Publishable Summary for 23IND07 RadonNET
Radon metrology: Sensor networks for large buildings and future cities

Overview

In compliance with the Directive 2013/59/Euratom, member states are required to mitigate ^{222}Rn activity concentration in public and private buildings, where levels regularly exceed the reference threshold of 300 Bq m^{-3}. Authorities are mandated to implement mitigation strategies that adhere to basic safety standards, safeguarding citizens from ionising radiation exposure due to ^{222}Rn progenies. This project addresses the challenge of quantifying ^{222}Rn activity concentrations indoors, particularly in large buildings for future cities with a focus on connected, low-energy consumption buildings. The development of methods and sensors for detecting radon activity concentration as well as the creation of quality assured sensor network will enhance on-site ^{222}Rn metrology and provide support to the European radiation protection industry.

Need

Reducing air exchange in large buildings offers cost savings, yet encounters resistance due to radiation protection concerns, particularly related to indoor ^{222}Rn activity concentration. As outdoor ^{222}Rn levels are generally lower, efficient ventilation remains a proven technique for mitigating exposure to this radioactive gas. However, ventilation increases energy usage and maintenance costs and should be employed only as much as needed due to indoor air quality and specifically ^{222}Rn activity concentrations. Fluctuations in ^{222}Rn emanation due to temperature, pressure, and humidity variations underscore the necessity of employing smart sensor networks in connected buildings to monitor the changes in ^{222}Rn levels. This technological adaptation is imperative for achieving energy-efficient designs for future buildings.

Despite these advantages, the current state of metrology for connected sensors and networks is insufficient in Europe. Vital for observing ^{222}Rn levels in expansive structures or multiple houses, sensor networks prevent wasteful energy use or overlooking high ^{222}Rn areas. Manual detector maintenance and analysis are labour-intensive, leading to unnoticed malfunctions. Relying solely on a single detector location risks inefficiency or missing regions with high ^{222}Rn concentrations. Furthermore, the calibration of sensors proves expensive and presently inefficient or non-existent for cost-effective sensors.

The solution necessitates the deployment of sensor networks, effectively balancing radiation protection and energy efficiency. The need to safeguard citizens from radiation is acknowledged by the European Directive 2013/59/Euratom which underscores the importance of ^{222}Rn mitigation. Connected radon instrumentation plays a pivotal role in reducing radon-related risks. Networked instruments bolster radiation protection and thus diminish lung cancer risks. Nonetheless, realising the deployment of sensor networks is complex, particularly concerning cost-effectiveness. Overcoming this challenge requires bespoke solutions and the integration of radon metrology and sensor network metrology expertise.

Sensors with long response times and unverified linearity thwart timely mitigation action. The project capitalises on connected technologies to ensure swift response and precise calibration. The main aim is to develop efficient devices that establish the calibration standard for low activity concentrations, reaching down to Bq m^{-3}, in connected buildings. The pursuit of novel sensor techniques, measurement methodologies, and metrological traceability for connected devices and networks is indispensable to position Europe as a front-runner in radon mitigation, all while considering energy-efficient connected building designs.

Objectives

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

The overall objective of this project is to develop new and to improve, expand and merge existing ^{222}Rn activity concentration measurement sensors to networks that automatically provide regular and reliable indoor ^{222}Rn activity concentration measurements.

The specific objectives are:

1. To develop new concepts and methods for sensors detecting radon activity concentration with lowered response time, increased sensitivity and reduced uncertainty compared to existing solutions. To build the sensors in a cost-effective and material-saving way through advanced manufacturing techniques using industrial production by SMEs. (WP1)
2. To develop traceable, in-situ operando calibration procedures for these sensors with less than 10 % uncertainty at an activity concentration level down to Bq m^{-3}, allowing for response time and dynamic linearity testing. (WP2)
3. To develop a quality assured sensor network suitable for large building monitoring, consisting of the developed sensors and based on the use of artificial intelligence, IoT and a digital twin. (WP3)
4. To develop an extension of the sensor network capable of including other existing and potential building sensor networks that incorporates intelligent data analysis and integration methods to enable the optimised use of energy, air quality management and radiation protection in a single monitoring system. (WP4)
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the industry, the measurement supply chain (NMIs, calibration laboratories), the standards developing organisations (e.g. IEC, ISO), end users in radiation protection and building air quality system manufacturing and via the EMN on Radiation Protection, to support the development of new, innovative products, thereby enhancing the competitiveness of EU industry. (WP5)

Progress beyond the state of the art and results

New methods and sensors for detecting radon activity concentration (objective 1)

Currently, there are numerous radon detectors available, both passive and active. However, many of these are based on outdated models and aging technology that have undergone various ownership changes between companies. Their primary drawback often lies in their cost, particularly for active detectors, and the fact that they are not IoT devices capable of enabling active radon mitigation.

By leveraging advanced manufacturing techniques, RadonNET aims to create next-generation prototypes of connected sensors that will not only be cost-effective and material-saving but also surpass the performance of existing ^{222}Rn detection devices. These future sensors will exhibit significantly lowered response time, be compact and network-connected for remote measurements with unparalleled sensitivity. These properties will contribute to a significant reduction in measurement uncertainties for the targeted concentration limit of 300 Bq m^{-3} given by the Directive 2013/59/Euratom. The development will focus on producing the sensors in a cost-effective way to enable technology transfer to SMEs in Europe. The sensor connectivity will enhance the radon mitigation and cost calibration by proposing new features in the metrology domain such as network calibration and type testing.

New in-situ operando calibration procedures for sensors (objective 2)

Radon instrument calibration is conducted in laboratories using primary standards and dedicated exposure chambers. While this method can be highly precise when properly executed, it may not be suitable for certain needs, particularly due to its high operational costs, especially for low-cost detectors. Additionally, it requires transporting the devices to calibration laboratories, making it incompatible with active radon mitigation.

RadonNET's vision includes achieving traceable in-situ operando calibration with the development of new, innovative measurement devices and primary measurement methods that will be developed to calibrate connected radon sensors. Operando calibration of a connected network of sensors will make it possible to avoid immobilising equipment and will limit the costs associated with calibration, making Europe the leader in this domain. The targeted measurement uncertainties are less than 10 % at an activity concentration level of Bq m^{-3}, six times lower than the normative limits to ensure reliable results, avoid false alerts and move closer to the recommended value of WHO at 100 Bq m^{-3}. Methods incorporating dynamic linearity testing and sensor response time optimisation will be developed. These new calibration procedures will transcend current capabilities and incorporate the measurement of sensor time response, which is missing from current calibration procedures. This change in the field of metrology will provide unprecedented precision in radon metrology and enhance radon mitigation in connected house while saving energy. The new calibration methods will be usable for other radioactive gases (e.g., ^{133}Xe, ^{85}Kr, ^{3}H, and ^{37}Ar), offering an impact beyond the scope of this project and enabling precise measurements of radioactive gases, which is of major importance for future developments in nuclear power generation, such as Small Modular Reactors (SMRs).

Quality assured fit-for-purpose sensor network (objective 3)

There is currently no network of radon sensors, despite the existence of current technologies for pollutants such as VOCs, CO_2, or even more recently, aerosols. This absence prevents active radon mitigation, even though all current IoT systems allow for it.

This project envisions the development of an intelligent sensor network that will revolutionise large building monitoring and environmental control. This visionary sensor network will seamlessly integrate artificial intelligence and IoT, ushering in a new era of sophisticated and interconnected air quality monitoring systems.

Extension to include other sensor networks (objective 4)

Radon sensors are often paired with pressure, temperature, or humidity probes, mainly to correct the displayed values based on the device's operation. However, these data are not generally used both for measuring and actively mitigating radon.

By incorporating the measurement of indoor ^{222}Rn activity concentration, this new network will enable the optimisation of energy use, air quality management, and radiation protection in a unified and intelligent manner, shaping the future of smart and sustainable cities with limited energy consumption. RadonNET will forge essential recommendations and guidance specifically tailored to radon metrology. RadonNET's advancements will also lay the groundwork for the incorporation of radon calibration and mitigations measures into the design of connected homes. This approach is groundbreaking, aligning indoor air quality, radiation protection, and overall well-being with the principles of future-oriented living environments.

Outcomes and impact

Outcomes for industrial and other user communities

Enhanced Safety and Health Measures: The project's development of advanced radon activity concentration sensors and traceable calibration procedures will empower industrial and user communities, such as building managers, regulators and authorities, construction companies, and homeowners, to implement more effective safety measures. With accurate real-time data on radon levels, these communities can proactively mitigate radon exposure risks and ensure healthier indoor environments, reducing the incidence of lung cancer associated with radon exposure.

Cost-Effective Sensor Networks: The project's focus on cost-effective, material-saving prototype sensors and automated data acquisition and transmission will result in sensor networks that are affordable and easily deployable for large buildings and future cities. This outcome will benefit industrial stakeholders, such as property developers and facility management companies, by offering cost-efficient solutions for implementing radon monitoring systems in various structures without significant extra financial burden.

Improved Energy Efficiency: The integration of radon sensor networks with other building sensor networks and the use of artificial intelligence will enable energy-efficient regimes for air exchange systems. Industrial communities will benefit from reduced utility costs in large buildings, as energy-saving approaches are optimised without compromising indoor air quality and radiation protection.

Market Opportunities for Sensor Manufacturers: The project's focus on strengthening European ^{222}Rn measurement manufacturers by developing new sensor technology and supporting regulations will create market opportunities for sensor manufacturers. With the increased demand for innovative, sensitive, and reliable radon sensors, manufacturers can expand their product portfolio and tap into a growing market for radon detection solutions.

Outcomes for the metrology and scientific communities

Advancements in Radon Metrology: The project's research and development of novel radon activity concentration sensors and calibration procedures will significantly advance radon metrology. The metrology community will benefit from new insights into radon detection techniques, improved measurement uncertainties at low concentration levels, and enhanced traceability of radon activity concentration measurements. The core of the project will be focused on in-situ operando metrology of connected measurement devices. The project will significantly improve existing strategies for radon sensor network calibration and develop necessary devices and methods to make the calibration more cost-effective.

Collaboration and Knowledge Exchange: The project's collaborative and international nature, involving multiple stakeholders, universities, and SMEs, will foster knowledge exchange within the metrology and scientific communities. Researchers and experts in radon metrology will share their expertise, methodologies, and best practices, leading to mutual learning and the advancement of the field. Although the project is primarily dedicated to ionising radiation, it will also directly connect with recent calibration work for sensor networks, especially in other quantities such as pressure, temperature, humidity, and any other measurements required in connected buildings.

Validation of Emerging Technologies: The project's validation of emerging technologies, such as artificial intelligence and IoT, and new methods for radon sensor calibration networks will serve as a valuable reference for the scientific community. The results and findings can be used to inform future research and applications in other fields of radionuclide metrology and environmental monitoring. The new sensor and calibration methods of sensor networks developed in this project could be used for other radioactive gases, particularly those measured for monitoring Evolutionary Power Reactor (EPR1 & 2), future emerging SMRs, and future fusion reactors, as well as in waste treatment monitoring.

Student Formation and Knowledge Transfer: The project's collaborative nature and involvement of SMEs and universities will provide valuable opportunities for student formation in the scientific communities. Students will have the chance to engage in cutting-edge research, gain hands-on experience in radon metrology and sensor network metrology, and work alongside experts, fostering knowledge transfer and nurturing the next generation of metrology professionals.

NMIs and DIs that are not participating in the project will be involved as collaborators, and their knowledge and installations will be used where appropriate (e.g., CIEMAT, STUK, FTMC, KRISS).

Outcomes for relevant standards

Improved Standardisation of Radon Metrology: The project's development of traceable calibration procedures and quality-assured sensor networks will contribute to the standardisation of radon metrology. By aligning with international standards organisations such as International Electrotechnical Commission (IEC) and International Organisation of Standardisation (ISO), the project's outcomes will influence the establishment of standardised protocols for radon detection and monitoring and can be extended to other radioactive gases as well.

Guidelines for Radon Mitigation Strategies: The project's research on radon monitoring for large building will provide valuable insights for the formulation of guidelines and standards related to radon mitigation. Regulatory bodies and standard-setting organisations can use this information to develop effective measures to reduce radon exposure in buildings.

Longer-term economic, social and environmental impacts

Public Health Benefits: The project's focus on improving radon detection and implementing mitigation strategies will lead to reduced incidences of radon-related lung cancer, improving public health and reducing mortality rates in radon-prone areas. Lower healthcare costs associated with radon-induced health issues will benefit European healthcare systems and society as a whole.

Improved Indoor Air Quality: By enabling the implementation of advanced radon sensor networks, the project will contribute to improved indoor air quality in large buildings and future cities. Cleaner and healthier indoor environments will positively impact the well-being and productivity of occupants, leading to a healthier society.

Energy Conservation: The integration of radon sensor networks with energy-efficient air exchange systems will lead to energy conservation in large buildings. Reduced energy consumption will contribute to environmental sustainability by lowering carbon emissions and mitigating the impact of buildings on climate change.

Market Growth and Job Creation: The expansion of the radon metrology market and the rising demand for radon sensors will energise economic growth in the EU. This surge will result in job creation across various sectors, including sensor manufacturing, technology advancement, and the establishment and upkeep of radon monitoring systems. Furthermore, the radon mitigation industry stands to gain significant momentum from the introduction of highly sensitive radon-calibrated sensor networks, a sector that is more advanced in the USA than in Europe.

Empowering the Workforce: By encouraging student support and involvement, the project will contribute to empowering the future workforce in the field of metrology and environmental monitoring. The expertise gained by students during the project will equip them with valuable skills and knowledge, enhancing employability and addressing the growing demand for skilled professionals in environmental safety and health sectors.

Overall, the outcomes of RadonNET will have far-reaching effects on various communities. The improvements in radon detection, safety measures, and indoor air quality will promote public health and safety. Furthermore, advancements in metrology and scientific knowledge will drive innovation in the field, while adherence to relevant standards will ensure consistency and reliability in radon measurements. The longer-term economic, social, and environmental impacts will contribute to a sustainable and resilient future for European cities and communities.

List of publications

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This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:	1 September 2024, 36 months	
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Internal Beneficiaries: 1. CEA, France 2. BFKH, Hungary 3. CMI, Czechia 4. PTB, Germany 5. SMU, Slovakia	External Beneficiaries: 6. CLOR, Poland 7. IFIN-HH, Romania 8. LivAir, Germany 9. NUVIA, Czechia 10. Radonova, Sweden 11. SUBG, Bulgaria 12. UCBL, France 13. UH, Finland 14. USIEG, Germany	Unfunded Beneficiaries: -
Associated Partners: 15. NPL, United Kingdom		