatment planning system. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00893-7
11. G. Simeonova, B. Todorov, V. Lyubomirova, Method for indirect radiofluorination with $[^{18}F]FDG$ by biorthogonal reaction. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00885-7
12. C.F. Savin, F.L. Forray, C. Tănăselia, R.-C. Begy, Radiological assessment of carbonated spring waters in regard to the lithological characteristics of Harghita county, Romania. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00879-5
13. I. Koraltan, O. Guven, F.O. Asri, O. Aktas, E. Aksoy, G. Yaprak, I. Boztosun, S.F. Ozmen, An assessment on levels of radionuclides and trace metals and radiological risk to marine biota in the North-Eastern Mediterranean sea. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00884-8
14. R.-C. Begy, C.F. Savin, D.K. Süle, E. Giagias, Radiological survey of geothermal water resources in Romania and dose estimation from their use in balneotherapy. Eur. Phys. J. Spec. Top. **5**, 5 (2023). https://doi.org/10.1140/epjs/s11734-023-00883-9
15. C.D. Ganzha, D.I. Gudkov, I.I. Abramiuk, O.K. Ye, Skeletal abnormalities in juvenile fish from the cooling pond of the chornobyl nuclear power plant. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/10.1140/epjs/s11734-023-00895-5
16. B. Kunovska, K. Ivanova, D. Djunakova, N. Chobanova, J. Djounova, Z. Stojanovska, Continuous diurnal radon measurements in Bulgarian caves and dose assessment. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00874-w
17. M. Kolovou, C. Potiriadis, N. Kallithrakas-Kontos, A study on the correlation between indoor radon concentrations and the construction year of the dwellings. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00888-4
18. F.R. Studenikin, U.A. Bliznyuk, A.P. Chernyaev, G.A. Krusanov, A.D. Nikitchenko, S.A. Zolotov, V.S. Ipatova, Electron beam modification for improving dose uniformity in irradiated objects. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00886-6
19. K. Krezhov, T. Malakova, E. Mihaylova-Dimitrova, E. Mladenova, P. Tzvetkov, B. Burdin, G. Raikova, On the performance of carbon-free zinc-air rechargeable batteries: characterization of some perovskite oxides as catalysts in gas diffusion electrodes. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00894-6
20. B. Vrban, Š Čerba, J. Lüley, V. Filová, V. Nečas, Printed circuit heat exchangers and fast neutron radiography. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00887-5
21. G. Rahimi, D. Chirlesan, Z. Soltani, Optimization of filler content and minimizing thickness of polymeric composite for shielding against neutron source by Response Surface Methodology (RSM) and Monte Carlo simulation. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00904-7
22. Š Čerba, B. Vrban, J. Lüley, V. Filová, V. Nečas, Thermal neutron measurement in the STU Mini labyrinth experiment. Eur. Phys. J. Spec. Top. (2023). https://doi.org/10.1140/epjs/s11734-023-00903-8