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Institute of Doctoral Studies: Physics

Habilitation Thesis

Multidisciplinary techniques of applied physics in life sciences – results and future challenges

Summary

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Summary

The habilitation thesis highlights my key scientific and professional accomplishments over the past five years. Since earning my PhD in physics in 2011, I have enhanced my expertise in physics research methods, applied environmental sciences, and nuclear energy innovations. I completed postdoctoral research at the Department of Analytical Chemistry, Palacký University in Olomouc, and at the Regional Center of Advanced Technologies and Materials (RCPTM), Faculty of Science, under the guidance of RNDr. Tomáš Pluháček, Ph.D., and Assoc. Prof. RNDr. Petr Bednář, Ph.D., the department head. I undertook additional specialization courses to strengthen my skills in ICP-MS and other instrumental techniques. Since then, I have supervised master's and bachelor's theses. From 2016 onwards, I have managed a unique laboratory in Southeastern Europe specializing in deuterium calibration and certification in Heavy Water (D₂O), alongside RENAR accreditation of testing labs. As a coordinator and internal auditor, I held key responsibilities within these laboratories. For this purpose, I have established procedural guidelines within the Heavy Water Laboratory (ICSI-LAG): (1) A standardized procedure for testing and calibrating the determination of deuterium content in heavy water samples within the concentration range of 1,000–99,000% by mass D₂O, utilizing vibrational densimetry; (2) A procedure for testing and calibration to determine deuterium content in heavy water samples within the same concentration range, employing Fourier transform infrared spectrometry (FTIR).

The worldwide scientific community has increased attention to investigating heavy metal contamination and the environmental processes governing the transformation of inorganic contaminants across various matrices in the context of rising temperatures attributable to global warming. I successfully obtained three research projects through competitive calls and managed four service contracts focused on *environmental security*. These projects primarily studied the quality of natural water resources in the context of climate change, a crucial issue for human development in the coming decades. Accordingly, we established a comprehensive database in Romania, encompassing continuous measurements conducted over the period 2018–2022, focusing on contaminants and biochemical reactions in the water and sediments of the Olt River along a transect approximately 260 km in length. The data obtained facilitated the publication of several scientific articles in esteemed, high- impact journals such as Environmental Pollution (IF

8. 07), npj Clean Water (IF 12. 12.19), and Scientific Reports (IF 6. 6.7). For the first time in Romania, we carried out analyses of metal concentrations and isotopic ratios derived from radial tree rings, employing a tandem of highly precise instruments, with continuous data collection spanning 176 years. These findings have been published in reputable journals including the Journal of Cleaner Production (IF 11. 11.07), Journal of Hazardous Materials (IF 11. 3), Environmental Research (IF 7.7. 7), and Journal of Hazardous Materials Advances (IF 7.7. 7). During this timeframe, we paid special attention to the priority research area concerning **food safety** and the examination of inorganic contaminants in food, beverages, and cosmetics. Several scholarly contributions documenting this focus have been disseminated through internationally recognized journals such as Frontiers in Public Health (IF 3.4. 4), Food (IF 5.1. 1), Toxics (IF 4.1. 1), Nutrients (IF 6. 6.7), and Molecules (IF 4.4. 4). Beginning in 2023, our research has been supported by exclusive funding obtained within Romania for a topic of considerable interest within the international scientific community, aligned with the principal agendas of global governments regarding **energy security**; specifically, the development of environmentally friendly technologies for nuclear energy production. To date, these efforts have resulted in two national patents and several scientific publications in specialized journals including Materials, MRS Advances, and Membranes.

With the funding secured, 4 highly budgeted projects and various other contracts, **I aimed to assemble a highly trained team within ICSI Analytics**, actively engaging in the process through participation in training courses, intercalibrations, national and international working groups, and conferences to disseminate results, totaling over 150 events. This initiative facilitated the establishment of professional connections, enabling collaboration with experienced researchers from various institutions both nationally and internationally, thereby enhancing my capacity to understand complex processes. An additional significant accomplishment was the development of **extensive databases**, which I recognize as valuable not only for their numerical data but also for having been evaluated within environmental matrices under natural conditions—an aspect that cannot be replicated with other proxies. The selected years for study exhibited climatic variability of notable historical importance, such as 2018, referred to as the "endless summer" in Europe, and 2019, identified as the "heat dome" during a major heatwave. Lastly, the allocated funds facilitated the **dissemination** of our findings through reputable international journals, fulfilling a primary objective of the funding initiative and laying the groundwork for future projects. Under these

conditions, my research achievements have resulted in two patents, 10 books or book chapters published by national and international publishers, and 60 articles in ISI-indexed journals, in which I was lead, corresponding, or co-author. Moreover, I authored 52 articles in BDI databases and delivered over 143 oral and poster presentations.

The habilitation thesis "*Multidisciplinary techniques of applied physics in life sciences - results and future challenges*" analyzes the author's theoretical and experimental contribution to the field of applied physics research in analytical chemistry, for the assessment of environmental processes, as well as for the development of the emerging technology of separation and enrichment of the ^6Li isotope, intended for use in the nuclear energy sector. The thesis is organized into three sections, which highlight the most recent and important scientific achievements of the last 5 years, demonstrating that the activity is dynamic and ongoing. I have elected to present my professional achievements in chronological sequence, emphasizing three principal research directions. I will enumerate solely the techniques employed, the international context, and the outcomes that underscore my personal contributions. For each, I will specify the financial resources secured and detail how these funds will be managed to enhance human capital, develop the institution's infrastructure, and augment its international visibility.

Section (B-i1) delineates the initial research trajectory focused on identifying and monitoring chemical elements in environmental and food matrices. During this phase, I have focused on continually updating my expertise and methodologies for detecting pollution hotspots in natural ecosystem matrices, followed by a monitoring phase to assess risks. Since completing my postdoctoral period, I have undertaken multiple studies to evaluate pollution levels in water, sediments, wood, food, cosmetics, and essential oils, resulting in publications in esteemed international journals. Subsequently, we examined the intricacies of processes and interactions among various variables measured within the same matrices and across different levels of natural ecosystems, including stable isotopes, physicochemical properties, microminerals, macrominerals, and potentially toxic metals ($\delta^{18}\text{O}$, $\delta^2\text{H}$, N, P, N-ammonium, N-nitrites, N-nitrates, pH, O_2 , saturation, filterable residue at 105°C , Cl^- , Ca, Na, CCO-Cr, Cr, Mg, Co, Ni, Cu, As, Cd, Pb, Hg, Zn, Fe, Se, Al, Sr, Pb).

For this area of interest, I submitted projects to national competitions and received funding for: (i) "*Assessment of the impact of wastewater discharges on the environment through advanced*

analytical investigations based on nuclear and related techniques," conducted in 2018 with a budget of 2,500,000 lei; (ii) *"Advanced techniques for identifying contamination sources and biochemical reactions in aquatic ecosystems"* carried out between 2019 and 2022 with a budget of 11,000,000 lei. These two high-value projects helped us explain the significant variability in toxic metal levels in the sediments and water of the Olt River from 2018 to 2022. We also quantified how these metals interact with global warming and extreme climate events. 2018 and 2019 marked key milestones in understanding global warming, and our findings revealed how metal remobilization and associations respond to rising temperatures and more frequent, intense heatwaves. Monitoring was temporarily halted due to ongoing infrastructure works on the Olt River bed, following a continuous five-year study involving three phases along a 260 km transect with 28 collection points, which gathered over 15,000 interdisciplinary data points.

Following this phase, we elected to cease monitoring the Olt Riverbed and redirected our focus toward a novel investigation into potentially toxic inorganic contaminants originating from areas associated with the metals identified along the Olt River and conveyed by its tributaries. A widely studied region was the industrial town of Copsa Mică, owing to its distinctive history rooted in industrial activity, which made it the most significantly impacted city in Europe, with pollution levels comparable to those at Chernobyl. The ongoing effects of past pollution still touch the lives of local residents today. Statistics show that their life expectancy is notably shorter than the national average, and even young children have detectable levels of mercury in their blood, highlighting the lasting impact of environmental issues. In light of these concerns, an active monitoring program was established, entailing the systematic collection of environmental samples across various matrices, alongside retrospective monitoring, which involved delineating the boundaries of tree growth rings for metal content analysis through laser ablation (LA) techniques coupled with ICP-MS. The resultant database is unprecedented in Romania, encompassing the analytical quantification of microelements, macroelements, and tracer isotopes of strontium (Sr) and lead (Pb) within the radial growth rings of trees. The findings to date reveal ongoing environmental issues that have not diminished since the cessation of industrial activities; indeed, these problems appear to have intensified. Toxic metal levels exhibit considerable variability and are strongly affected by climatic conditions. Furthermore, the nutrient analysis underscores significant challenges to the resilience of plant communities in resisting the extreme and aggressive

impacts of regional climate patterns, particularly due to disturbances in the ecosystem's mineral cycle.

Section (B-i2) examines the extent of contamination in the monitored areas and the effects of potentially toxic metals on human health and ecosystems. Various matrices were analyzed, and the results often reveal issues that require special attention and constant monitoring. In this section, I have presented a collection of herbaceous plants found in spontaneous flora that were evaluated for their antioxidant activity. Plants were chosen from the Transylvania region, which was previously noted as having been exposed to historical industrial and mining activities that caused significant environmental enrichment with hazardous heavy metals.

Section (B-i3) emphasizes the effort to develop a new technology for separating and enriching the lithium-6 isotope. This process is highly complex, currently in international testing stages, with early findings documented in specialized literature. To support this goal, we secured substantial funding of 8,185,783 lei for the project "*Development of innovative technology for the separation of lithium isotopes through electromobility and artificial intelligence algorithms*". So far, I have led my team at ICSI Analytics Râmnicu Vâlcea in developing the technology at the laboratory scale and establishing testing and calibration infrastructure. The modular assembly is customizable and can be continually improved by replacing segments as needed. We have filed two patents for validation and published several results aligned with our objectives. I achieved an impressive milestone by conducting isotope measurements using a less sensitive instrument—a quadrupole ICP-MS—under specialized laboratory conditions and with a dedicated method. This involved intercalibration in two sessions with Jena Analytics, the instrument manufacturer. The successful results, driven by ICSI Analytics, my leadership, and personal initiative, led to an intercalibration at the manufacturer level, ensuring the laboratory method meets the performance standards for the Q-ICP-MS instrument. In this context, we have successfully performed tests confirming the operation of the technological flow detailed in the habilitation thesis. A unique database containing technology-specific measurements has been established. We laid the groundwork for developing a technology with industrial potential by implementing artificial intelligence algorithms. Additionally, we supported its development at various stages, including for documentation and educational purposes. After obtaining the patent and complying with ICSI Râmnicu Vâlcea regulations, this technology can be transferred to final users.

We have conducted, for the first time, stable isotope analyses of ^6Li and ^7Li on various matrices, and the results are being prepared for publication. Additionally, we have established the first database in Romania of isotopes and metals (both toxic and nutrient elements) based on annual tree growth rings. This database, which will be published, monitors various aspects of tree growth and development, as well as decline induced by climatic and pollution-related factors. An introductory article, encompassing data from 5815 individual trees and referencing pollution, has already been submitted for review to the esteemed Journal of Environmental Management. This article examines the combined effects of environmental factors on growth, and specific data pertaining to the tree network evaluated throughout Romania, including metal and isotope measurements, are also planned for publication. Our targeted journals for these publications include ACS Environmental Science and Technology, Chemical Engineering Journal, and Journal of Hazardous Materials.

My short-term perspective is to train talented doctoral students and provide them with learning and performing opportunities both within our national team and with international partners. This aims to support the future progress of research and education in physics applied to environmental processes and cutting-edge technologies. Another important professional aim is to establish new partnerships with local and global institutions and researchers. My engagement with the international research community is based on qualities like promptness, integrity, commitment, professionalism, and perseverance. I have demonstrated these traits through successful collaborations, often taking the lead. These partnerships enhance knowledge and skills, which can be further utilized by securing joint international funding or publishing in high-impact journals.