Annex I – JRP protocol

Version Date: 20 May 2024

23IND07 RadonNET

Radon metrology: Sensor networks for large buildings and future cities

Start date: 01 September 2024

Duration: 36 months

Coordinator
Benoit Sabot
CEA

<u>Glossary</u>

AI	Artificial Intelligence
ALARA	As low As Reasonably Achievable
ANSTO	Australia's Nuclear Science and Technology Organisation
AURN	Automatic Urban and Rural Monitoring Network
BIPM	International Bureau of Weights and Measures *(Bureau international des poids et mesures)*
CCRI	Consultative Committee for Ionising Radiation (BIPM Committee)
CIEMAT	Research Centre for Energy, Environment and Technology (Spain)
CTU	Czech Technical University
DI	Designated Institute
DMP	Data Management Plan
EANR	European Atlas of Natural Radiation
EMN	European Metrology Networks
EPR	Evolutionary Power Reactor *(European pressurised reactor)*
EU-BSS	European Union - Basic Safety Standards
EURAMET	European Association of National Metrology Institutes
EURATOM	European Atomic Energy Community
FAIR	Findable Accessible Interoperable Reusable
FTCM	Center for Physical Sciences and Technology (Lithuania)
FWHM	Full-Width Half-Maximum
IAEA	International Atomic Energy Agency
ICRM	International Committee for Radionuclide Metrology
ICRP	International Commission on Radiological Protection
IEC	International Electrotechnical Commission
IP	Intellectual Properties
IPGP-PSN	Institut de Physique du Globe de Paris – Physique des Sites Naturels
ISO	International Organization for Standardization
KRISS	Korea Research Institute of Standards and Science
MCNP	Monte-Carlo N-Particle transport
ML	Machine Learning
MQTT	Message Queuing Telemetry Transport
NMI	National Metrology Institute
SI	International Systems of Units
SMEs	Small and Medium-sized Enterprises
SMEAR	Station for Measuring Ecosystem-Atmosphere Relations
STUK	Radiation and Nuclear Safety Authority (Finland)
TC-IR	EURAMET Technical Committee for Ionising Radiation
TDCR	Triple to Double Coincidence Ratio
WHO	World Health Organisation

Contents

Section A: Key data

A1 Project data summary

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Participant details:

no.	Participant Type	Short Name	Organisation legal full name	Country
1	Internal Beneficiary	CEA	Commissariat à l'énergie atomique et aux énergies alternatives	France
2	Internal Beneficiary	BFKH	Budapest Főváros Kormányhivatala	Hungary
3	Internal Beneficiary	CMI	Cesky Metrologicky Institut	Czechia
4	Internal Beneficiary	PTB	Physikalisch-Technische Bundesanstalt	Germany
5	Internal Beneficiary	SMU	Slovenský Metrologický Ústav	Slovakia
6	External Beneficiary	CLOR	Centralne Laboratorium Ochrony Radiologicznej	Poland
7	External Beneficiary	IFIN-HH	Institutul National de Cercetare-Dezvoltare pentru Fizica si Inginerie Nucleara "Horia Hulubei"	Romania
8	External Beneficiary	LivAir	LivAir GmbH	Germany
9	External Beneficiary	NUVIA	NUVIA a.s.	Czechia
10	External Beneficiary	Radonova	Radonova Laboratories AB	Sweden
11	External Beneficiary	SUBG	Sofia University St. Kliment Ohridski	Bulgaria
12	External Beneficiary	UCBL	Université Claude Bernard Lyon 1	France
13	External Beneficiary	UH	Helsingin Yliopisto	Finland
14	External Beneficiary	USIEG	Universitaet Siegen	Germany
15	Associated Partner - linked to all internal beneficiaries	NPL	NPL Management Limited	United Kingdom

A2 Financial summary

	Internal Beneficiaries	External Beneficiaries	Unfunded Beneficiaries	Associated Partners	Total	Total eligible
Labour (€)	881 853.00	465 000.00		185 000.00	881 853.00	465 000.00
Subcontracts (€)						
T&S (€)	71 500.00	82 000.00		11 500.00	71 500.00	82 000.00
Equipment (€)						
Other Goods, Works and Services (€)	102 000.00	37 000.00		3 500.00	102 000.00	37 000.00
Internally Invoiced Goods and Services (€)						
Financial Support to Third Parties (€)						
Indirect (€)	263 838.25	146 000.00		50 000.00	263 838.25	146 000.00
Total costs (€)	1 319 191.25	730 000.00		250 000.00	1 319 191.25	730 000.00
Costs as % of Total costs	57 %	32 %	0 %	11 %	57 %	32 %
Total Eligible Costs (€)	1 319 191.25	730 000.00			1 319 191.25	730 000.00
EU contribution (€)	1 319 191.25	730 000.00			1 319 191.25	730 000.00
EU contribution as % of total EU contribution	64 %	36 %	0 %	0 %	64 %	36 %
Months	139.6	112.2		18.6	139.6	112.2

A3 Work packages summary

WP No	Work Package Title	Active Participants (WP leader in bold)	Months
WP1	New concepts and methods for radon concentration measurements	**CEA**, CMI, SUBG, UCBL, PTB, USIEG, LivAir, NUVIA, Radonova	61.1
WP2	Traceable, in situ operando calibration procedures	**PTB**, CEA, BFKH, CMI, SMU, CLOR, IFIN-HH, SUBG, USIEG, UCBL, NPL, NUVIA, Radonova, UH, LivAir	71.0
WP3	Network of radon sensors and data analysis	**NPL**, SUBG, PTB, UH, NUVIA, Radonova, IFIN-HH, CEA, CMI, LivAir, SMU, USIEG, UCBL	53.8
WP4	New methods for the integration of the radon network technology into other existing sensor networks	**CLOR**, NPL, PTB, UH, CMI, Radonova, LivAir, CEA, IFIN-HH, SMU	48.5
WP5	Creating impact	**CMI**, all other participants	22.3
WP6	Management and coordination	**CEA**, all other participants	13.7
		Total months	**270.4**

The information in tables A2 and A3 reflect the estimates of resources as of the start of project in September 2024. The tables will not necessarily be updated during the course of the project.

Section B: Overview of the research

B1 Summary of the project

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.

Needs

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

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.

B2 Excellence

B2.a Overview of the objectives

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.

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B2.b List of deliverables

Relevant objective (Activity delivering the deliverable)	Deliverable number	Deliverable description	Deliverable type	Participants (Lead in bold)	Delivery date
1 (A1.3.6)	D1	Good practice guide on new methods and sensors developed for radon concentration monitoring in sensor network with lowered response time, increased sensitivity and reduced uncertainty. This will include at least three detection concepts based on the use of i) semiconductors, ii) ionisation chambers and iii) scintillators	Good practice guide	**CMI**, CEA, SUBG, UCBL, PTB, USIEG, NUVIA	Aug 2027 (M36)
1 (A1.4.5)	D2	Report on solutions of newly developed radon concentration measurement instruments that can be transferred to industry for SMEs through advanced manufacturing including i) low-cost and material-saving technology and ii) highly sensitive system for on-site calibration	Report	**CEA**, CMI, SUBG, UCBL, PTB, USIEG, NUVIA	Aug 2027 (M36)
2 (A2.2.7)	D3	Paper on the influence of environmental parameters (temperature, pressure, humidity and CO_2 concentration) on the radon activity concentration measurements of sensors submitted to a peer-reviewed journal	Paper	**PTB**, CEA, CMI, CLOR, SMU, USIEG, SUBG	Feb 2027 (M30)
2 (A2.4.6)	D4	Good practice guide for traceable laboratory calibration procedures for ^{222}Rn activity concentration sensors of different types of technologies with less than 10 % standard uncertainty at an activity concentration down to 50 Bq m^{-3} allowing for response time and dynamic linearity testing	Good practice guide	**PTB**, CEA, CLOR, CMI, NPL, SMU, SUBG, USIEG, BFKH, IFIN-HH	Aug 2027 (M36)

3 (A3.4.5)	D5	Summary report on data analysis of radon measurement anomalies and application of AI/ML methods for their detection to validate the radon sensor network suitable for large building monitoring	Report	**NPL**, UH, PTB	Feb 2026 (M18)
3 (A3.4.7)	D6	Report on the newly developed universal radon sensor network with associated data analysis and calibration procedures	Report	**CEA**, PTB, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, SUBG, UH, NPL	Aug 2027 (M36)
4 (A4.2.5)	D7	Good practice guide on the development of an extension of the sensor network enabling inclusion of other existing and potential building sensor networks	Good practice guide	**NPL**, PTB, LivAir, CLOR, Radonova, UH, IFIN-HH	Feb 2027 (M30)
4 (A4.3.6)	D8	Report on the intelligent data analysis and integration methods to optimise the use of energy saving, air quality management and radiation protection in connected buildings. This will include recommendations on how to efficiently combine radon and other air quality measurements, considering air quality aspects, energy consumption and possible cross-correlations between different monitored parameters (e.g., CO_2, temperature)	Report	**UH**, CLOR, SMU, CEA, PTB, CMI, NPL	Aug 2027 (M36)
5	D9	Evidence of contributions to or influence on new or improved international guides, recommendations and standards with a specific focus on the following guides and committees: ISO TC45/TC146/TC207, BIPM CCRI, EURAMET TC-IR, ICRM, EURATOM/ Group of Experts. Examples of early uptake of project outputs by end-users. Updated dissemination, communication and exploitation plan.	Reporting documents	**CEA**, all participants	Aug 2027 (M36) + 60 days
n/a	D10	Delivery of all technical and financial reporting documents as required by EURAMET.	Reporting documents	**CEA**, all participants	Aug 2027 (M36) + 60 days

B2.c Need for the project

The earliest cases of radon induced lung cancer were reported in 1567 by Paracelsus [1], although neither radon nor cancer were known at the time. Radon naturally occurs as part of the ^{238}U decay chain and is found everywhere above land masses. Trace amounts of ^{238}U exist in varying concentrations in the Earth's crust, making radon a global issue [2]. As the only gaseous component of this decay chain, radon can enter the air. As it decays, its progenies become metal ions that attach to aerosols. These can enter the lungs through the respiratory system and deposit in the bronchi, emitting alpha and beta radiation, which can lead to lung cancer in the long term. Radon itself has a half-life of 3.8232(8) d [3] and exists in the respiratory system before causing significant radiation exposure. The radon activity concentration in the air is used as an indicator of risk at a specific time and place.

European legislation

Indoor radon exposure significantly increases the risk of lung cancer and has been included in the European Union's basic safety standards (EU-BSS) through Council Directive 2013/59/Euratom [4]. This directive defines an upper limit of 300 Bq m^{-3} for radon activity concentration. Numerous studies have shown this limit to be exceeded in many European buildings, sometimes regularly and unpredictably. This is particularly true for workplaces, including schools and offices, where radon tends to accumulate overnight when windows are closed, but levels drop during the morning with open windows [5]. Continuously mitigating radon risks in a building is economically impractical, contradicting the goals of the European Green Deal concerning energy consumption and posing a significant cost burden on the public in terms of energy consumption [6]. Continuous mitigation also fails to account for non-continuous factors affecting radon activity concentration, such as weather, the day-night cycle, and seasonal variations.

Radon mitigation and competitiveness

Precise radon activity concentration measurements are essential for effective mitigation. Yet, current devices are costly or yield uncertain results, especially at typical indoor radon levels. Radon levels can change on timescales of hours due to factors such as temperature, pressure, and humidity. This project tackles these challenges through enhanced sensors and calibration methods, ensuring Europe's competitive edge while complying with EU-BSS rules. Ventilation is a common mitigation method, but it conflicts with maintaining indoor comfort, a significant factor in energy consumption. To optimise radon mitigation per the ALARA principle (exposure As Low As Reasonably Achievable) and conserve indoor comfort, the project aims to deploy a network of radon sensors in large buildings. The consortium recognises calibration costs from previous projects (e.g., EMPIR JRP 16ENV10 MetroRADON [7]) that often necessitate transporting equipment to calibration labs, incurring costs nearly equal to the device's price. These methods pose calibration challenges, are often overlooked, and lag in European competitiveness. It is imperative to develop operando and in-situ calibration techniques for radon metrology, alongside connected radon measurement and mitigation devices in future buildings. The radon mitigation industry stands to gain significant momentum from the introduction of highly sensitive radon-calibrated sensor networks, a sector that is currently more advanced in the USA than in Europe.

Radon measuring sensors and innovative methods (objective 1)

The project's core objective is to develop dual-purpose sensors, functioning as both enhanced, cost-effective alternatives to existing radon sensors and as transfer standards for on-site calibration. The work will focus on three key sensor technologies: semiconductors, ionisation chambers, and innovative porous scintillators, developed for other radioactive gases under the FET-open SPARTE project [8]. Collaboration is vital, requiring expertise and input from NMIs, universities, and industry. The new sensors will prioritise cost-effectiveness, aligning with European radon mitigation regulations, and easy integration into sensor networks for on-site calibration with minimal human intervention. Additionally, the project aims to create a self-diagnostic detector network, automatically identifying malfunctions, signalling recalibration needs, and conducting automated data analysis. This enhances operator efficiency. Environmental sustainability is a parallel focus, ensuring reduced energy and material usage and ecologically friendly production. The consortium will follow ionising radiation and sensor network metrology principles, working closely with industrial organisations to achieve these goals.

In-situ operando calibration methods (objective 2)

The current approach to radon mitigation and detector maintenance is highly reliant on user intervention, leading to gradual calibration discrepancies and the potential oversight of elevated radon activity concentrations over extended periods [9]. Drawing upon the principles of ionising radiation metrology and sensor network metrology, this project is dedicated to enhancing detector calibration through cost-effective, in-situ operando methods. Most radon sensors are influenced by environmental factors such as temperature, humidity, pressure, dust particles, and the concentration of gases such as CO_2 in the air. The precise impact of these factors on detector performance remains inadequately understood, contributing to uncertainties in the measured radon concentration. Building upon the technological foundations established in WP1, which encompass three primary radon measurement technologies, this project will delve into the influence of these factors on detector calibration and performance. Furthermore, the project recognises the need for on-site calibration, which typically necessitates data not conventionally collected by radon sensors, including details about time response and linearity. Within the framework of this project and in conjunction with the development of new sensor technology by WP1, the consortium will devise complementary methods to acquire these essential data points. This will enable on-site calibration through the sensor network, a significant advancement to be explored and refined within the context of the new calibration techniques.

Network for radon measurements and sensor calibration (objective 3)

The contemporary market is witnessing a surge in smart homes and integrated indoor air quality monitoring networks equipped with automated ventilation and temperature control systems. However, there is a notable absence of adequate metrological perspectives in this domain, and engineering solutions are often ad-hoc and not reproducible. To successfully develop new, suitable sensors and integrate them into the radon measurement network, high-level metrological support is imperative. This support will draw upon the principles of ionising radiation metrology and the rapidly advancing field of sensor network metrology. The project aims to surmount the challenges associated with incorporating radon sensors into such comprehensive networks, with integration of standardised data management approaches. This inclusion is essential for maintaining European competitiveness, particularly in comparison with prominent global players (notably South Korea) in the areas such as smart home with safety measures (in particular, radon detection). Consequently, the project envisions fruitful collaboration with the South Korean metrology institute, KRISS. While certain connected measurement technologies are beginning to emerge in Europe, with some being developed by project participants, there is a critical need for metrologically solid design and calibration procedures for these devices. This project will focus on developing network calibration methods for this field, addressing a significant gap in the current industrial landscape.

Extension to include other sensor networks (objective 4)

The goal of integrating a radon network into existing infrastructure is to improve building sustainability while prioritising occupant well-being and safety from natural radiation. As buildings become more energy-efficient, there is growing concern about ^{222}Rn accumulation due to reduced air exchange. This issue becomes increasingly critical in densely populated cities with tall buildings. As urbanisation continues, cities must accommodate more residents, necessitating taller structures with less energy-efficient profiles and challenging ventilation scenarios. This intensifies the radon mitigation challenge, emphasising the urgent need for improved radon metrology solutions. This project seeks to address these issues by incorporating radon sensors into advanced building technologies.

B2.d Progress beyond the state of the art

Radon mitigation regulation and industries

Current state of the art

Up-to-date information about the spatial distribution of radon in Europe has been published by the European Atlas of Natural Radiation (EANR) [10]. In addition, the EANR provides further information about the number of radon measurements at each place, showing that in some places there are very few or no measurements. Radon mitigation is classified as either passive or active remediation. Typical examples of passive remediation are insulation and sinks. By definition passive remediation is continuous and, therefore, no special attention is given to (potentially rapidly) changing environmental parameters. Active mitigation on the other hand is not continuous and while there are other methods, ventilation is also a useful option. Active remediation by ventilation, as compared to passive remediation, has the advantage that it can be adjusted to a change in environmental parameters like temperature or humidity (which are known to influence the radon activity concentration in certain places [6]) and according to the radon level. The disadvantage is that active mitigation by ventilation is highly user dependent. Thus, it can conflict with the desire of having comfortable air. This is typically compensated by heating or cooling which give the highest contribution to energy consumption in buildings.

Progress beyond the state of the art

This project will lay the basis for intelligent, radon level-based mitigation in dwellings, workplaces and large buildings. The new devices that will be connected on networks with associated calibration techniques and time response measurement will make it possible to accurately observe rapid changes in radon activity concentration and mitigate the risk immediately. One of the goals is to bring together the need for radiation protection with the need for comfortable air by pinpointing mitigation against radon in time and space. This dual aim not only enhances occupant well-being, but also addresses the pressing challenges faced by the radon mitigation industry, where timely and location-specific mitigation becomes increasingly important. Mitigating only when necessary and only in necessary locations (rooms) will provide the best compromise between energy consumption and radiation protection. For this purpose, a network (objective 3) of improved radon activity concentration sensors (objective 1) with improved calibration methods (objective 2) set in a network of sensors for other environmental parameters (objective 4), is needed.

Radon measurement sensors and innovative methods (objective 1)

Current state of the art

State-of-the-art radon activity concentration sensors face significant challenges. They are either prohibitively expensive, or suffer from high uncertainty levels, particularly at typical indoor radon activity concentrations. This undermines their reliability for active automated radon mitigation and effective radiation protection. To estimate the associated lung cancer risk due to radon exposure, epidemiological risk models are commonly employed. However, the lack of reliable radon activity concentration sensors introduces a significant source of uncertainty, as evidenced by a recent study from Finland [11]. Currently, the most sensitive transportable sensors for radon are based on ionisation chambers stemming from the EMPIR JRP 19ENV01 traceRadon

[12]. Their implementation in the industry is still a work in progress. This project will implement three different methods for measuring radon activity concentration:

- Semiconductor-Based Sensors: These sensors feature advanced alpha particle resolution, allowing for the separation of all radon isotopes and their decay products. Simple and cost-effective diodes are already available for these developments, potentially offering an affordable and compact solution for radon detection.
- Ionisation Chambers: These sensors directly measure the charge generated by ionisation when alpha particles traverse the chamber. However, the process is highly sensitive to minor changes in the position of the electrodes, leading to electrical noise and increased measurement uncertainty, known as "microphonics".
- Scintillators: Scintillators are the most sensitive sensors for radon, boasting a detection efficiency of up to 500 % for a single radon decay event, significantly enhancing sensitivity. However, current scintillators employ organic compounds containing nonylphenol ethoxylate (NPE), which are restricted under European Directive 2003/53/EC [13], and produce mixed wastes (aqueous-organic) for each measurement.

Progress beyond the state of the art

This project aims to advance manufacturing techniques to create prototype sensors with improved ecological footprints and enhanced performance. These sensors must also be cost-effective and material-saving to be viable for use in new industrial products, suitable for implementation as non-research-grade sensors in large buildings. Three distinct types of sensors will be developed, intended for use as measurement devices in networks or for the calibration of these sensors as transfer standards.

- Semiconductor-Based Sensors: The goal is to produce highly compact systems with simplified electronics. Their advanced resolution will enable direct radon measurement via alpha spectrometry, facilitating the development of new methods for radon sensor time response measurements.
- Ionisation Chambers: The consortium aims to minimise the impact of microphonic effects to enhance overall measurement accuracy and explore size optimisation of the chamber.
- Scintillators: The consortium's approach involves a revolutionary shift in concept, utilising recently developed porous inorganic scintillators [8]. By harnessing these innovative materials in conjunction with associated measurement methods and devices, the project will eliminate any contribution from hazardous organic compounds, resulting in a reusable product with no waste generation over an extended period. These inorganic compounds are less susceptible to detection quenching effects, such as those observed in organic liquids like oxygen.

<u>In-situ operando calibration methods (objective 2)</u>

Current state of the art

New methods for on-site calibration, initially developed in the EMPIR JRP 19ENV01 traceRadon [12] for climate change observation, offer significant promise. While these methods have been field-tested effectively outside buildings, further refinement is required to adapt them for indoor use [14]. Currently, this represents the only viable avenue for on-site calibration, addressing a critical need within the radon measurement field. Conventional laboratory-based calibration methods are not only cost-intensive but also entail significant downtime for measurement devices. As such, the development of on-site calibration techniques holds the potential to offer a more cost-effective and efficient calibration solution.

Progress beyond the state of the art

The aim is to develop tailor-made, traceable, in-situ operando calibration methods specifically designed for the sensors developed in WP1. These methods, unlike existing ones, need to be cost-effective and suitable for calibrating a large number of similar sensors, particularly those integrated into networks. Ideally, these methods should be automated or, at the very least, straightforward enough not to necessitate specialised knowledge from operators. The ultimate aim is to pave the way for the creation of a digital twin capable of autonomously detecting when a detector requires calibration. Relying on a specialist for every detector on every occasion would not be a practical option for operators. In addition to exploring an already identified technique, we are also planning to develop a direct primary measurement method based on porous scintillators and the Triple To Double Coincidence Ratio (TDCR) principle. This endeavour seeks to provide a wholly innovative solution that could potentially evolve into an industrial product. To enhance the precision of detector measurements, the project also intends to investigate the influence of environmental parameters on the measurement uncertainty of the sensors developed in WP1. These parameters encompass temperature, pressure, humidity, CO_2 concentration, and various combinations thereof.

Network for radon measurements (objective 3)

Current state of the art

Connected radon sensors have already found their way into various projects, especially among the participants of this consortium [15] [16]. However, these sensors remain at the research-grade level and are currently lacking in quality assurance. Notably, both data collection and data analysis still heavily rely on human intervention. Consequently, a significant amount of operator time is consumed in tasks related to detector monitoring, maintenance, data analysis, and the initiation of active mitigation measures. Moreover, the operation of these emerging sensors is currently limited to scientists and specially trained personnel. These sensors lack essential attributes such as network calibration, linearity checks, anomaly detection and response time measurements. Their performance can be inconsistent, particularly when faced with substantial variations in radon concentration, often resulting in false alarms of high concentrations. This issue is particularly relevant in buildings where people live or work.

Progress beyond the state of the art

While calibration methods for individual sensors are established, the project's focus lies in calibrating sensors within a network as an ensemble. By harnessing the collective expertise of metrological institutes, universities, and industry, the consortium aims to establish a quality-assured radon network with traceability to the SI system. For that, the project will employ conventional metrological and recently developed AI techniques. The goal is to automate the entire data lifecycle, encompassing data collection, analysis, and background estimation for real-time monitoring of detector statuses. This holistic approach ensures not only the reliability of individual sensors but also the seamless operation of the entire network, paving the way for enhanced radon monitoring and mitigation efforts.

Extension to include other sensor networks (objective 4)

Current state of the art:

In large buildings and smart homes, networks of sensors for monitoring environmental parameters such as temperature and humidity are already commercially available and widely adopted by facility managers and private homeowners. However, the integration of radon sensors into these networks has not been realised. Consequently, the potential cross-correlations between these environmental parameters and radon levels remain poorly understood and have not been factored into radon mitigation efforts.

Progress beyond the state of the art:

This project aims to break new ground by seamlessly integrating radon sensors into existing networks designed to monitor parameters like temperature and humidity in large buildings. This innovative approach not only enables to optimise a building's energy consumption but also provides valuable data on radon concentrations. Furthermore, it opens up the possibility of investigating the complex interplay and correlations between radon levels and other environmental parameters. This holistic perspective promises more efficient and effective radon mitigation strategies, ultimately contributing to healthier and safer indoor environments.

B2.e Gender dimension

This project does not have a gender dimension. The research and innovation content of the project does not directly involve sex and/or gender analysis. As the project focuses on radon metrology, sensor development, calibration procedures, and intelligent sensor networks for large buildings and future cities, the primary objectives pertain to technical advancements, safety measures, and environmental impact. The goal is to reduce the concentration of radon in connected building with calibrated devices and IoT bellow the recommendation level when a human is inside.

While recognising the significance of gender dimensions in various contexts, such as understanding health disparities or ensuring AI products' fairness, the scope of the project does not directly intersect with sex and/or gender analysis. In fact, as the project aims to automate calibration processes for radon sensor network taking into account other connected sensors or devices, the air quality process in buildings will be less dependent on human judgement and will, therefore, help remove differences arising from gender. However, this does not diminish the project's commitment to promote gender equality and inclusivity in other aspects of the project and organisational practices.

As the project's results will be unaffected by gender dimension, the project will target its dissemination and impact activities equally to all genders and in a way that attracts all genders.

B2.f Open science

During the lifetime of this project, open science practices will be implemented as an integral part of our methodology. As stipulated in the Partnership Grant Agreement (Annex 5) and planned in the Data Management Plan (DMP), the data and other research outputs generated in the project will be managed responsibly, in line with the FAIR principles. Open access will also be provided to scientific publications under the conditions set in the Grant Agreement (Annex 5).

The project's approach is focused on systematic sharing of knowledge and tools as early and widely as possible. This practice is already widely performed within the metrology institutes participating in the project and will be promoted by the whole consortium. To ensure the reproducibility of our research outputs, the consortium will adopt measures such as transparent research output management, where data, software, models, and algorithms will be openly shared and clearly linked to the research data management.

In addition to the mandatory open science practices, the project will implement the following practices:

Early and Open Sharing of Research:

Pre-prints of the project paper(s) will be submitted to reputable open access platforms such as https://arxiv.org/, preprints.org, and techrxiv.org. This proactive sharing accelerates the dissemination of the project findings ahead of formal publication, fostering rapid collaboration and knowledge exchange within target scientific communities.

Measures to Ensure Reproducibility of Research Outputs:

Ensuring the reproducibility of our research outputs is paramount. To achieve this, the consortium will provide comprehensive information on the tools, instruments, and methodologies required to validate scientific conclusions and research data. Digital or physical access to the results needed for validation will be facilitated. Feedback from the Stakeholder Committee, as well as peer review, will contribute to robust and reliable research outcomes.

The participants are either accredited to or work in full compliance with ISO/IEC 17025 'Testing and calibration laboratories'. This accreditation demonstrates their competence and ability to consistently generate valid and reliable results, instilling confidence in the quality of their work. To further ensure the reliability of our research outputs, the project will actively engage in laboratory trials, including measurement comparison campaigns with the different standard from NMIs, aimed at investigating the performance of sensors developed in the project. During these calibration ad trials, repeated measurements will be conducted and compared between participating institutes. To uphold stringent quality assurance and quality control procedures, all participants will adhere to an agreed-upon measurement protocol. Variations between measurements will be meticulously determined and assessed, and comprehensive uncertainty budgets will be meticulously produced.

Moreover, the calibration methods developed in WP2 will undergo rigorous validation through interlaboratory comparisons within the consortium. These comparisons will involve repeated measurements made and compared between participants, including those who did not directly contribute to the development of each method. This robust validation process ensures the accuracy and reliability of our research outputs, adhering to the highest standards of scientific rigor. Reliability and reusability of the project's results and methods will be demonstrated not only by the peer-review process but also by verification of the project's outcomes through standardisation committees that the project disseminates too.

Providing Open Access to Research Outputs:

The project will disseminate its other research outputs in an open science manner through trusted open access repositories like Zenodo and GitHub. This includes datasets, software, methods, good practice guides, and reports. To ensure usability, the project will accompany its software with ReadMe files and usage instructions. The choice of open-source languages and platforms will further foster accessibility.

Involving All Relevant Knowledge Actors:

The project's dedication to open science extends to actively engaging with diverse knowledge actors. The consortium will create forums and discussion groups on platforms like ResearchGate, the project's website and the talkspirit exchange server, fostering information exchange between stakeholders and project participants. Input and feedback from the Stakeholder Committee will enrich the research. Collaborative research mobility between university and NMI participants will facilitate knowledge transfer. Graduate students and young researchers will be invited to participate, ensuring a wider spectrum of perspectives and expertise contributes to the project's success.

By embracing these open science practices, the project not only adheres to industry standards but also enhances the robustness, transparency, and accessibility of our research outcomes. This approach promotes collaboration, accelerates innovation, and builds trust among various stakeholders, ultimately amplifying the impact of the research within and beyond the target scientific community.

B2.g Research data management and management of other research outputs

Types of data/research outputs

The project will generate a variety of data, including images (JPEG), numerical data (CSV), and text descriptions (Markdown). Additionally, the project will produce research outputs such as software, calibration methods, protocols, and materials. The total data size falls in the range of 100 GB – 2 TB. The project will combine this new data with existing sources from participants, scientific literature, simulations, and real-world measurements.

Findability of data/research outputs

All generated datasets will be assigned unique identifiers (e.g., DOIs, GIT Commit/tags, Handles, https://hal.science/) for easy retrieval. These identifiers include bibliographic information, funding details, and licensing terms. Where applicable, the metadata will include PIDs for authors (ORCID), organisations (ROR, ISNI), funders (ROR, GRID, FundRef), and related publications and research outputs (DOI, URN, ISBN, Handle). The data/research outputs will be deposited in trusted repositories like http://www.re3data.org/. Software and protocols will be stored, documented and version-controlled in e.g. GitHub, GitLab.

Accessibility of data/research outputs:

All of the data needed to validate the results presented in scientific publications/research outputs will be made openly available by default unless there is a specific reason not to publish them. Other data/research outputs will be made available on a case-by-case basis if relevant for third parties. Open access decisions will be case-specific, respecting data/research output owners' preferences. IPR considerations will be managed in line with the Data Management Plan (DMP), Consortium and Grant Agreements, and Dissemination, Communication and Exploitation (DCE) plan. Open access will be granted as soon as IPR considerations allow. The data/research outputs will remain accessible for the lifetime of the repository. Users will be required to acknowledge the project and the funding source, according to the latest CC BY license.

Interoperability of data/research outputs

The project will ensure interoperability by using trusted repository metadata standards and discipline-specific vocabularies and formats (e.g., GUM-VIM, OBO, DICOM). To facilitate compatibility, the consortium will map project-specific vocabularies to commonly used ones, which will also be published. The datasets will stand alone without references to other datasets.

Reusability of data/research outputs

The data/research outputs will either be licensed under the latest available version of the CC BY license or a license with equivalent rights as set out in the Grant Agreement. Users will be required to acknowledge the consortium and the source of the data in any resulting publications. Templates will be documented with embedded instructions rather than with separate README files to maintain reusability by minimising the number of files required. The data are in a common format and can be read using widely available software (open source or commercial). All data published in open access journals will be usable by third parties after the datasets have been deposited in a trusted repository. The data that does not relate to peer-reviewed publications will be made available for reuse on a case-by-case basis.

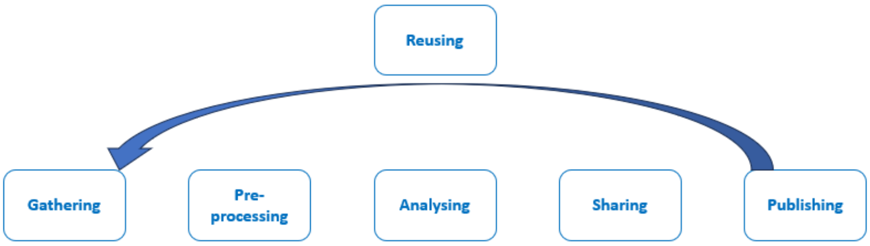
Curation and storage/preservation cost

Personnel costs of 1 000 € are included for making data/research outputs FAIR. Costs will be minimised by using trusted repositories with no costs for long-term preservation, and by making only relevant data/research outputs FAIR. These costs will be claimed if compliant with the Grant Agreement’s conditions.

Participant, person or team responsible for data management and quality assurance

This consortium will not establish a Data Access Committee (DAC). Instead, the coordinator, with support from the participants, will be responsible for the management of data/research outputs, quality assurance, coordinating updates to the DMP and for deciding on a case-by-case basis which data/research outputs will be kept and for how long. The selection of data to be openly accessible will take into consideration ethical aspects and data security, especially concerning the protection of intellectual property (IP) for any project outputs that are deemed to be commercially exploitable. In such cases, it may be necessary to withhold all or some of the data generated.

By adhering to these data management practices and considering the protection of IP, the consortium seeks to promote transparency, collaboration, and the broad use of its research data, contributing to the advancement of knowledge and scientific progress within the scientific community and beyond.



Schematic of data management plan

B3 Potential outcomes and impact from the project

B3.a Projected outcomes for industrial and other user communities

This project is poised to deliver transformative outcomes for industrial and other user communities. By developing novel concepts and methods for measuring indoor radon activity, significant advancements in radon metrology are anticipated. The implementation of advanced manufacturing techniques will result in cost-effective and material-saving prototype sensors with unparalleled performance characteristics. These sensors will boast lowered response time, increased sensitivity compared to existing ^{222}Rn detection devices used in dwellings, and will provide precise and reliable data for industrial applications and end-users. Their connectivity will be key for the future of radon mitigation in Europe. The project will present competitive solutions surpassing current European industrially produced sensors and challenging the developments in South Korea. The project participants will work in close collaborative cooperation with the radon group of the South Korean metrology institute KRISS.

Of particular note is the project's relevance to the radon mitigation industry. The industry needs sensitive, continuously working, metrologically sound sensors reliable even at low radon concentrations, which the project will provide. While this industry is well-established in the United States, it has yet to fully develop in Europe. The project participants plan close cooperation with the International Committee for Radionuclide Metrology (ICRM), hosted by the US metrology institute NIST. The project will boost the growth of this industry in Europe. This dual benefit, improving public health and fostering economic growth, underscores the importance and impact of the research work.

The establishment of traceable, in-situ operando calibration procedures for radon sensors will represent a ground-breaking achievement. These calibration procedures will set new standards in radon metrology, bolstering confidence in the accuracy and reliability of radon measurements for regulatory compliance and safety assessments in large buildings and future cities. Unlike current systems, the automated, operando calibration procedures developed in this project will not affect uptime and will remove the need to physically access the sensors. The ensuing reduction in cost will make calibration, regular performance monitoring, and re-calibration of the radon sensors feasible in large-scale, commercial applications, both from safety and financial considerations.

The development of a quality-assured sensor network, incorporating artificial intelligence and IoT, will revolutionise large building monitoring. This intelligent sensor network will not only measure indoor ^{222}Rn activity concentration but will also seamlessly integrate with other building sensor networks, optimising energy use, air quality management, and radiation protection in a unified and efficient manner. These outcomes will have significant implications for industrial stakeholders, building operators, and city planners, providing real-time data to enhance building safety, environmental sustainability, and occupant well-being.

Early uptake of the project's output can only be achieved by engaging stakeholders and end-users throughout the project. This requires incorporating the vision of the different actors involved from the outset, as well as establishing communication channels that allow for exchange throughout the lifetime of the project. These aspects have been considered in the project design through the following elements:

- The nature of the consortium, which brings together 7 leading NMIs/DIs and 8 external participants, including 4 universities, 1 national radiation protection authorities and 2 SMEs and 1 large company. The joint work among these different actors with different capacities and responsibilities in several countries allows for a wide-ranging approach to the problems associated with the implementation of EU Directive 2013/59/Euratom at European level.

- The Stakeholder Committee, which will be established at the beginning of the project, will clarify the needs of interested parties and feed them into the project to make sure that the project is aligned with end-users' needs.
- The training and knowledge transfer activities defined in WP5, which, beyond simply making the results of the research available, seek for a continuous interaction with the groups of interest that will benefit from the project outputs by means of workshops and training courses.

B3.b Projected outcomes for the metrological and scientific communities

As a part of the commitment to fostering the next generation of scientists and promoting the goals of Europe, this project holds great potential for a positive impact to both the metrological and the scientific communities. The consortium will actively promote young student formation and involvement in the project, aiming to cultivate a new generation of metrologists and researchers who are well-equipped and ready for the future of metrology. By providing opportunities for students to engage in cutting-edge research and gain hands-on experience, the project seeks to empower and inspire young minds, ensuring that Europe remains at the forefront of metrological advancements and scientific innovation.

The project will pioneer new measurement methods based on innovative materials, presenting high-risk/high-reward, challenging ideas that have the potential to revolutionise not only radon metrology but also other radioactive gas metrology as seen in the recent EIC Pathfinder SPARTE project (grant agreement N°899293) for pure beta emitter gases [8]. Embracing inorganic scintillators instead of the traditional organic ones offers significant advantages, reducing waste generation and environmental impact while advancing the understanding of the scintillation process. This paradigm shift in ionising radiation metrology brings forth new opportunities and a deeper exploration of physics, leading to innovative approaches in radiation detection and measurement.

The techniques developed in this project will have a direct impact on the fields of geophysics and space studies, e.g., solar system exploration. The advancements made in radon metrology will enable future studies of radon adsorption and emanation in low-concentration conditions. In the consortium, some of the work will find applications in lunar, Mars, and meteorite studies, contributing valuable data for space research initiatives such as the currently ongoing DORN project [17] studying radon emanation on the moon. By advancing radon detection methods now, the project will maximise the synergy between metrological advancements and space research, expanding the knowledge of celestial bodies and their radon behaviour for a very different domain than risk mitigation. The highly sensitive metrological devices developed within the framework of this project for radon measurement are already regarded as a potentially very sensitive system. This system is on the verge of enabling the non-destructive analysis of lunar samples to be brought back from the DORN mission in 2024. This achievement will mark the very first non-destructive analysis of lunar rock in Europe.

Ultimately, the project will contribute to the assessment of radiation hazards to the general public. In epidemiology, risk models are employed to gauge potential health risks. These models often require data on radon activity concentration levels that fall below the reliable measurement ranges of current non-research grade sensors. This limitation has posed a significant challenge in previous studies [11]. The dissemination and application of the research findings will substantially enhance the accuracy of these risk models, thereby contributing to a more comprehensive understanding of radiation hazards within the scientific and metrology communities.

In summary, the projected outcomes of this project extend beyond conventional measurement methods. Through student formation, use of innovative materials, and the exploration of inorganic scintillators, the project seeks to enrich the metrological and scientific communities with novel ideas, improved measurement techniques, and a deeper understanding of the scintillation process. The far-reaching impacts of the research hold promise for advancing metrology practices, promoting sustainability, and inspiring future generations of scientists and researchers, while also contributing directly to geophysics and space studies, enabling innovative explorations of the solar system.

The project participants will closely cooperate with the NMIs/DIs not participating in the project as collaborators. CIEMAT, STUK, FTMC and KRISS will provide the consortium with their expertise and/or facilities and, in return will be provided with the project results improving their metrological work.

B3.c Projected outcomes for relevant standards

The main aim of the project is to support the effective implementation of EU Directive 2013/59/EURATOM and better radon risk mitigation by improving the reliability, traceability, and calibration of radon sensors and sensor networks. These new developments in the measurement of radon in air with connected sensor networks will also ensure Europe's ability to stay competitive in this developing industrial field.

The consortium will promote the project developments within the standardisation community and contribute to the standardisation process. The most significant input to the standardisation work is expected to take place in the framework of the ISO and IEC standards in the field of radioactivity measurements in the environment. The standards relevant to the project that are in preparation/revision will be identified, and the work on these standards will be suggested to the appropriate working groups or committees.

The participants who are members of the corresponding technical committees will inform their committees on the results of this project and will ensure that these results are incorporated in relevant technical documents. The exchange will be done by the representatives on the corresponding committee or working group from the participants, who will jointly ask the chairperson to include a point in the agenda to briefly present the outputs of the project related to working group activities and ask for comments from the other committee/working group members. When appropriate, a written report will be submitted for consideration by the committee or working group.

Standards Committee / Technical Committee / Working Group	**Participants involved**	**Likely area of impact / activities undertaken by participants related to standard / committee**
IEC/TC45: Nuclear Instrumentation	**CEA,** PTB, NPL	IEC/TC45 meets every 2 years with the next meeting expected in 2025. CEA with support from PTB and NPL will present progress and disseminate the results of the project to IEC 60846 and IEC 61017, in particular the work related to new sensors (WP1) and calibration procedures (WP2) development and participate in the draft of any relevant documentary standard that the committee decides to revise or initiate. The participants involved will ask for feedback on the work and results presented.
ISO/TC146: Air quality	**PTB**, CEA, NPL	IEC TC146 meets every 2 years with the next meeting expected in 2025. PTB with support from NPL and CEA will present progress and disseminate the results of the project to ISO 19694 ‘Stationary source emissions’, in particular the work related to new sensors (WP1) and calibration procedures (WP2) development and participate in the draft of any relevant documentary standard that the committee decides to revise or initiate. The participants involved will ask for feedback on the work and results presented.
ISO/TC207: Environmental management	**PTB**, CEA, NPL	ISO/TC207 meets annually. PTB with support from NPL and CEA will present progress and disseminate the results of the project to ISO/CD 14065 ‘General principles and requirements for bodies validating and verifying environmental information’, in particular the work related to new sensors (WP1) and calibration procedures (WP2) development and participate in the draft of any relevant documentary standard that the committee decides to revise or initiate. The participants involved will ask for feedback on the work and results presented.
EURAMET TC-IR Technical Committee for Ionising Radiation	**CMI**, BFKH, CEA, IFIN-HH, NPL, PTB	CMI, BFKH, CEA, IFIN-HH, NPL and PTB will present progress within the project at the annual committee meetings held in 2025, 2026 and 2027. The committee members will be invited to share the project achievements in their respective countries and actively collect feedback from these open discussion groups.
EURAMET TC-IM Technical Committee for Interdisciplinary Metrology WG M4D Metrology for Digital Transformation	**PTB**	TC-IM meets annually. PTB will present progress and disseminate the results of the project to WG M4D in particular. The following areas where the working group on Metrology for Digital Transformation is pooling expertise will be relevant for this project: Sensor network metrology (TC-IM 1551) and Metrology for Internet of Things (IoT) and sensor networks. PTB will ask for feedback on the work and results presented.
ICRM Alpha-Particle Spectrometry WG	**PTB**, NPL	NPL and PTB will present progress within the project, in particular the work related to **alpha measurement of radon and its progenies** at the working group meetings to be held in 2025 and 2027. The committee members will be invited to share the project achievements in their respective countries and actively collect feedback from these open discussion groups.

ICRM Low-Level Measurement Techniques WG	**PTB**, NPL	PTB and NPL will present progress within the project, in particular the work related to low **radon activity concentration measurement** at the working group meetings to be held in 2025 and 2027. The committee members will be invited to share the project achievements in their respective countries and actively collect feedback from these open discussion groups.
ICRM Liquid Scintillation Counting WG	**CEA**	CEA will present progress within the project, in particular the work related to scintillation material and associated measurement techniques and methods at the working group meetings to be held in 2025 and 2027. The committee members will be invited to share the project achievements in their respective countries and actively collect feedback from these open discussion groups.
BIPM CCRI (II) Measurement of radionuclides	**CMI**, NPL, PTB	CMI, NPL and PTB will present progress within the project at the annual committee meetings held in 2025, 2026 and 2027. The committee members will be invited to share the project achievements in their respective countries and actively collect feedback from these open discussion groups.

B3.d Projected wider impact of the project

Social Impact: The significance of this project extends to a large number of people, as radon represents a widespread concern in Europe. With approximately 447 million people residing in the European Union alone, the potential impact of improved radon metrology is immense, affecting the health and well-being of citizens across the continent. By providing accurate and accessible radon sensor networks for large buildings and future cities, the project outcomes have the potential to safeguard millions of individuals from radon-related health risks, fostering a safer living environment for European communities. According to a new WHO survey, more countries than ever before are protecting their population from radon exposure, but many still need to take action to mitigate the impacts of this carcinogenic radioactive gas. So far, a total of 56 countries - over a quarter of all WHO member states - have responded to the WHO radon survey [18]. The vast majority has set national reference levels for homes and workplaces, 44 % have developed national radon action plans, and 39 % have included radon mitigation in codes for new buildings. Globally, residential radon exposure alone was estimated to have caused 84,000 deaths by lung cancer annually; in some countries, it is among the leading causes of lung cancer. This project will help the countries to improve their national radon action plans and codes for new buildings.

Economic Impact: As this project seeks to develop cutting-edge radon metrology technologies, it presents a unique opportunity for Europe to establish itself as a global leader in this field. By promoting the adoption and implementation of advanced sensor networks and intelligent devices, Europe can bolster its competitiveness in the rapidly evolving market of connected technologies. The economic impact may extend beyond European borders, as the advancements made in radon detection and intelligent monitoring have the potential for worldwide adoption, contributing to the growth of the global smart technology industry. According to an analysis by The Economist Intelligence Unit [19], lung cancer treatment costs eclipse the costs of other major cancers. In Europe, researchers estimate the costs associated with the care of lung cancer patients at more than 3 billion Euros per year. Putting project results in practice will significantly reduce treatment costs for diseases caused by indoor radon exposure.

Environmental Impact: The adoption of inorganic scintillators over organic ones reduces waste generation, promoting environmental sustainability in radon detection methods. By minimising waste production, the project aligns with environmentally conscious practices, reducing the ecological footprint of metrological processes.

Beyond the radon metrology - space studies: The techniques developed in the project for radon adsorption and emanation studies hold relevance for space exploration. The data and insights gained may contribute to the understanding of radon behaviour on celestial bodies like the Moon, Mars, and meteorites. Such information is valuable for ongoing space research initiatives, such as the DORN project.

Beyond the radon metrology - other gas metrology: The novel measurement methods and innovative materials pioneered in the project may have applications beyond radon metrology. They hold the potential to advance other areas of radioactive gas metrology, allowing for broader applications and potential collaborations with industries and research fields concerned with other radioactive gases.

Overall, the impacts of this project can extend to social, economic, and environmental spheres, while also transcending its immediate scope to contribute to space studies and other gas metrology. The project outcomes are poised to create positive changes in public health, industry practices, and scientific knowledge, leaving a lasting legacy in the fields of metrology and beyond.

B3.e Summary of the project's impact pathway

SPECIFIC NEEDS	EXPECTED RESULTS	DCE MEASURES
What are the specific needs that triggered this project? Compliance with the European directive: the Directive 2013/59/Euratom, mandates a maximum indoor radon level of 300 Bq m^{-3}. Enhanced sensitivity: Current radon detection technologies often lack the sensitivity required for early and accurate measurements. There is a specific need for sensor technologies that can detect lower concentrations of radon, allowing for timely interventions and mitigation strategies. Real-time monitoring: Traditional radon sensors may provide delayed results, hindering the ability to respond promptly to fluctuations in radon levels. Developing real-time monitoring systems, integrated with 'smart' sensor technology, is crucial to enable swift reactions and proactive measures in the event of elevated radon concentrations. Calibration procedures: Establishing standardised and rigorous calibration procedures for radon sensors is essential. The lack of consistent calibration methods can lead to inaccurate measurements, hindering the reliability of collected data. Addressing this specific need involves defining and implementing calibration protocols that ensure the precision and accuracy of radon monitoring devices. Alternative scintillator materials: Given the restrictions on toxic organic compounds imposed by European Directive 2003/53/EC, there is a specific need to invest in research and development of alternative scintillator materials. Identifying and utilising eco-friendly compounds without compromising detection efficiency is crucial for aligning radon detection methods with regulatory standards. Innovative ventilation strategies: The specific need in this context is the development and implementation of innovative ventilation strategies that can effectively mitigate radon exposure without contradicting the energy efficiency goals outlined in initiatives such as the European Green Deal. This may involve exploring advanced ventilation systems, air purification technologies, or other creative solutions that maintain a balance between energy conservation and radon reduction. Integrated building design: There is a need for integrated building design approaches that consider both energy efficiency and radon mitigation from the outset. Collaboration between architects, engineers, and health experts is essential to create buildings that seamlessly blend sustainability with health-conscious design, minimising the need for retroactive interventions.	*What results do you expect to generate by the end of the project?* Development of cost-effective and sensitive radon sensors New scintillator for radionuclide metrology without organic compounds New procedure for the calibration of radon sensors with linearity, time response and low activity concentration; 50 Bq m^{-3} New on-site traceable calibration procedures Intelligent sensor network, ensuring accurate and real-time radon measurements for enhanced safety AI / ML technique to improve time response and background correction and radon sensors Active radon mitigation with connected radon device to large building ventilation Cost-effective mitigation with IoT connection of radon sensors to standard house sensor and active devices (ventilation, heating system) Testbed facility with radiation sensors included for future development of efficient mitigation techniques	*What dissemination, communication and exploitation measures will you apply to the results?* Stakeholders committee with online meeting organised by work package leader SharePoint with vote function for stakeholders and sharing documents Project webpage with public access to disseminate information and advertise for meetings 12 conferences with either poster of oral presentation 10 papers to peer-reviewed scientific journals with more than 60 % from a collaborative work 2 articles in popular journals Project flyer and poster for general dissemination 3 good practice guides Dissemination of the results to at least 9 standardisation bodies Social media: LinkedIn, ResearchGate, X

TARGET GROUPS	OUTCOMES	IMPACTS
Who will use or further up-take the results of the project? Who will benefit from the results of the project? Metrology research laboratories that do not possess radon calibration such as CIEMAT, NIST, NPL, KRISS Regulation authorities such as ASN, UK Sigma network, STUK, PHE Large companies developing solutions for connected houses such as Legrand NETATMO, Velux, Somfy, Wellcome Trust, Cancer Research, UCL CAVE SMEs developing or selling radon measurement sensors such as LivAir, Radonova, Algade, Pe@rl or larger companies - Mirion, Bertin Technology, NUVIA Defense networks such as the UK SIGMA homeland security network run by AWE / UK Gov Home Office or the Finnish fixed gamma dose network for environmental monitoring and security	*What change do you expect to see after successful dissemination and exploitation of project results to the target group(s)?* Advancements in radon metrology methods, technologies, and data analysis, resulting in reliable indoor air quality monitoring and better-informed decision-making for radon remediation. Available intelligent radon monitoring solutions and metrology procedures for the companies developing large buildings and the cities of future and for the radon mitigation industry. Extend beyond radon metrology, benefiting other areas of radioactive gas metrology with broader applications and implications. Greater protection enhanced by better monitoring leading to increased safety and a reduction in radon related cancers.	*What are the expected wider scientific, economic and societal effects of the project contributing to the expected impacts outlined in the work programme and call scope?* *Economic:* Cost-effective sensor networks with improved energy efficiency Market opportunities for sensor manufacturers New device and testbed to test new concepts of radon mitigation and develop the mitigation industry in Europe *Scientific:* Advancements in radon metrology, collaboration and knowledge exchange for other radioactive gas metrology Validation of emerging technologies, new on-site techniques for the validation of connected device, calibration and network standardisation Student formation and knowledge transfer, for new young people in the field of metrology Improved standardisation of radon metrology, guidelines for radon mitigation strategies *Societal:* Enhanced safety and health measures, public health benefits, reduction of lung cancer and health costs Improved indoor air quality, energy conservation, market growth and job creation, empowering the workforce

B4 The quality and efficiency of the implementation

B4.a <u>Overview of the consortium</u>

The consortium brings together 15 institutes from eleven European countries: 7 leading NMIs/ DIs, 4 university laboratories, 1 national radiation protection authority, 2 SMEs and 1 larger company. This combination of different actors with different demands and capacities will enable to address the issues connected to the implementation of Council Directive 2013/59/EURATOM to propose solutions for a radon mitigation network for large building that fit the needs of a broad spectrum of stakeholders.

- **CEA** is the French DI for ionising radiation. It brings a solid experience in radioactive gas metrology, especially in the development of primary standard for both radon isotopes and associated calibration method. CEA is one of the leading public institutes in Europe in terms of technology transfer and has participated in, and coordinated, many European projects (including EMRP project IND57 MetroNORM and EMPIR project 16ENV10 MetroRADON). CEA is a work package leader in the H2020 FET-Open SPARTE, developing new metrology methods for pure beta emitter noble gases based on porous scintillators. CEA will coordinate this project, lead WP1 and support work in all other WPs.

- **BFKH**, the Hungarian NMI, carries out a broad scale of activities on governmental legal administration. The Metrological and Technical Supervisory Department performs metrological tasks, maintains the National Standards, and undertakes international comparisons and assures the national dissemination with calibrating the measuring instruments. It provides the type-examination and authentication of those measurement instruments, which need to be authenticated, and issues the EU compliance certification. BFKH will take part in WP2.

- **CMI**, the Czech NMI, has expertise in the measurement of radioactivity, the identification of radionuclides by spectrometric methods using semiconductors, and related Monte Carlo calculations. CMI is also experienced in the development of applied technical solutions for the measurement of radioactivity and ionising radiation under real environmental and complex technical conditions and works closely with private enterprises specialising in those fields. CMI has coordinated and/or participated in several EMRP, EMPIR and EPM projects (e.g. EMRP project IND57 MetroNORM, EMPIR project 16ENV10 MetroRadon, EMPIR project 19ENV01 traceRadon) dealing with ionising radiation measurement. CMI will lead the Impact WP and contribute to work in all other WPs.
- **PTB,** the German NMI, has a long-term experience in the provision of activity standards, the measurement of airborne radioactivity concentrations, the investigation and calibration of various detector systems from environmental radiation to commercial standards as well as in the operation of related calibration facilities traceable to primary standards. This also includes ^{222}Rn gas standards and primary, active ^{222}Rn emanation standards. PTB has organised several intercomparison exercises and coordinated several EMRP and EMPIR projects, e.g. EMPIR project 19ENV01 traceRadon. PTB will lead WP2 and contribute to work in all other WPs.
- **SMU**, the Slovak NMI, maintains the national standard of radon in Slovakia, and provides metrological services such as verification, calibration, and testing to national stakeholders. In 2016, SMU received funding for the realisation of a radon chamber with AlphaGUARD as a secondary standard. SMU works in close collaboration with local metrology or academic institutes in field of ^{222}Rn and participated in many projects (e.g., EMRP projects IND04 MetroMetal and ENV54 MetroDecom, and Partnership project 21GRD08 SoMMet). SMU will contribute to work in WP2, WP3 and WP4 with its own equipment for radon measurements.
- **CLOR** is a Polish research institute tasked with functions concerning the protection of the state from radiation hazards. CLOR fulfils this task by routine practical activities, preventive and operational tasks, scientific studies, and by advising private and governmental organisations. CLOR’s duties include monitoring of radioactive contamination in foodstuffs and environmental components, monitoring of personal radiation doses, calibration and attestation of radiation measurement instruments, radiation protection and professional training in radiation protection. CLOR will lead the WP4 and contribute to work in WP2.
- **IFIN-HH** is a leading physics research institute of Romania, involved in a wide range of fields of physics. It has a long experience in primary and secondary methods of activity standardisation including ^{222}Rn and in providing calibration services to national stakeholders. IFIN-HH has participated and/or participates in EMRP, EMPIR, and EPM projects dealing with the metrology of ionising radiation (e.g. EMPIR projects 16ENV10 MetroRadon and 19ENV01 traceRadon) and in many national R&D projects related to ^{222}Rn metrology. IFIN-HH will participate in WP2, WP3 and WP4.
- **LivAir,** is an innovative company that provides unique services and solutions concerning air measurement with special focus on radon. In addition to the innovative and patented real-time radon sensor, LivAir develops and manufactures most of the hardware in-house. The complete data transmission and the cloud database are also developed in-house. In 2013, the founders of LivAir were among the first radon professionals in Germany approved by state offices for environment on the new 2013/59/EURATOM directive for radon protection. LivAir will participate in all WPs.
- **NUVIA** is a Czech company with more than twenty years of experience in the development, production, and sale of ionising radiation instrumentation. NUVIA specialises in manufacturing, industrial automation, mechanical construction, software development, and implementation of such systems. NUVIA has a broad experience in the realisation of complex customised solutions and will participate in WP1, WP2 and WP3.
- **Radonova** is a Swedish company. Its core business is radon and caesium measurement. With their laboratory in Uppsala, Sweden, and customers in more than 85 countries, they are a leader in radon measurement. Radonova provides radon measurement services with passive sensors accredited ISO 17025 and develops and designs radon measuring instruments such as ARMON, ATMOS, MARKUS, SPIRIT and ROBIN. Radonova will participate in all WPs.
- **SUBG**, Sofia University, has long-term experience in radon and thoron research and measurement. SUBG participated in the EMPIR project 16ENV10 MetroRadon. SUBG has a pioneering role in the creation of radon sensor networks for evaluation of radon dynamics in dwellings and workplaces in Bulgaria. SUBG also has expertise in prospective and retrospective radon and thoron measurements as well as other radioactivity measurement techniques. Within the EURATOM low-doses research project DOREMI, SUBG has developed a laboratory facility to create reference radon and thoron concentrations under static and dynamic conditions. SUBG will contribute to work in WP1, WP2 and WP3.

- **UCBL** (Université Claude Bernard Lyon 1) laboratories ILM and LC-ENS have a long-term experience in the characterisation and synthesis of scintillating materials, in particular transparent aerogel prepared with inorganic scintillators. This participant has facilities required for the formation of scintillating aerogels. UCBL coordinated the H2020 FET-Open project SPARTE and provided all structural and chemical characterisation needed for the development of novel materials in this project. UCBL will participate mainly in WP1 and will also contribute to work in WP2 and WP3.
- **UH** (University of Helsinki) has extensively studied and developed distributed sensor networks for air quality measurements. This project will use their expertise in machine learning methods, remote calibrations and quality control, detector development, and data analysis methods for distributed systems. UH has a research cooperation agreement with Finnish Radiation and Nuclear Safety Authority (STUK), the national expert in radon measurements and dosimetry. UH will contribute to WP2, WP3 and WP4.
- **USIEG** (University of Siegen) has worked on modelling, simulation, and experimental determination of optimal topology, intersection of multiple fields and the dynamic fracture behaviour of solid-state bodies since 2008. Its expertise has led to multiple collaborations with regional enterprises including BSW, Mubea, and IGI and international players including the California Institute of Technology or the technical University of Brünn. USIEG will bring strong expertise for the development and calibration of a pulse ion chamber in WP1 and WP2, and will also contribute to work in WP3.
- **NPL**, the UK NMI, has extensive experience in radioactive gas metrology, air quality measurements, monitoring of outdoor radon and data science. This experience covers development of new sensors, calibration of instruments, establishing and maintaining sensor networks and developing machine learning techniques to analyse network data. NPL has taken part in a number of nuclear metrology and air quality EMPIR projects. NPL will lead WP3 and will contribute to work in WP2 and WP4. NPL is associated to all internal beneficiaries.

Section C: Detailed project plans by work package

C1 WP1: New concepts and methods for radon concentration measurements

The aim of this work package is to devise novel concepts and methodologies for sensors that will detect and measure radon activity concentration in indoor air with improved response time, heightened sensitivity, and decreased measurement uncertainty. The new high-precision measurement sensors will be calibrated and tested for linearity and time response in WP2, used in sensor networks developed in WP3, and offered to SMEs as cost-effective and material-conserving option, facilitating industrial-scale production.

Three detection concepts will be studied in this work package. Each of these concepts has its own advantages and drawbacks, requiring in-depth optimisation, and a combination of these technologies is assumed to be optimal.

Task 1.1 will study the first approach that uses semiconductors for detection of radon and its progeny. Silicon-type diodes offer high-quality alpha spectrometry with simple acquisition electronics. Their excellent energy resolution (down to 10 keV full-width half maximum (FWHM)) allows to identify and distinguish radon isotopes, their decay products, and other alpha-emitting radionuclides in air in case of radiological incidents. This makes it also a highly promising tool for time response measurement instruments developed in WP2. Although cost-effective diodes suitable for radon detection already exist, their parameters must be optimised, electronics miniaturised, and software improved for inclusion into a radon sensor network. Their low power consumption and operating voltage are beneficial for cost-effective miniaturisation.

The second approach, involving ionisation chambers, will be studied in Task 1.2. This solution can be scaled up to larger volumes (up to several litres), allowing decreased detection limits necessary for high-precision measurements at very low activity levels. However, their spectral resolution for alpha particles is much lower than that of silicon sensors, around 250 keV FHWM. They have several drawbacks, including sensitivity to microphonics due to mechanical vibrations of the wires due to ambient sounds. Other challenges for use in-situ would be the potential dependency on environment variables such as pressure, humidity, CO_2 content - all of which can affect ionisation yields and ion drift in the chamber. Developing solutions to correct these effects will contribute to advancing this technology for low-level radon concentration measurement and therefore usage for metrological traceability in WP2.

Task 1.3 aims at investigating the third concept that is based on scintillators. This project intends to explore a recent innovation for pure beta-emitting gases, utilising porous inorganic scintillators. The feasibility of using this technology for the detection of alpha radiation from radon and its progeny as well as its suitability for inclusion into a radon sensor network will be investigated. Porous inorganic scintillators combine excellent sensitivity, offering a significant surface-to-volume ratio with a detection efficiency close to unity, and the potential to discriminate between various beta and alpha emitters. With the ability to detect radon and all its descendants, they can achieve even greater sensitivity than ionisation chambers, which are limited to alpha emitters.

Task 1.4 aims at transferring the new technological developments for radon concentration measurements to industrial partners. Whereas in the case of semiconductor and ionisation chamber, it involves assembling materials and sensors, (i.e., mostly mechanics and electronics), the scintillator process is twofold: (1) the production of scintillation material by a chemistry lab on a large scale, and (2) the packaging of the scintillator and its associated electronics to construct the sensor. These two competences are distinctly different and, therefore, are kept separate as a first approach of commercial product.

C1.a <u>Task 1.1: Development of measuring devices based on semiconductor sensors</u>

The aim of this task is to design semiconductor-based detection systems. These sensors offer the best energy resolution, thus providing the best ability to distinguish the various isotopes in the radon decay chain. The optimisation of these sensors will improve the instruments' response time for radon measurement or enhance their efficiency and sensitivity to radon progenies (based on previous research, not both, response time and sensitivity, are expected to be improved at the same time). The task will develop instrumentation based on semiconductors transferred to SMEs and used in WP3 for sensor network. An instrument that is focused on a fast time response without cost-effectiveness limitations for WP2 will also be created.

Activity number	Activity description	Participants (Lead in bold)
A1.1.1 M06	CMI, CEA, SUBG and NUVIA will conduct a review of published studies on semiconductor sensors used for alpha-particle detection with emphasis on alpha-emitting radon progenies. This will include single and pixelated sensors. The results of this survey will be evaluated by CMI, CEA, SUBG and NUVIA.	**CMI**, NUVIA, CEA, SUBG
A1.1.2 M12	Based on A1.1.1, CMI and NUVIA will jointly develop at least 1 CMI detection system with monolithic and pixelated Si sensors and optimise its parameters for high detection efficiency of alpha-particles emitted by radon progenies. CEA will arrange their portable, silicon-based sensor focused on a very fast time response. SUBG will test and use the CEA system while developing the time response measurement method in A2.3.2.	**CMI**, NUVIA, CEA, SUBG
A1.1.3 M20	Using experimentally validated (Monte Carlo) simulation tools, CMI and CEA will calculate detection efficiencies for radon concentration in air and estimate minimum detection concentrations for the systems developed in A1.1.2 and will create Monte Carlo N-Particle Transport (MCNP) model. The target will be below 100 Bq m^{-3}.	**CMI,** CEA
A1.1.4 M24	Using input from the Stakeholder Committee (A5.1.1), CMI, CEA and SUBG will test the systems from A1.1.2 for the response stability, response time, energy resolution and sensitivity (detection efficiency), using radionuclide standard sources and radon emanators with ^{226}Ra. CMI, CEA and SUBG will compare the experimental results with those calculated in A1.1.3. Differences between measured and calculated values for detection efficiency up to 5 % would confirm the correctness of the MCNP model created in A1.1.3. However, if differences are higher than 5 %, a reason will be investigated and clarified by CMI, CEA and SUBG.	**CMI**, SUBG, CEA
A1.1.5 M20	CMI, SUBG and CEA will calculate relative combined standard uncertainty for radon concentration measurement in air for the systems developed in A1.1.2 and compare it with the conclusions from A1.1.1. The target relative standard uncertainty will be below 20 %.	**CMI**, SUBG, CEA
A1.1.6 M34	CMI, with support from NUVIA, CEA and SUBG, will review the results from A1.1.1-A1.1.5. This review will provide an input into the good practice guide on new methods and sensors developed for radon concentration monitoring in sensor network produced in A1.3.6.	**CMI**, NUVIA, CEA, SUBG

C1.b Task 1.2: Development of a measuring device based on ionisation chamber

The aim of this task is to address issues for the pulsed ionisation chamber including complexity, high cost, and susceptibility to environmental factors that can affect its performance, making the device more accessible and affordable for users, and enhancing its performance. The pulsed ionisation chamber's design will be optimised to ensure long-term stability, widen its dynamic range, and create a reliable and cost-effective solution for radon detection and metrology at low volume activity.

Activity number	Activity description	Participants (Lead in bold)
A1.2.1 M06	PTB, USIEG, CEA and SUBG will conduct a review of published studies on ionisation chamber sensors used for alpha-particle detection. The results of this survey will be evaluated by PTB, USIEG, CEA and SUBG.	**PTB**, USIEG, CEA, SUBG
A1.2.2 M10	Using input from A1.2.1 and preliminary results from A3.1.1, PTB and USIEG will conduct simulations of the detection efficiency of ionisation chambers based on their characteristic size. Based on these simulations, PTB and USIEG will calculate the detection limit depending on the chamber's dimensions.	**USIEG**, PTB
A1.2.3 M12	Based on preliminary results from A2.2.2-A2.2.4, USIEG and PTB will conduct a joint study on the influence of environmental parameters such as temperature, humidity and pressure on the measurement principle, using at least 2 of their ionisation chambers. This will include optimisation of the pulsed ionisation chambers' design to ensure long-term stability, widen its dynamic range, and create a reliable and cost-effective solution for radon detection and metrology at low volume activity. The outcome will be a new "universal data set" for optimising the chamber's dimensions based on the environmental variables, which will be coupled with the results from A1.2.2.	**USIEG**, PTB

A1.2.4 M18	Using input from A1.2.1-A1.2.3, USIEG will investigate and implement techniques to compensate noise in their ionisation chamber related to mechanical perturbations (microphonics), including mechanical springs, coaxial construction of the detector, and active electronic filters. PTB will test the noise changes using their facilities to assess the improvement.	**PTB,** USIEG
A1.2.5 M24	Based on input from A1.2.1-A1.2.4, A3.1.1 and A5.1.1, PTB and USIEG will develop 2 sensors based on the principle of ionisation chambers. One sensor will involve low-cost technology and will represent a compact, cheap solution suitable for commercialisation. The other sensor will be dedicated to radon metrology and will be used as a highly-sensitive calibration device for on-site calibration in A2.3.5.	**PTB**, USIEG
A1.2.6 M34	USIEG with support from PTB, CEA and SUBG will review the results from A1.2.1-A1.2.5. This review will provide an input into the good practice guide on new methods and sensors developed for radon concentration monitoring in sensor network produced in A1.3.6.	**USIEG**, PTB, CEA, SUBG

C1.c Task 1.3: Development of measuring devices based on scintillators

Scintillators offer a very high efficiency, close to unity, for detecting alpha and beta particles, making them an excellent choice of detector due to their lower sensitivity to external radiation. They can be categorised into different types, each with its own advantages and disadvantages, including organic scintillators, inorganic scintillators, and gases. The aim of this task is to explore the diverse possibilities for designing sensitive instrumentation, which involves exploring innovative materials based on the principle of scintillation, particularly utilising porous materials with a completely new shaping approach. These inorganic scintillation materials with high efficiency have the potential to offer excellent spectral resolution and high sensitivity of detection, independent of environmental conditions.

Activity number	Activity description	Participants (Lead in bold)
A1.3.1 M06	UCBL with support from CEA and SUBG will conduct a literature review on the various performance aspects of scintillator-based sensors for radon concentration measurement. The analysis will focus on their photophysical properties, their capabilities to detect alpha and beta rays, as well as their specific characteristics in relation to radon concentration measurement, such as solubility, adsorption, or absorption and shaping.	**UCBL**, CEA, SUBG
A1.3.2 M12	Using input from A1.3.1 and A3.1.1, UCBL will manufacture a first prototype of a monolithic porous inorganic scintillator, e.g., YAG:Ce. Based on this first sample, CEA with support from UCBL will assemble the scintillator, prepare it for use, and create a sensor prototype. This sensor will be a compact device with simple detection processing for monitoring indoor radon concentration. The performances of the scintillators will be tested in A1.3.3 and A2.1.3 and optimisation will be applied according to these results.	**CEA**, UCBL
A1.3.3 M18	Using input from A1.3.1, UCBL will develop at least 3 types of porous inorganic scintillators based on CeF_3, or SiO_2-YAG:Ce (i.e., other than the type in A1.3.2), using alternative formulations (e.g., garnet) to enhance performances, solidity, functionality and production feasibility. UCBL will assess the scintillator's photophysical performance (including the one from A1.3.2) by conducting optical and scintillation property characterisations in their laboratory. This characterisation process will include measurements of emission (Time resolved Radio-Luminescence), absorption, and time response. Once this characterisation is done, UCBL will ship these scintillators to CEA who will then test the samples with radioactive gas with quick benchmark with radon, and then carry out a performance assessment including aspects related to ease of production and integration. CEA and UCBL will identify the potential applications of these scintillators for ionising radiation metrology (A1.3.4 and A1.3.5). Subsequently, the measurement properties will be extended to other gas, taking into account the scintillator properties as well as their reusability and mechanical robustness.	**UCBL**, CEA
A1.3.4 M18	Using input from A3.1.1 and A5.1.1, CEA will develop a portable circulating Triple to Double Coincidence Ratio (TDCR) counting unit utilising the scintillator identified as having the best performances in A1.3.3 for metrological purposes and continuous traceability of radon in low activity concentrations within the atmosphere. This design will be entirely manufactured at CEA, allowing complete modularity, including the use of other scintillators such as those developed in A1.3.3 with different properties. SUBG with support from CEA will develop a TDCR code for detection efficiency calculations, then run simulations of electron interactions within the scintillator and incorporate them into the code. The code will take the scintillator properties as input data, making it easily	**CEA**, SUBG

	adaptable for new compounds. This detection system will serve as a new very compact direct primary method for in-situ calibration.	
A1.3.5 M26	CEA, UCBL and SUBG will prepare a specifications document for the development of the tools to collect data from the two types of sensors developed in A1.3.2 and A1.3.4. The aim of the specification document is to present a solution to enable the communication between a reference device, such as the TDCR unit developed in A1.3.4, and at least 1 device such as the prototype developed in A1.3.2, to facilitate the future application of on-site calibration methodologies. Based on the specification document, LivAir with support from CEA, UCBL and SUBG will develop these tools.	**CEA**, LivAir, UCBL, SUBG
A1.3.6 M36	CMI and CEA with support from SUBG, UCBL, PTB, USIEG and NUVIA will review the results from A1.3.1-A1.3.5 and collate it with the input from A1.1.6, A1.2.6 and A5.1.1 into a good practice guide on new methods and sensors developed for radon concentration monitoring in sensor network with lowered response time, increased sensitivity and reduced uncertainty. The guide will also include three detection concepts based on the use of i) semiconductors, ii) ionisation chambers and iii) scintillators. Once agreed by the consortium, the coordinator on behalf of CMI, CEA, SUBG, UCBL, PTB, USIEG and NUVIA will submit the good practice guide to EURAMET as D1: '*Good practice guide on new methods and sensors developed for radon concentration monitoring in sensor network with lowered response time, increased sensitivity and reduced uncertainty. This will include at least three detection concepts based on the use of i) semiconductors, ii) ionisation chambers and iii) scintillators*'.	**CMI**, CEA, SUBG, UCBL, PTB, USIEG, NUVIA

C1.d Task 1.4: Preparation of the transfer to industry

The aim of this task is to prepare the technological transfer of developed measuring devices to industrial partners (e.g., radon sensor producers). It can be divided into two categories: low-cost connected sensors for radon concentration measurement in buildings and sensors for metrology and on-site operando calibration. The proposed approach allows for both, an interconnected network of radon concentration measurement devices and the necessary instruments for in-situ calibration.

Activity number	Activity description	Participants (Lead in bold)
A1.4.1 M28	CEA with support from NUVIA, SUBG, PTB, USIEG and UCBL will investigate the technical aspects of the current radon sensors available for commercial purposes including those developed in the framework of previous European projects (e.g., EMRP JRP IND57 MetroNORM and EMPIR JRP 16ENV10 MetroRADON). This study will outline the different technologies used in the development of measuring devices based on semiconductor sensors (Task 1.1), ionisation chamber (Task 1.2) and scintillators (Task 1.3).	**CEA**, NUVIA, SUBG, PTB, USIEG, UCBL
A1.4.2 M32	Using input from A5.1.1, CMI, NUVIA, CEA and SUBG will select the most appropriate system for radon concentration measurement based on semiconductor sensors based on the results of A1.1.2-A1.1.5 and with respect to cost effective and material saving criteria. NUVIA will produce a prototype of the selected system that can be widely deployed. CMI, NUVIA, CEA and SUBG will study the potential technological transfer of the system based on semiconductor sensors to industrial organisations.	**CMI**, NUVIA, CEA, SUBG
A1.4.3 M32	Using results of the development of measuring devices based on ionisation chamber from A1.2.1-A1.2.5, PTB, USIEG and SUBG will study the potential industrial transfer of the two developments: i) a compact, low-cost technology device using ionisation chamber measurements, ii) a highly sensitive device necessary for on-site calibration of measuring instruments.	**PTB**, USIEG, SUBG
A1.4.4 M32	Using results of the development of measuring devices based on scintillators in A1.3.1-A1.3.5, and early results from A1.3.6, CEA, UCBL and SUBG will consider several approaches. UCBL and CEA will investigate routes to bring the scintillator technology to market, and will contact an industrial organisation specialised in material production for large-scale manufacturing of the scintillator material (e.g. a chemical company such as NUVIA) to provide their assistance with the technological transfer to a large company. CEA, UCBL and SUBG will collaborate with LivAir on choosing the most suitable scintillator out of the scintillators from A1.3.3 and packaging it along with its associated electronics and sensors to develop an affordable, connected radon measurement	**CEA**, UCBL, SUBG, LivAir, Radonova, NUVIA

	device. This device can be either manufactured by SMEs in the consortium such as Radonova or LivAir or prepared for transfer to a larger-scale company such as NUVIA or stakeholders (such as Mirion Technologies, Bertin Technologies, SDEC, KEP-Technology).	
A1.4.5 M36	CEA with support from CMI, SUBG, UCBL, PTB, USIEG and NUVIA will draft a report on the different possibilities for technology transferred to SMEs. Once agreed by the consortium, the coordinator on behalf of CEA, CMI, SUBG, UCBL, PTB, USIEG and NUVIA will submit the report to EURAMET as **D2:** '*Report on solutions of newly developed radon concentration measurement instruments that can be transferred to industry for SMEs through advanced manufacturing including i) low-cost and material-saving technology and ii) highly sensitive system for on-site calibration'.*	**CEA**, CMI, SUBG, UCBL, PTB, USIEG, NUVIA

C2 WP2: Traceable, in situ operando calibration procedures

This work package aims to develop traceable, *in-situ* operando calibration procedures for ^{222}Rn activity concentration sensors, achieving less than 10 % calibration relative standard uncertainty at an activity concentration level down to 50 Bq m^{-3} while considering response time, linearity and dynamic range testing. The methods developed in this task will be significantly improved by the technology obtained from WP1 such as time response measurement from A1.1.2 and radon measurement obtained with ionisation chamber from A1.2.5. To avoid delays in establishing the new methods due to the development time within WP1, a comprehensive literature review will be conducted to select representative commercial devices and the method will be established based on the various findings and development paths established in WP1. This progress in the work on existing instruments will allow to quickly apply techniques with the new developments from WP1 and limit the risks that could arise in the development of new sensors within the project.

While the development of in-situ calibration techniques in radon metrology is a major challenge, the knowledge gained, and the techniques developed will address other critical metrological questions. Recent studies have highlighted the importance of time response and linearity for radon sensors, and therefore, this work package will not only enhance radon metrology in general (uncertainty and activity concentration limits) but also extend the impact beyond the project's primary goal of building a radon activity concentration detector network.

Task 2.1 will develop traceable laboratory calibration procedures for the existing commercially available and newly developed sensors from WP1. This task will have the dual purpose of selecting commercial instruments as test models and, more importantly, ensuring good calibration practices for various measurement technologies for the production of the good practice guide for traceable laboratory calibration procedures.

Task 2.2 will investigate the influence of environmental parameters on the calibration of existing commercially available and the new sensors from WP1. Evaluating these parameters on typical instruments will allow to properly identify the necessary parameters in radon sensor networks. This identification will lead to the development of real-time correction techniques, particularly for WP3 and WP4

Task 2.3 aims to determine the response characteristics of radon sensors that are already available and then on the sensors developed in WP1. This task addresses critical points characterising radon instruments, which are absent in current calibration procedures. It will enable the proposal of methodologies suitable for the proper comprehensive calibration of radon measurement instruments. Additionally, it will provide essential parameters for on-site calibration.

Task 2.4 will develop a method for traceable, in-situ operando calibration of ^{222}Rn activity concentration detector networks.

C2.a <u>Task 2.1: Development of calibration procedures for the radon sensors</u>

The aim of this task is to develop laboratory calibration methods for the commercially available radon sensors and the radon sensors developed in WP1. They will be designed as cost-effective and in-situ operando methods. Special attention will be given to the specific needs of the sensors. This will result in a good practice guide for calibration under laboratory conditions.

Activity number	Activity description	Participants (Lead in bold)
A2.1.1 M06	CLOR will perform a literature review on existing calibration methods for radon activity concentration sensors and measurement uncertainties. This will include an internal survey among CEA, PTB, SMU, SUBG, BFKH, IFIN-HH and USIEG, conducted by CLOR. Based on the results of the survey, CLOR with support from CEA, PTB, SMU, SUBG, BFKH, IFIN-HH and USIEG, conducted by CLOR will identify the currently most widely adapted device to perform calibration and also select at least one already existing, commercially available, device based on the three technologies (i.e. semi-conductor, ionisation chamber and scintillation,) identified in A1.1.1, A1.2.1 and A1.3.1.	**CLOR**, CEA, PTB, SMU, SUBG, BFKH, IFIN-HH, USIEG
A2.1.2 M15	Based on input from A2.1.1, CEA and CMI with support from PTB, SMU, BFKH, IFIN-HH and SUBG will develop a new traceable laboratory calibration procedure for the commercially available and the newly developed **semiconductor** sensors from A1.1.2.	**CEA**, CMI, PTB, SMU, SUBG, BFKH, IFIN-HH
A2.1.3 M16	Based on input from A2.1.1, CEA with support from PTB, SMU, BFKH, IFIN-HH and SUBG will develop a new traceable laboratory calibration procedure for the commercially available **scintillation** detector(s) and also those being developed in A1.3.2 and A1.3.3.	**CEA**, PTB, SMU, SUBG, BFKH, IFIN-HH
A2.1.4 M18	Based on input from A2.1.1, PTB and USIEG with support from CLOR, SMU, BFKH, SUBG and IFIN-HH will develop a new traceable laboratory calibration procedure for the commercially available **ionisation chamber** detector(s) and also those being developed in A1.2.5.	**PTB**, CLOR, SMU, USIEG, BFKH, IFIN-HH, SUBG

C2.b Task 2.2: Influence of environmental parameters on the calibration of the radon sensors

The aim of this task is to determine the quantitative influence of environmental parameters (temperature, pressure, humidity, and the CO_2-concentration) on the performance of the sensors from WP1. Additionally, their combined effects will be investigated by using the Design of Experiments (DOE) method. This will be crucial to determine if the sensors are suitable for implementation on–site in future connected buildings.

Activity number	Activity description	Participants (Lead in bold)
A2.2.1 M08	CEA and SUBG with support from CLOR, PTB, BFKH, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, UCBL, UH, USIEG and NPL will conduct a literature review on known environmental effects on established radon activity concentration sensors. Based on the results, PTB and CEA will determine the ranges for each of the environmental parameters (temperature, pressure, humidity, and the CO_2 concentration) for A2.2.2, A2.2.3, A2.2.4 and A2.2.5.	**CEA,** CLOR, PTB, SUBG, BFKH, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, UCBL, UH, USIEG, NPL
A2.2.2 M16	Based on input from A2.2.1, PTB with support from CLOR, CEA, USIEG, and CMI will determine the **temperature** (at least in the range found in houses between 16 °C - 30 °C) dependence of the radon activity concentration measurements of sensors selected in A2.1.1.	**PTB**, CLOR, CMI, CEA, USIEG
A2.2.3 M18	Based on input from A2.2.1, CEA with support from USIEG, PTB and CMI will determine the **pressure** (at least in the range found in houses between 900 hPa - 1000 hPa) dependence of the radon activity concentration measurements of sensors selected in A2.1.1.	**CEA,** USIEG, CMI, PTB
A2.2.4 M19	Based on input from A2.2.1, CEA with support from USIEG, PTB and CMI will determine the **relative humidity** (at least in the range found in houses between such as 40 % RH - 60 % RH) dependence of the radon activity concentration measurements of sensors selected in A2.1.1.	**CEA**, CMI, PTB, USIEG
A2.2.5 M20	Based on input from A2.2.1, CEA with support from USIEG, PTB and CMI will determine the **CO_2-concentration** (at least in the range found in houses between such as 1000 ppm – 1500 ppm) dependence of the radon activity concentration measurements of sensors selected in A2.1.1.	**CEA**, CMI, PTB, USIEG

A2.2.6 M22	Using input from A2.2.1-A2.2.5 and A5.1.1, CLOR and SUBG with support from SMU, CEA, USIEG, PTB and CMI will investigate the influence of environmental parameters (temperature, pressure, humidity, and CO_2-concentration) and their combination on the calibration for radon activity concentration measurement of selected sensors. PTB will optimise the combinations and ranges of environmental parameters (identified in A2.2.2-A2.2.5) to be surveyed using the Design of Experiments method [23]. This will determine if the sensors are suitable for implementation on–site in future connected buildings.	**CLOR**, CEA, CMI, PTB, SMU, SUBG, USIEG
A2.2.7 M30	The results from A2.2.1 to A2.2.6 will be summarised by PTB with support from CEA, CLOR, SMU, USIEG, SUBG and CMI into a report on the influence of environmental parameters on the radon activity concentration measurements. Once agreed by the consortium, the coordinator on behalf of PTB, CEA, CMI, CLOR, SMU, USIEG and SUBG will submit the quantitative report to EURAMET as **D3**: '*Paper on the influence of environmental parameters (temperature, pressure, humidity and CO_2 concentration) on the radon activity concentration measurements of sensors submitted to a peer-reviewed journal*'.	**PTB**, CEA, CMI, CLOR, SMU, USIEG, SUBG

C2.c Task 2.3: Determination of the response characteristics of the radon sensors

The aim of this task is to develop methods to determine (i) the time response, (ii) the linearity and, (iii) the dynamic range of radon sensors selected in A2.1.1 and to apply them to the radon sensors developed in WP1. In addition, their long-term stability and their sensitivity to small changes in the radon activity concentration will be tested.

Activity number	Activity description	Participants (Lead in bold)
A2.3.1 M08	SUBG with support from CEA, CLOR, PTB, BFKH, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, UCBL, UH, USIEG and NPL will perform a literature review and comparisons of time response, energy resolution and sensitivity (detection efficiency) of existing ^{222}Rn activity concentration sensors and reference standards, using pre-existing measurement data from SUBG. SUBG will investigate their applicability to the sensors to be developed in A1.1.2, A1.2.5, A1.3.2 and A1.3.3.	**SUBG,** CEA, CLOR, PTB, BFKH, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, UCBL, UH, USIEG, NPL
A2.3.2 M12	Based on input from A2.3.1, SUBG with support from CEA, USIEG, PTB and CMI will develop a method to measure the **time response** of any radon sensors using the radon transfer standard (CEA system from A1.1.2) and reference radon atmosphere with very fast changing ^{222}Rn activity concentrations (bellow 5 min) produced in the radioactive gas test bench at CEA. The method will be applied to at least 2 commercial devices identified in A2.1.1.	**SUBG**, CEA, CMI, PTB, USIEG
A2.3.3 M14	Based on input from A2.3.1, SUBG with support from CEA, USIEG, PTB and CMI will develop a method to measure the **linearity** of any radon sensors. The method will be applied to at least 2 commercial devices identified in A2.1.1.	**SUBG**, CEA, CMI, PTB, USIEG
A2.3.4 M16	Based on input from A2.3.1, SUBG with support from CEA, USIEG, PTB and CMI will develop a method to measure the **dynamic range** of any radon sensors. The method will be applied to at least on 2 commercial devices identified in A2.1.1.	**SUBG**, CEA, CMI, PTB, USIEG
A2.3.5 M32	Using input from A2.3.1-A2.3.4, PTB with a support from CEA, USIEG, SUBG and CMI will determine the sensitivity to slow or small changes in the ^{222}Rn activity concentration on the uncertainty of ^{222}Rn activity concentration measurements with the newly developed sensors from A1.2.5.	**PTB**, CEA, CMI, SUBG, USIEG
A2.3.6 M32	PTB with support from CEA, USIEG, SUBG and CMI will perform a long-term stability test of the sensors selected in A2.2.1 over a duration of at least 6 months in order to confirm the robustness of the results of the time response, linearity, dynamic range and sensitivity measurements.	**PTB**, CEA, CMI, SUBG, USIEG

C2.d Task 2.4: Development of a method for traceable, in-situ operando calibration of ^{222}Rn sensors

The aim of this task is to develop traceable, in-situ operando calibration procedures for the sensors from WP1. A decision on which sensors are to be used in WP3 (i) as measurement devices and (ii) as transfer standards will be made. In addition to the usage of a transfer standard, the possibility to use a calibration source will be investigated. This task will serve as a link between WP1 and WP3.

Activity number	**Activity description**	**Participants (Lead in bold)**
A2.4.1 M03	PTB with support from CEA, SUBG, NPL, CLOR, BFKH, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, UCBL, UH, and USIEG will perform a literature review on existing in-situ operando calibration techniques, including legal and societal considerations. The review will also collate techniques for radon network Quality Assurance and Quality Control (QA/QC). Comparison of calibration techniques used in existing air-quality monitoring networks will be carried out by PTB with support from CEA, SUBG, NPL and CLOR, BFKH, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, UCBL, UH, USIEG within the review. PTB will define a realistic framework for the implementation of the reviewed techniques in a non-laboratory environment.	**PTB**, CEA, SUBG, NPL, CLOR, BFKH, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, UCBL, UH, USIEG
A2.4.2 M05	PTB with support from CEA, SUBG, NPL, CLOR, BFKH, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, UCBL, UH and USIEG will perform a literature review on existing commercially available ^{222}Rn sensors and investigate the possibility to implement them as alternatives to the sensors to be developed in A1.2.5 and the measurement system to be developed in A1.3.4 for on-site calibration to achieve less than 10 % calibration relative standard uncertainty at an activity concentration level of 50 Bq m^{-3}.	**PTB**, CEA, SUBG, NPL, CLOR, BFKH, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, UCBL, UH, USIEG
A2.4.3 M12	Based on input from A2.4.1, A2.4.2 and A3.1.1, PTB with support from CEA, USIEG, SUBG, and CMI will develop decision criteria (e.g., time response of the sensor; sensitivity to humidity, robustness) for the implementation of the best suited sensors (from those to be developed in A1.1.2, A1.2.5, A1.3.2 and A1.3.4, and the commercially available ones) into WP3 as (i) measurement sensors and (ii) transfer standards. Criteria such as the spatial distribution of radon and the positioning of instruments that may have an impact or limitation in establishing calibration methods will also be identified. To achieve this, PTB with support from CEA, CMI, BFKH, SMU, USIEG, SUBG and NPL will be assisted by Radonova, LivAir, and UH who have vast amount of experience with numerous completed as well as ongoing experimental installations with radon sensors.	**PTB**, CEA, CMI, USIEG, SUBG, NPL, BFKH, SMU,Radonova, LivAir, UH
A2.4.4 M18	NPL with support from PTB will investigate machine learning methods for calibration of networked sensors using existing data from Bulgarian radon monitor network run by SUBG from existing commercial sensors. This investigation will also identify the limitations of a radon detector calibration technique, particularly to verify if criteria such as spatial distribution or instrument positioning identified in A2.4.3 have a significant impact.	**NPL**, PTB, SUBG
A2.4.5 M30	PTB with support from CEA, SUBG, USIEG, BFKH, SMU, IFIN-HH and CMI will jointly apply the decision criteria developed in A2.4.3 for a **transfer standard sensor or source** and for a **networked ^{222}Rn activity concentration sensor**, selected from those developed in A1.1.2, A1.2.5, A1.3.2 and A1.3.4, and/or the commercially available ones. At least 2 sensors will be placed by PTB with support from CEA, SUBG, USIEG, BFKH, SMU, IFIN-HH and CMI inside a building or a laboratory facility and connected to the network. The methods to measure time response, linearity and dynamic range developed in A2.3.2, A2.3.3 and A2.3.4 respectively will be used in order to measure the limitations of a radon detector calibration technique identified in A2.4.4. Using these experiments, the commercial devices investigated in A2.4.2 and the ML methods investigated in A2.4.4, PTB, SUBG, CMI, SMU, INFIN-HH, NPL and CEA will develop and apply a calibration method including uncertainties for at least one detector (a commercial one from a network as investigated in A2.4.2).	**PTB,** CEA, SUBG, CMI, NPL, BFKH, SMU, USIEG

A2.4.6 M36	Using the results from A2.1.1--A2.1.4, A2.2.1-A2.2.7, A2.3.1-A2.3.5 and A2.4.1-A2.4.5, PTB with support from CEA, CLOR, CMI, SMU, SUBG, USIEG, BFKH, IFIN-HH, NPL will write a good practice guide for the calibration of semiconductor, scintillation, and ionisation chamber sensors. The calibration procedures will be suitable also for sensors based on other types of technologies. Once agreed by the consortium, the coordinator on behalf of CEA, CLOR, CMI, PTB, SMU, SUBG, USIEG, BFKH, NPL and IFIN-HH will submit the good practice guide to EURAMET as **D4**: *'Good practice guide for traceable laboratory calibration procedures for ^{222}Rn activity concentration sensors of different types of technologies with less than 10 % standard uncertainty at an activity concentration down to 50 Bq m^{-3} allowing for response time and dynamic linearity testing*'.	**PTB**, CEA, CLOR, CMI, NPL, SMU, SUBG, USIEG, BFKH, IFIN-HH

C3 WP3: Network of radon sensors and data analysis

The aim of this work package is to facilitate the future development of quality assured, fit-for-purpose radon, sensor networks. A test network consisting of commercial sensors and the sensors developed and tested in WP1 for large buildings in future cities, integrated with data analysis framework suitable for real-time monitoring for anomalies, will be developed. The project will make use of emerging technologies such as edge computing, including techniques of machine learning and artificial intelligence. Digital SI to facilitate collaborative research, development, as well as self-sustaining expandability, will be implemented. This work package comprises both ionising radiation metrology and sensor network metrology and data science. As a result, it will establish links with other existing European metrology networks compatible with the environmental parameters that were identified within WP2.

The work package will focus on the development of a testbed, established within a large building or campus of buildings, that will be available for realistic trials of new radon networks. In parallel, existing radon and comparable radiation sensor networks will be reviewed to identify existing best practise (e.g. covering data collection, analysis, QA/QC, calibration etc). This best practise will be used as a starting point for further development (e.g. though implementation of AI methods to automate analysis). Technical solutions will be developed for the interfacing with radon sensors. A test network will be established at the testbed that will be type-tested against appropriate ISO and IEC standards to determine its metrological validity.

Task 3.1 will review existing networks in order to determine suitable methods for the radon sensor network. A radon network testbed at a large building or campus of buildings will be developed within which a test network will be established.

Task 3.2 will leverage existing network data within the consortium, as well as data from the literature, to lay the groundwork and guide the necessary developments for on-site calibration, particularly in the operation of radon sensor networks.

Task 3.3 will develop universal interfaces for the radon sensor network. This task will establish a universal interface following current standards for the connectivity of radon instruments (and in general for IoT devices), with the MQTT protocol already identified as the best candidate.

In Task 3.4 data from radon sensors will be investigated and analysis methods will be developed based on AI and ML to increase time response of the device and to make the background correction more efficient. The methods will be tested on the radon sensor network used in the testbed.

C3.a Task 3.1: Development of a testbed framework for radon monitoring networks

The aim of this task is to establish a testbed in a large building, series of buildings or experimental facilities that have existing infrastructure for air quality monitoring and climate control. The goal is for radon to be a new variable that can be measured in real time and decisions / countermeasures can be implemented based on radon activity concentration levels. Ultimately, the testbed will enable the sensors developed in WP1 and the calibration procedures developed in WP2 to be tested within a common environment. The task will culminate with an extended trial of a test network within the testbed.

Activity number	Activity description	Participants (Lead in bold)
A3.1.1 M12	Using input from A5.1.1, UH with support from PTB, NPL, CEA, Radonova and SUBG will establish criteria for buildings suitable to host a testbed facility (e.g., people flow, location in a radon prone area). UH with support from PTB, NPL, CEA, Radonova and SUBG will identify and review at least 2 candidate buildings or experimental facilities that both are large building or campus of buildings with existing and state-of-the-art infrastructure for air quality monitoring and climate control, (e.g., at CEA, UH, PTB, NPL). CEA with support from PTB, NPL, UH, Radonova, LivAir and SUBG will contact stakeholders (e.g., Orano, Legrand, Wellcome Trust, Cancer Research, UCL CAVE, UH Test Facility) and request their advice and provision of site through the lifetime of the project. UH with support from PTB, NPL, CEA, Radonova and SUBG will select one host building based on the established criteria. UH with support from PTB, NPL, CEA, Radonova and SUBG will identify the host building characteristics (e.g., air circulation, ventilation system, doors/windows parameters) that will be used to influence the design and calibration of sensors within A1.1.2, A1.2.5, A1.3.2, A1.3.4 and A2.4.3.	**UH**, CEA, PTB, NPL, Radonova, LivAir, SUBG
A3.1.2 M18	Based on input from A2.4.1-A2.4.3, PTB with support from CEA, Radonova, and SUBG will develop a radon network testbed within the host building selected in A3.1.1. This will include design and implementation of the network testbed. The network testbed will be utilised in A3.1.3 and A3.1.5 to test new sensors and new sensor network methods. PTB with support from NPL and NUVIA will provide guidance on how to set up networks within the testbed and how to ensure the network and sensors are compatible with a future digital twin such as the one to be developed in A3.3.4.	**PTB**, CEA, Radonova, SUBG, NPL, NUVIA
A3.1.3 M30	PTB with support from CEA, CMI, NUVIA, SUBG, USIEG, SMU, UH, NPL and UCBL will establish a new feature within/of the testbed developed within A3.1.2: a test network for radon sensors. This feature will involve the installation and testing of at least one of the sensors developed in A1.1.2, A1.2.5, A1.3.2 and A1.3.3, and also at least 2 commercial sensors (based on different technologies), within the testbed developed in A3.1.2. LivAir and Radonova will each install at least 1 commercial radon monitor into the testbed.	**PTB**, CEA, CMI, NUVIA, SMU, UH, NPL, SUBG, USIEG, UCBL, LivAir, Radonova
A3.1.4 M32	An extended trial will be performed by CEA with support from CMI, NUVIA, SUBG, PTB, USIEG, UCBL, LIvAir and Radonova within the test network established in A3.1.3. This will include investigating of the effect of air flow on radon levels in the host building selected in A3.1.1. CEA with support from CMI, NUVIA, SUBG, PTB, USIEG, UCBL, LivAir and Radonova will artificially increase and decrease the radon activity concentration in the building if permitted by local radiation protection authorities and will use the building management system to vary the air flow through the building. The impact on radon levels will be recorded. The target threshold will be 300 Bq m^{-3}.	**CEA**, PTB, CMI, NUVIA, SMU, UH, NPL, SUBG, USIEG, UCBL, LivAir, Radonova
A3.1.5 M32	Using input from A2.4.1, and A2.4.2, CEA with support from PTB, SUBG, and NPL will establish another feature within/of the network testbed developed in A3.1.2, this time for radon sensor calibration. This feature will be used to demonstrate the calibration method, necessary for IoT, developed in A2.4.5 on the test network established within A3.1.3. This will include in-situ and network calibration procedure (A2.4.5) and the usage of methods developed within A2.3.2, A2.3.3 and A2.3.4.	**CEA**, PTB, SUBG, NPL
A3.1.6 M35	Using input from A3.1.1-A3.1.5, UH with support from PTB, CEA, CMI, NUVIA, SUBG, USIEG, UCBL, SMU, NPL, LivAir and Radonova will prepare a report on the results of the testbed and test network trial. The report will provide input to the report on newly developed universal radon sensor network in A3.4.6.	**UH**, PTB, CMI, CEA, NUVIA, SUBG, USIEG, UCBL, SMU, NPL, LivAir, Radonova

C3.b Task 3.2: Building on knowledge from existing networks

The aim of this task is to build on the knowledge, results, best practices, and advice from an existing Bulgarian state-of-the-art radon monitor network run by SUBG and covering 30 x 30 km^2, with sensors located within dwellings and workplaces, and possibly other suitable networks. This will include using information from available networks, such as data collection, harvesting and pre-analysis. This will provide a starting point to develop new methods for calibration and analysis in conjunction with the methods tailored for the detector types developed in WP1 and environmental factors identified in WP2.

Existing networks to be reviewed include: the Bulgarian state-of-the-art radon monitor network run by SUBG and covering 30 x 30 km^2, with sensors located within dwellings and workplaces; the UK 'Sigma' homeland security network run by AWE / UK Gov Home Office; and SPIRAD [21].

Activity number	Activity description	Participants (Lead in bold)
A3.2.1 M03	SUBG will provide data from an existing Bulgarian state-of-the-art radon monitoring network run by SUBG containing sensors that were deployed following an optimisation strategy (prior to the project) and that is a first demonstration of the potential of such IoT network. Data from a newly developed network from LivAir will also be provided. The data from both networks will include measurement of low and high indoor radon activity concentrations, meta-data and sensor information and will be used for A3.2.2, A3.2.3 and A3.2.4. NPL and UH will collect data from existing gamma dose/spectrometry networks. Two networks have been identified to which the NPL and UH already have access: the UK 'Sigma' network of portable and fixed gamma-ray spectrometers for Homeland Security and the Finnish fixed gamma dose network for environmental monitoring and security. SUBG, LivAir, NPL and UH will prepare a summary of these networks, including the methods, techniques and equipment utilised by the operators. SUBG, LivAir, NPL and UH will ensure all permissions are obtained for accessing and distributing data from another four networks identified prior to the start of the project (i.e., Bulgarian network run by SUBG, UK Sigma network, Finnish network and SPIRAD). PTB with support from CEA, IFIN-HH and SUBG will review the state-of-the-art methods for data analysis for radon sensors. This will include assessing how data from existing radon networks (such as those run by Radonova, LivAir and SUBG) are analysed, utilising the summary reports prepared by SUBG, LivAir, NPL and UH.	**SUBG**, LivAir, NPL, UH, CEA, IFIN-HH, PTB, Radonova
A3.2.2 M06	Using input from A3.2.1, NPL and UH with support from PTB, NUVIA, SMU and CMI will review data from existing gamma dose/spectrometry networks and will determine which calibration methods can be adopted by the radon monitoring networks.	**NPL**, PTB, UH, NUVIA, SMU, CMI
A3.2.3 M12	Using input from A3.2.2 and data from the UK 'Sigma' network, NPL will establish how remote calibration techniques can be developed, leveraging their experience with Air Quality Monitoring. Using existing data from the Bulgarian radon monitor network run by SUBG, PTB, CEA and NPL will develop and apply a calibration method including quantification of uncertainties in radon measurements. This will be performed at the beginning for a commercial instrument (existing ^{222}Rn activity concentration sensor) and then at least for one type of the sensors that are being developed within A1.1.2, A1.2.5, A1.3.2 and A1.3.3. In-situ and remote calibration will be performed and compared.	**NPL,** SUBG, CEA, PTB
A3.2.4 M15	Using input from A3.2.1-A3.2.3 and A5.1.1, NPL with support from SUBG, LivAir, IFIN-HH, NUVIA, PTB, SMU and CMI will prepare a synthesis on the lessons learned from other state-of-the-art radon and radiation monitoring networks. The synthesis will provide an input into the report on the newly developed universal radon sensor network in A3.4.6.	**NPL**, SUBG, LivAir, NUVIA, PTB, SMU, CMI, IFIN-HH

C3.c Task 3.3: Development of universal interface for radon sensor networks

The aim of this task is to develop universal interface for radon sensor networks based on Message Queuing Telemetry Transport (MQTT) that can be used with different communication protocols (Wi-Fi, Ethernet, cellular networks such as LTE or 3G/5G).

Activity number	Activity description	Participants (Lead in bold)
A3.3.1 M06	NUVIA, Radonova, LivAir, IFIN-HH and CMI will review the state-of-the-art solutions utilised by existing networks and IoT devices (such as those run by Radonova and LivAir) and identify the most commonly used and beneficial settings focused on the transport and communication protocol and data storage solution by means of cloud storage. NUVIA and CMI will select best suited solution for the radon sensor networks with respect to operability, reliability and user friendliness for operators of the networks in large buildings.	**NUVIA**, CMI, Radonova, LivAir, IFIN-HH

A3.3.2 M12	Using input from A3.3.1, NUVIA and CMI with support from LivAir and Radonova will investigate implementation options of Message Queuing Telemetry Transport (MQTT) for IoT radon sensor networks, examining a transport protocol, and will evaluate the major benefit of using this MQTT standard, recommended by ISO/IEC 20922.	**NUVIA**, CMI, LivAir, Radonova
A3.3.3 M18	NUVIA will perform a detailed analysis of required network security for protection of the networking infrastructure from unauthorised access, misuse, or theft, with emphasis on data being transmitted within the network. The analysis will be carried out in accordance with the ISO/IEC 27033-1:2015, reviewed and confirmed in 2021.	**NUVIA**
A3.3.4 M35	Using input from A3.3.1 and A3.3.2, NUVIA with support from CMI, LivAir and Radonova will create a prototype MQTT and tailor it for implementation into radon IoT sensor networks. Using input from A3.3.3, the required network security protocol will be created by NUVIA with support from CMI and Radonova to enable the secure network operation. This will complete the development of universal interface for radon sensor networks based on MQTT. NUVIA, with support from CMI and RadonNova, will develop a digital twin of the sensors from the network testbed developed in A3.1.2 to allow real-time assessment of network performance and results. NUVIA with support from CMI, LivAir and Radonova will provide guidance on how a universal interface for radon sensor networks can be developed. This will feed into the report on the newly developed universal radon network in A3.4.6.	**NUVIA**, CMI, LivAir, Radonova

C3.d Task 3.4: Data gathering, analysis and testing

The aim of this task is to develop techniques for data gathering and analysis for the sensors designed and deployed in WP1 and WP2. This will include development of methods to identify background levels of radon and application of AI/ML techniques for detection of anomalies. The purpose is, in general, to be able to properly collect the right data and to use them to correct the measurements, for example from calibrations and background measurements, and to apply the technique that is usually used in the laboratories directly on the data from the network testbed. High amount of measurement data will help to improve the device system. By using AI, the time response of the device can be increased to make it more efficient.

The task aims to establish the metrological validity of the radon sensor network developed within Task 3.1. This will be achieved by analysis of data from a complex measuring unit that will be tested for compliance with relevant ISO and IEC standards in the fields of both ionising radiation and sensor network metrology.

Activity number	Activity description	Participants (Lead in bold)
A3.4.1 M03	PTB with support from CEA, IFIN-HH and SUBG will review the state-of-the-art methods for data analysis for radon sensors. This will include assessing how data from existing radon IoT sensor networks (such as those run by Radonova, LivAir and SUBG) are analysed.	**PTB**, CEA, IFIN-HH, SUBG
A3.4.2 M12	Using input from A3.4.1, SUBG with support from UH, NPL and PTB will investigate time period over which data are collected and transmitted (the shortest time period the better), with focus on suitability within the network testbed (to be developed in A3.1.2) that has limited data transfer/storage. SUBG will perform statistical analysis of the data collection process form commercial sensors installed on site such as the SUBG network. This will include uptime estimation, data collection efficiency, etc. NPL and SUBG will investigate correlations between measured rates from at least 1 commercially available sensor identified in A2.1.1 with the overall aim to improve the measurements made with a network of distributed sensors.	**NPL,** UH, SUBG, PTB
A3.4.3 M18	Using input from A3.4.1 and A3.4.2, NPL with the help of PTB and UH will investigate measurements of background levels of radon, published in peer-reviewed journals. Data will be gathered from previous research such as the data from the network run by SUBG, as well as from background levels in an artificial atmosphere without radon produced at PTB and CEA. NPL will develop a suitable model of the background correction using AI/ML techniques. This will allow the correction of background in the conventional measurement device to ensure a faster and correct measurement response.	**NPL**, PTB, UH, CEA

A3.4.4 M24	Using input from A3.4.1-A3.4.3, PTB with support from NPL and UH will develop methods for anomaly detection and correction on an individual device and at network level by using AI/ML routines that solve specific tasks by learning from data and making predictions without direct instructions. Foreseen application areas are detector diagnostics, fault detection and true-false positive signal separation. Data from the network run by SUBG will be used.	**PTB**, NPL, UH
A3.4.5 M25	Using input from A3.4.1-A3.4.4, NPL with support from PTB and UH will draft a summary report on data analysis of anomalies and application of AI/ML methods for their detection'. Once agreed by the consortium, the coordinator on behalf of NPL, PTB and UH will submit the report to EURAMET as **D5**: '*Summary report on data analysis of radon measurement anomalies and application of AI/ML methods for their detection to validate the radon sensor network suitable for large building monitoring*'.	**NPL**, UH, PTB
A3.4.6 M34	CMI, with support from PTB, CMI, SMU, IFIN-HH, LivAir, CEA NUVIA, Radonova, SUBG, UH and NPL will review documentary standards in the field of radon metrology and sensor network metrology (e.g. ISO and IEC standards such as ISO/IEC 29182-2:2013). Based on the outcome of the review, CMI, with support from PTB, CMI, SMU, IFIN-HH, LivAir, CEA NUVIA, Radonova, SUBG, UH and NPL will develop a procedure for testing and calibration of the radon sensor network. This procedure will be used to test the network testbed developed in A3.1.2 with the methods developed for calibration (such as A2.1.2, A2.1.3, A2.1.4 and A3.1.5) with the associated new method (such as A2.3.2, A2.3.3, A2.3.4 and A2.4.5) taking into account the environmental parameters influence on radon measurement (such as A2.2.2, A2.2.3, A2.2.4 and A2.2.5). The network tests will be carried out by at least 3 participants involved in this activity. Once the tests are validated in the laboratory by CMI, PTB and CEA, the procedure will be applied in the testbed with IoT sensors to demonstrate to stakeholders the interest of developing such testbed with the associated procedures.	**CMI**, PTB, CEA SMU, IFIN-HH, LivAir, NUVIA, Radonova, SUBG, UH, NPL
A3.4.7 M36	Using input from A3.1.6, A3.2.4, A3.3.4 and A3.4.3-A3.4.6, CEA, PTB and CMI will draft a report on the newly developed radon sensor network and send it to SMU, IFIN-HH, LivAir, NUVIA, Radonova, SUBG, UH and NPL for comments and/or improvements. Once agreed by the consortium, the coordinator on behalf of CEA, PTB, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, SUBG, UH and NPL will send the report to EURAMET as **D6**: '*Report on the newly developed universal radon sensor network with associated data analysis and calibration procedures*'.	**CEA**, PTB, CMI, SMU, IFIN-HH, LivAir, NUVIA, Radonova, SUBG, UH, NPL

C4 WP4: New methods for the integration of the radon network technology into other existing sensor networks

This work package will lay the foundations for the seamless integration of the radon network testbed developed in WP3 into various pre-existing sensor networks. The result of this integration will be the establishment of a framework that facilitates the development and implementation of intelligent and holistic data analysis and integration methods.

By successfully integrating the radon network testbed with other sensor networks, the ultimate goal is to enable a harmonious synergy that improves the efficiency of energy consumption, air quality management and radiation protection within building. This synergy would enable to strategically optimise the use of resources, leading to more sustainable and environmentally conscious practices.

In essence, this work package serves as a crucial stepping stone towards the realisation of a cohesive and intelligent network that goes beyond the capabilities of individual sensors. This will include recommendations for how AI/ML can be utilised for intelligent analysis, and how to prepare the network for implementation of a digital twin.

Task 4.1 will collect and analyse technical information on different sensors and environmental monitoring technologies commonly used in large buildings and other relevant environments. This will be done through a literature review on the main pollutants monitored in existing IAQ networks, an analysis of existing European air quality networks and the solutions they have enabled, and through a review of European legal requirements and national recommendations.

The aim of Task 4.2 is to produce a good practice guide for the development of an extension of the sensor network to include other existing and potential building sensor networks (i.e., the extension goes larger than radon). The work within this task will include identifying gaps in existing radiation networks, proposing suitable parameters for the networks, and investigating possible inclusion of other radiation sensors.

Task 4.3 will perform measurements of radon and other parameters in existing sensor networks and on this basis a model for integrating data from the above networks will be developed. In addition, AI/ML methods in data analysis of air quality sensor networks will be investigated. Recommendations for comprehensive air quality measurements, including indoor radon, will be produced.

C4.a Task 4.1: Investigation of the state-of-the-art sensor networks

The aim of this task is to collect and analyse technical information on various sensors and environmental monitoring technologies commonly used in large buildings. Existing air quality networks and sensor network solutions and their limitations will be investigated. Legal requirements and recommendations for indoor radon measurements will be analysed.

Activity number	Activity description	Participants (Lead in bold)
A4.1.1 M03	CLOR with support from CEA, CMI, PTB, SMU, IFIN-HH, LivAir, Radonova, UH and NPL will carry out a literature review on key pollutants (such as CO_2, carbon monoxide, aerosol, volatile organic compounds) that are monitored in existing Indoor Air Quality (IAQ) networks (e.g., network run by UH). Based on the results, CLOR with support from CEA, CMI, PTB, SMU, IFIN-HH, LivAir, Radonova, UH and NPL will compile a list of key pollutants and their ranges in typical environmental conditions. NPL will also ask European Metrology Network for Pollution Monitoring (PolMo) for their assistance in providing information on these values.	**CLOR**, CEA, CMI, PTB, SMU, IFIN-HH, LivAir, Radonova, UH, NPL
A4.1.2 M06	Radonova, UH, CLOR, IFIN-HH and NPL will investigate existing European air quality networks (e.g., in EMN PolMo and EMPIR project FunSNM 22DIT02) and sensor network solutions for comprehensive air quality measurements in large buildings (e.g., from AirParif, MClimate, Terabee). This includes an analysis of the measurement techniques, sensor technologies, wired and wireless communication technologies, data transfer solutions, placement of sensors, user interfaces, power supply, data output and algorithms of these readily available networks/solutions and their limitations. Radonova and LivAir will identify at least 2 low-cost sensors from the existing IAQ networks to be used in A4.2.4. Radonova with support from UH, CLOR, IFIN-HH and NPL will summarise the results in a report which will feed into the good practice guide on the development of an extension of the radon sensor network in A4.2.5 and into the report on the development of intelligent data analysis and integration methods in A4.3.6.	**Radonova**, LivAir, UH**,** IFIN-HH, CLOR, NPL
A4.1.3 M06	LivAir, CLOR, CEA, IFIN-HH and UH will prepare an overview of European legal requirements, standards, recommendations (Directive 2008/50/EC and Directive 2004/107/EC) and national and international recommendations (WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide) concerning indoor air quality and radon measurements.	**LivAir**, CLOR, CEA, IFIN-HH, UH
A4.1.4 M12	Based on input from A4.1.1-A4.1.3, CLOR with support from PTB, CEA, LivAir, Radonova, IFIN-HH, UH and NPL will write a report on characteristics and limitations of existing IAQ, covering at least data transfer solutions, placement of the sensors, power supply, data collection and analysis, user interfaces, and measurement uncertainties. This report will feed into the good practice guide on the development of an extension of the radon sensor network in A4.2.5.	**CLOR**, PTB, CEA, LivAir, Radonova, IFIN-HH, UH, NPL

C4.b Task 4.2: Investigation on the use of radiation sensors in air quality networks

The purpose of this task is the investigation of the possibility of the application of radiation sensors in air quality networks. It will first identify the air quality parameters that may have synergy with radon, and the gaps in existing sensor networks. The task will then investigate how other radiation sensors can be integrated into a building management system for nuclear preparedness purposes. A good practice guide will be provided for the development of an extension of the sensor network to include other existing and potential building sensor networks.

Activity number	Activity description	Participants (Lead in bold)
A4.2.1 M12	PTB, CLOR, LivAir and IFIN-HH will use the findings from A2.2.1 and A4.1.1 (dependency of radon sensor response on environmental parameters) to formulate requirements (such as concentration-in-air range) on air quality monitoring in the testbed in large building (such as the one identified in A3.1.1), This will provide the necessary understanding of the ambient environmental conditions. PTB, CLOR, LivAir and IFIN-HH will identify key air quality parameters (such as CO_2 concentration, pollution in the building, volatile organic compounds, aerosols) that may have synergy with radon.	**PTB**, LivAir, CLOR, IFIN-HH
A4.2.2 M18	NPL with support from PTB, LivAir, Radonova, UH and CLOR will identify gaps in existing sensor networks for the key air quality parameters identified in A4.2.1. Based on the identified gaps and the input from A4.1.4, NPL, with support from PTB, LivAir, Radonova UH and CLOR will propose a set of parameters that monitoring networks within the testbed facility should include. This will enable radon sensor response to be corrected for environmental effects, and for radon levels to be inferred from other air quality parameters (and vice-versa).	**NPL,** PTB, LivAir, CLOR, Radonova, UH
A4.2.3 M24	NPL and UH will investigate how other radiation sensors (i.e., gamma and dose sensors of NPL and UH) can be integrated into a building management system for nuclear preparedness purposes (e.g. fallout from civil NPP accident, false alarms, or nuclear attack). This includes measuring radon and other radioactivity content at the same time and looking into a fall out or at the opposite false alarms due to radon.	**NPL,** UH
A4.2.4 M24	NPL, Radonova, IFIN-HH and LivAir will investigate and test the inclusion of other novel air quality monitors (such as low-cost sensors identified in A4.1.2) into the network testbed developed in A3.1.2. Using the list of key pollutants compiled in A4.1.1, NPL, Radonova, IFIN-HH and LivAir will identify which calibration support exist for each key pollutant. This will complete the development of the extension of the sensor network that will enable inclusion of other existing and potential building sensor networks.	**NPL,** Radonova, IFIN-HH, LivAir
A4.2.5 M30	Using input from A4.2.1-A4.2.4 and A5.1.1, NPL with support from PTB, LivAir, CLOR, Radonova, IFIN-HH and UH will draft a good practice guide on the extension of the sensor network**.** Once agreed by the consortium, the coordinator on behalf of NPL**,** PTB, LivAir, CLOR, Radonova, UH, IFIN-HH will send the good practice guide to EURAMET as **D7**: '*Good practice guide on the development of an extension of the sensor network enabling inclusion of other existing and potential building sensor networks*'.	**NPL,** PTB, LivAir, CLOR, Radonova, UH, IFIN-HH

C4.c Task 4.3: Data analysis and integration

The aim of this task is to produce recommendations regarding comprehensive air quality measurements that include indoor radon, considering how to efficiently combine radon and other air quality measurements (identified in 4.1.1.), and including air quality aspects, energy consumption, and possible cross-correlations between different monitored variables (e.g., CO_2, temperature and radon levels). Beyond this, synergies between indoor and outdoor radon and other radiation measurements will be investigated.

Activity number	Activity description	Participants (Lead in bold)
A4.3.1 M22	CLOR with support from NPL will identify at least 2 suitable **indoor** air quality networks (such as the network run by UH) for incorporating radon measurements. CLOR, NPL and UH will contact the networks and make arrangements for including radon sensors into at least one of the networks. Networks monitoring the key pollutants identified in A4.1.1 or the air quality parameters identified in A4.2.1 will be prioritised. NPL and UH will place at least 2 sensors (as the incorporation of the sensor is here the important parameter, it can be either a commercial sensor or at least one of the radon sensors being developed within A1.1.2, A1.2.5, A1.3.2 or A1.3.3) into at least one of the indoor networks and carry out measurements on the radon concentration combined with the indoor air quality measurements (on other pollutants) provided by the networks.	**CLOR,** UH, NPL

A4.3.2 M28	Based on the data obtained from A4.3.1, UH and NPL will develop a model how to integrate indoor radon measurements in the existing air quality monitoring networks, taking into account air quality aspects, energy consumption, and possible cross-correlations between different monitored parameters (e.g., CO_2, radon levels, temperature). This will include a development of integration methods.	**UH**, NPL
A4.3.3 M26	NPL with support from CLOR will identify suitable urban air quality networks (such as the NPL Air Quality Monitoring Networks) for incorporating **outdoor** radon measurements. NPL and CLOR will contact the networks and make arrangements for including radon sensors into the networks. Networks monitoring the key pollutants identified A4.1.1 or the environmental parameters identified in A4.2.1 will be prioritised. NPL and CLOR will place at least 2 commercial radon devices (provided by UH, LivAir or Radonova) into the identified outdoor networks and perform measurements on the radon concentration combined with the air quality measurements (on other pollutants) provided by the networks. Based on the data from this outdoor campaign, NPL with support from CLOR, PTB and UH will investigate the relationship between indoor/outdoor radon activity concentrations and the feasibility of incorporating outdoor radon measurements into urban air quality networks.	**NPL**, UH, PTB, CLOR, LivAir, Radonova
A4.3.4 M28	Using data from the indoor network(s) from A4.3.1, NPL, UH and PTB will investigate AI/ML methods in data analysis of air quality sensor networks and assess how the networks' pollutant measurements can be applied to radon monitoring.	**NPL**, UH, PTB
A4.3.5 M32	UH, CLOR, CMI, CEA, SMU and NPL will discuss the results of the investigations from A4.3.1-A4.3.4 with the Stakeholder Committee (A5.1.1) and at least 3 national authorities in Europe responsible for air quality and indoor radon (e.g., Autorité de sûreté nucléaire (ASN), Radiation and Nuclear Safety Authority (STUK), Österreichische Agentur für Gesundheit und Ernährungssicherheit (AGES), CLOR).	**UH**, CLOR, CMI, CEA, SMU, NPL
A4.3.6 M36	Based on input from A4.3.1-A4.3.4 and A5.1.1, UH, CLOR, SMU, CEA, CMI, NPL and PTB will prepare a report containing recommendations regarding air quality measurements based on radon concentration, other air quality parameters and energy consumption. Once agreed by the consortium, the coordinator on behalf of UH, CLOR, SMU, CEA, CMI, NPL and PTB will submit the recommendation report to EURAMET as **D8**: '*Report on the intelligent data analysis and integration methods to optimise the use of energy saving, air quality management and radiation protection in connected buildings. This will include recommendations how to efficiently combine radon and other air quality measurements, considering air quality aspects, energy consumption and possible cross-correlations between different monitored parameters (e.g., CO_2, temperature)*'.	**UH**, CLOR, SMU, CEA, PTB, CMI, NPL

C5 WP5: Creating impact

C5.a Task 5.1: Dissemination and communication

Activity number	Activity description	Participants (Lead in bold)
A5.1.1 M36	The project will create a Stakeholder Committee (SC) of at least 20 members including ICRM and EURAMET TC-IR representatives, NMIs/DIs not participating in the project (FTMC, STUK, CIEMAT, KRISS, others), nuclear instrumentation manufacturers, construction industry community, calibration laboratories, universities (students) and standards developing organisations from at least 15 European countries. The aim of the Stakeholder Committee is to clarify the needs of the various interested parties and to feed these into the project. Additionally, the SC members will be asked to provide input to technical activities, e.g. A1.1.4, A1.2.5, A1.3.4, A1.3.6 (GPG), A1.4.2, A2.2.6, A2.4.6 (GPG), A3.1.1, A3.2.4, A4.2.5 (GPG) and A4.3.6 and communicate and disseminate the project within their networks. Interaction of the Stakeholder Committee will be achieved via a project website (A5.1.3), online meetings organised by the coordinator and WP leaders and project progress meetings.	**CEA**, all participants

A5.1.2 M36	CEA Talkspirit, a web-based platform for the project participants created by CEA, will be used to share documents and for communication between the project participants, collaborators and other stakeholders. The communication will be efficient by providing the following tools inside the Talkspirit: - A permanent video conference meeting link administered by the coordinator without participant limits, without the need for third-party software, and with recording options. - Project tracking tools with a calendar reproducing the Gantt chart and deliverables from the project start date. - A voting launch system administered by the coordinator and project managers at CEA to conduct surveys and multiple-choice studies at the consortium and stakeholder levels. - A project file and document management system with multiple backups and network archiving to preserve all types of data and enable collaborative work on the same Word/PowerPoint or Excel document.	**CEA**, all participants
A5.1.3 M36	A project webpage with public access will be created by CMI. The webpage will be regularly updated with information such as project reports, papers published by the participants, project meetings. The project website will clearly acknowledge, in a prominent position on the homepage (e.g. in the header, footer or centre and in a readable size), the Metrology Partnership. This will be done by including either i) the Partnership project website header/footer badge and acknowledgement text (this text can be anywhere on homepage) or ii) the Partnership acknowledgement badge.	**CMI**, all participants
A5.1.4 M36	The project participants plan to present at least 12 papers/posters at the following international conferences: • International Conference on Radionuclide Metrology (ICRM) (Paris, France, April 2025, organised by CEA) • IAEA Radiation Protection and Nuclear Safety International conferences (tbd, 2026) • International Radon Symposium (AARST) (tbd, 2026) • ENVIRA conferences on environmental radioactivity (tbd, September 2025) • 7th European Congress on Radiation Protection (IRPA) (Liverpool, UK, June 2026) • International Conference on Scintillating Materials and their Applications (SCINT) (tbd, 2026) • IEEE Symposium on Radiation Measurements and Applications (SORMA) (tbd, 2025) • International Topical Meeting on Industrial Radiation and Radioisotope Measurement Applications (IRRMA) (tbd, 2026) • Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA) (tbd, 2025) • IEEE Nuclear Science Symposium (IEEE NSS) (tbd, 2025) Further relevant conferences will be identified during the project.	**CMI**, all participants
A5.1.5 M36	The participants plan to submit at least 10 papers to peer-reviewed scientific journals during the project. Target journals include: • Applied Radiation and Isotopes • Radiation Protection and Dosimetry • Radiation Measurements • Metrologia • Journal of Environmental Radioactivity • Journal of Instrumentation • Atmospheric Chemistry and Physics • Atmospheric Measurement Techniques • Health Physics. • IEEE Transactions on Nuclear Sciences	**CMI**, all participants

	• Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Sensors and Associated Equipment • Nature – Photonics The expectations are that at least 6 out the 10 papers will be the result of a collaborative effort from participants from different countries. The authors of the peer reviewed papers will clearly acknowledge the financial support provided through the Partnership as required by EURAMET in accordance with Article 17, Article 18, and Annex 5 of the Grant Agreement with the following text: "The project (23IND07 RadonNET) 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 authors will ensure that the following meta data is submitted and included for each paper: • Funder name: European Partnership on Metrology • Funder ID: 10.13039/100019599 • Grant number: 23IND07 RadonNET The participants will comply with open access requirements detailed in the Grant Agreement Section 17 by also depositing each paper in a suitable open access trusted repository.	
A5.1.6 M36	To enable other stakeholders and wider community to understand and have access to the results of the projects, at least 2 articles will be submitted to trade and popular journals. The topics and target journals will be agreed by the project participants after the project starts, in accordance with the project results most relevant for the wider population. Radiation protection against radon concentration in air will be emphasised.	**CMI**, all participants
A5.1.7 M36	A project flyer and a project poster will be designed and produced in the beginning of the project addressing all relevant information about the project and the participants. Basic principles of ionising radiation metrology and radiation protection will be explained for non-specialist audience. The flyer and poster will be available for download on the public webpage (A5.1.3) and used during project presentations at conferences (A5.1.4), workshops (A5.1.11), training (A5.1.12) and other events. An annual e-newsletter will be produced and sent by email to the stakeholders and other collected contacts (starting at the kick-off meeting and ending at the final meeting). The e-newsletter will also be available on the webpage (A5.1.3). The e-newsletter will cover general information about the project, participants, project results and upcoming events.	**SMU**, all participants
A5.1.8 M36	CEA, with the support from all participants will produce and publish 3 good practice guides (GPG) on the project website (A5.1.3). • Good practice guide on new methods and sensors developed for radon concentration monitoring in sensor network with lowered response time, increased sensitivity and reduced uncertainty. This will include at least three detection concepts based on the use of i) semiconductors, ii) ionisation chambers and iii) scintillators (A1.3.6) • Good practice guide for traceable laboratory calibration procedures for ^{222}Rn activity concentration sensors of different types of technologies with less than 10 % uncertainty at an activity concentration down to 50 Bq m-3 allowing for response time and dynamic linearity testing (A2.4.6) • Good practice guide on the development of an extension of the sensor network capable of including other existing and potential building sensor networks. (A4.2.5) CEA and all participants will actively disseminate the GPGs to the stakeholders by publishing them on the project website (A5.1.3), the participant's websites, presenting them at conferences (A5.1.4), at the project's workshops (A5.1.11), the project's social media (A5.1.10) and through the project's stakeholder committee (A5.1.1).	**CEA**, all participants

A5.1.9 M36	Information on the results of the project will be disseminated to a range of standards bodies and committees and feedback sought (see details below and in the table in Section B3.c).	**NPL**, all participants

Standards Committee / Technical Committee / Working Group	**Participants involved**	**Likely area of impact / activities undertaken by participants related to standard / committee**
IEC/TC45: Nuclear Instrumentation	**CEA,** PTB, NPL	IEC/TC45 meets every 2 years with the next meeting expected in 2025. CEA with support from PTB and NPL will present progress and disseminate the results of the project to IEC 60846 and IEC 61017, in particular the work related to new sensors (WP1) and calibration procedures (WP2) development and participate in the draft of any relevant documentary standard that the committee decides to revise or initiate. The participants involved will ask for feedback on the work and results presented.
ISO/TC146: Air quality	**PTB**, CEA, NPL	IEC TC146 meets every 2 years with the next meeting expected in 2025. PTB with support from NPL and CEA will present progress and disseminate the results of the project to ISO 19694 ‘Stationary source emissions’, in particular the work related to new sensors (WP1) and calibration procedures (WP2) development and participate in the draft of any relevant documentary standard that the committee decides to revise or initiate. The participants involved will ask for feedback on the work and results presented.
ISO/TC207: Environmental management	**PTB**, CEA, NPL	ISO/TC207 meets annually. PTB with support from NPL and CEA will present progress and disseminate the results of the project to ISO/CD 14065 ‘General principles and requirements for bodies validating and verifying environmental information’, in particular the work related to new sensors (WP1) and calibration procedures (WP2) development and participate in the draft of any relevant documentary standard that the committee decides to revise or initiate. The participants involved will ask for feedback on the work and results presented.
EURAMET TC-IR Technical Committee for Ionising Radiation	**CMI**, BFKH, CEA, IFIN-HH, NPL, PTB	CMI, BFKH, CEA, IFIN-HH, NPL and PTB will present progress within the project at the annual committee meetings held in 2025, 2026 and 2027. The committee members will be invited to share the project achievements in their respective countries and actively collect feedback from these open discussion groups.
EURAMET TC-IM Technical Committee for Interdisciplinary Metrology WG M4D Metrology for Digital Transformation	**PTB**	TC-IM meets annually. PTB will present progress and disseminate the results of the project to WG M4D in particular. The following areas where the working group on Metrology for Digital Transformation is pooling expertise will be relevant for this project: Sensor network metrology (TC-IM 1551) and Metrology for Internet of Things (IoT) and sensor networks. PTB will ask for feedback on the work and results presented.

<table>
<tr>
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<table>
<tr><td>ICRM Alpha-Particle Spectrometry WG</td><td>PTB, NPL</td><td>NPL and PTB will present progress within the project, in particular the work related to alpha measurement of radon and its progenies at the working group meetings to be held in 2025 and 2027. The committee members will be invited to share the project achievements in their respective countries and actively collect feedback from these open discussion groups.</td></tr>
<tr><td>ICRM Low-Level Measurement Techniques WG</td><td>PTB, NPL</td><td>PTB and NPL will present progress within the project, in particular the work related to low radon activity concentration measurement at the working group meetings to be held in 2025 and 2027. The committee members will be invited to share the project achievements in their respective countries and actively collect feedback from these open discussion groups.</td></tr>
<tr><td>ICRM Liquid Scintillation Counting WG</td><td>CEA</td><td>CEA will present progress within the project, in particular the work related to scintillation material and associated measurement techniques and methods at the working group meetings to be held in 2025 and 2027. The committee members will be invited to share the project achievements in their respective countries and actively collect feedback from these open discussion groups.</td></tr>
<tr><td>BIPM CCRI (II)
Measurement of radionuclides</td><td>CMI, NPL, PTB</td><td>CMI, NPL and PTB will present progress within the project at the annual committee meetings held in 2025, 2026 and 2027. The committee members will be invited to share the project achievements in their respective countries and actively collect feedback from these open discussion groups.</td></tr>
</table>
The representatives on the corresponding committee or WG from the participants will jointly ask the chairperson to include a point in the agenda to briefly present the outputs of the project related to the WG activities and ask for comments. Where appropriate a written report will be submitted for consideration by the committee or WG.
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<tr>
<td>A5.1.10
M36</td>
<td>An on-line Discussion Group on LinkedIn will be set-up by IFIN-HH for project participants, stakeholders and end-users to exchange latest information about project progress and achievements. The project will be also presented on ResearchGate and linked with all participants to increase visibility amount participants’ network.
Other social media platforms such as X (previously known as Twitter) will also be used for communication between project participants and end-users.
The consortium will tag EURAMET on X and LinkedIn with ‘@EURAMET’ ‘and @EURAMET’ - The European Association of National Metrology Institutes’ respectively so that EURAMET can share if appropriate. Also, hashtags such as #measurementscience, #metrology, #EUfunded, #EUPartnership should be used if possible.</td>
<td>IFIN-HH, all participants</td>
</tr>
<tr>
<td>A5.1.11
M36</td>
<td>Two workshops for stakeholders will be organised and held during the project.
The first workshop will be organised by PTB and CEA and held either at PTB Braunschweig or at CEA premises, approx. in M18-M20 (February-April 2026). At the workshop, project results from WP1 and WP2 will be presented with emphasis on new sensors for radon monitoring (Tasks 1.1, 1.2 and 1.3) and calibration procedures (Task 2.1).
The second workshop will be organised by NPL and held at NPL Teddington, approx. in M30-M32 (February–April 2027). At the workshop, project results from WP3 will be presented with emphasis on new network developed for sensors monitoring indoor radon concentration.
The target number of delegates for each workshop will be 30. European NMIs and DIs not participating in the project, measurement technique manufacturers, construction industry community, calibration laboratories, standards developing organisations (ISO, IEC), EMN for Pollution Monitoring, EMN for Radiation Protection and EMN for Climate and Ocean Observation members will be invited. Invitation will be also sent to</td>
<td>CEA, all participants</td>
</tr>
</table>

	international organisations representatives, such as ICRP, ICRM and IAEA, and EURAMET TC-IR members. Stakeholders and end-users will be regularly offered by on-line seminars via the project website and by e-mail. These seminars will be organized by project participants after achievement of significant results, e.g. new sensors and calibration methods developed, and sensor network prepared and tested.	
A5.1.12 M36	NPL will organise a training course to be held in conjunction with the second stakeholder workshop at NPL Teddington. The training course will focus on the results from the project regarding the use of new sensors, calibration procedures and new network for sensors (Tasks 2.1, 2.4 and 3.1). The training course will be targeted at radon measurement experts, technical staff and students. The target number of participants is 15. The training course will be announced on the project webpage (A5.1.3), the project participants' websites and through the Stakeholder Committee. In addition, based on interest, ad-hoc on-line training(s) focusing on project results may be organised.	**NPL,** all participants
A5.1.13 M36	The participants are linked with and are members of various scientific, metrological and industrial networks. These networks will be used to gain additional contacts with potential stakeholders. Therefore, participants will actively engage in various networking activities. Links to the relevant user networks will be also sought and created or expanded. The following networks were identified for further activities: - EMN for Radiation Protection - EMN for Climate and Ocean Observation - EMN for Pollution Monitoring - Indoor Air Pollution Network (INDAIRPOLLNET), - MegaSense (Sensing and Analytics of Air Quality) programme - European Partnership on Metrology project 22DIT02 FunSNM In addition, the consortium will be linked to Euratom Group of Experts attached to the European Commission to help the EU make decisions concerning radioactivity. This Group of Experts will be regularly informed about the results and advances within the project to promote the uptake of the project's outcomes and contribute to the decision-making concerning radioactivity by the European Commission.	**CEA**, all participants

C5.b Task 5.2: Exploitation and uptake

Activity number	Activity description	Participants (Lead in bold)
A5.2.1 M36	A dissemination, communication and exploitation plan (DCE) will be created at the beginning of the project by CEA, with support from all participants, and submitted to EURAMET at M6. It will be reviewed and updated at least at each project meeting. The DCE plan will provide further details on the following expected results: • Expected result 1 – New methods and sensors for detecting radon (WP1) • Expected result 2 – Traceable in-situ calibration procedures for new sensors (WP2) • Expected result 3 – A quality assured radon sensor network (WP3) • Expected result 4 – Data analysis and integration methods (WP4)	**CEA**, all participants
A5.2.2 M36	*Expected result 1:* New methods and sensors for detecting radon (WP1) Using the new methods and sensors for radon detection developed in A1.1.2, A1.2.5 and A1.3.3, CEA with the support of all participants will provide assistance to NUVIA, RadonNova and LivAir (SMEs) to install some of the new devices into their infrastructure. It is envisaged that the process will start during the project and will continue after the project has finished. NUVIA, RadonNova, LivAir will evaluate their characteristics and propose possible improvement.	**CEA**, all participants
A5.2.3 M36	*Expected result 2: Traceable in-situ calibration procedures for new sensors* PTB, with the support of all participants will provide the calibration procedures developed in A2.1.2, A2.1.3, A2.1.4 and A2.4.5 to NMIs/DIs not participating in the project (e.g. CIEMAT, FTMC, STUK, KRISS, ANSTO), and to Czech Technical University and MIRION Technologies, for calibration of their radon measurement instruments. Other laboratories, interested in the implementation of the new calibration procedures, can be identified during the project.	**PTB**, all participants

A5.2.4 M36	*Expected result 3: A quality assured radon sensor network* CMI, PTB and CEA will perform testing of the developed radon sensor network at CMI's and/or PTB's facilities using standard radionuclide sources and reference materials traceable to the national standards for activity of radionuclides (A3.4.6). During the project lifetime, CMI, PTB, CEA and all other participants, with support from stakeholders and collaborators, will look for a company/companies interested in keeping and implementation of the network in a big building. After the testing, the sensor network will be demonstrated to interested company/companies as a prototype.	**CMI**, all participants
A5.2.5 M36	*Expected result 4: Data analysis and integration methods* CLOR, UH and NPL will investigate air quality measurement networks, and analyse their output, control mechanisms and analysis algorithms for efficient combination of radon concentration and other air quality measurements (Task 4.2). IPG-PSN, SHU and CTU will be invited to collaborate in this research, and it is expected that they will use the results in their practice.	**CLOR**, all participants

All IP and potential licencing/exploitation will be handled in accordance with the Grant Agreement and the Consortium Agreement.

C6 WP6: Management and coordination

C6.a Task 6.1: Project management

Activity number	Activity description	Participants (Lead in bold)
A6.1.1 M36	The project will be managed by the coordinator from CEA, who will be supported by the project management board consisting of one representative from each beneficiary, including the leaders of each work package. The members of the project management board will guide the project, attend the project meetings, organise the progress meetings at their local institutes and call additional meetings if needed to ensure the overall project's success.	**CEA**, all participants
A6.1.2 M36	The work package leaders will report on the on-going progress to the coordinator mainly by e-mail and telephone conferences. If necessary, other ways of communication such as videoconferencing will be used.	**CEA**, all participants
A6.1.3 M36	The coordinator, with support from the participants, will manage the project's risks to ensure timely and effective delivery of the scientific and technical objectives and deliverables.	**CEA**, all participants
A6.1.4 M36	The consortium will ensure that any ethics issues identified are addressed.	**CEA**, all participants

C6.b Task 6.2: Project meetings

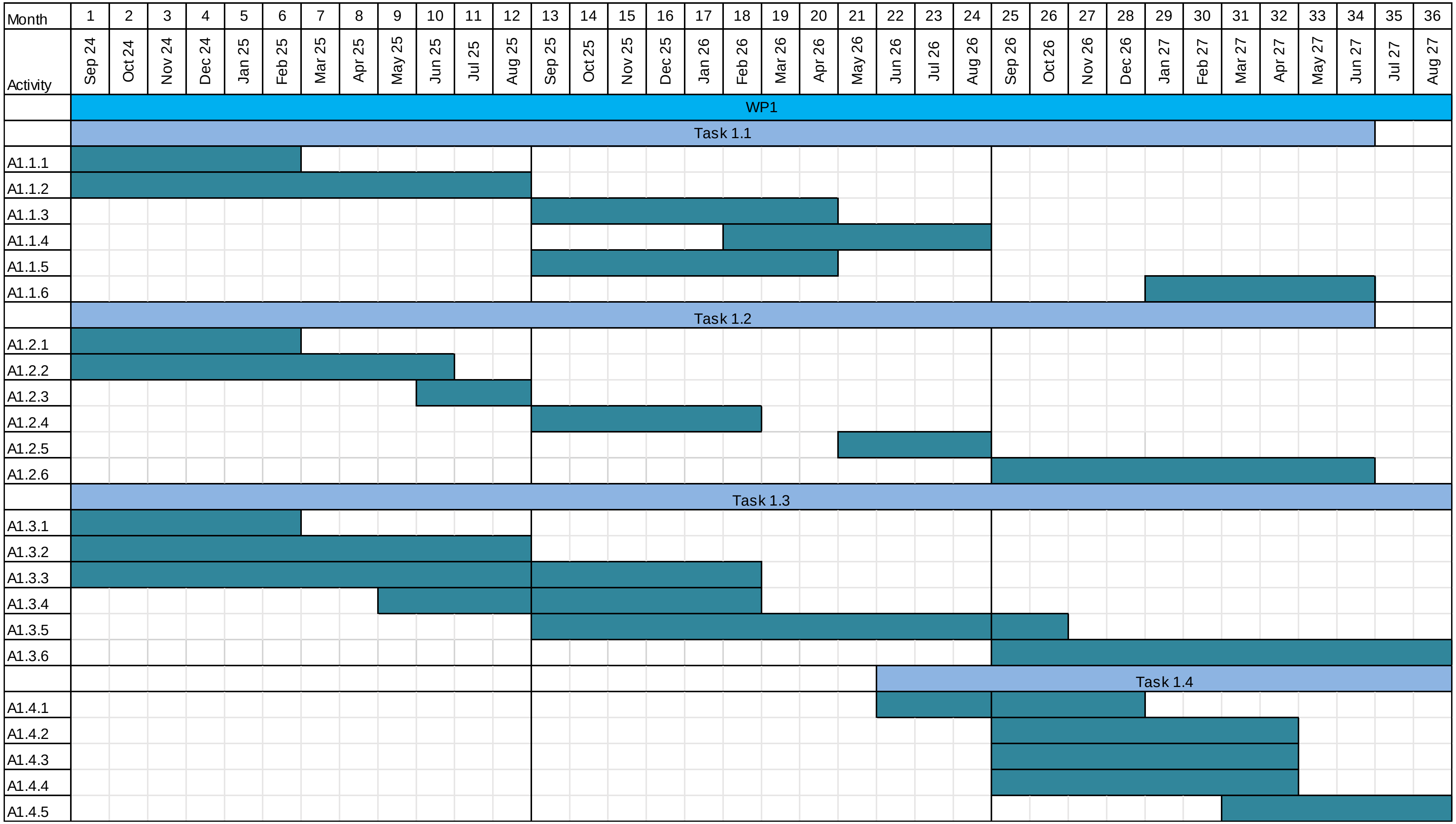
Activity number	Activity description	Participants (Lead in bold)
A6.2.1 M01	The kick-off meeting involving all participants will be held approximately one month after the start of the project, in France at LNE Paris.	**CEA**, all participants
A6.2.2 M36	There will be five formal project meetings. These meetings include the kick-off (A6.2.1), 1st interim (around M9 (May 2025)), mid-term (around M18 (February 2026)), 2nd interim (around M27 (November 2026)) and final meeting (around M36 (August 2027)). The meetings will be held prior to reporting. The meetings will review progress and will be used to ensure participants are clear as to their role for the next period. The location of the meetings will rotate among the participants. Where possible, meetings may be held as satellite meetings to important conferences or committee meetings.	**CEA**, all participants
A6.2.3 M36	In addition, technical meetings of work package groups may be held whenever necessary, and will be arranged on an ad-hoc basis.	**CEA**, all participants

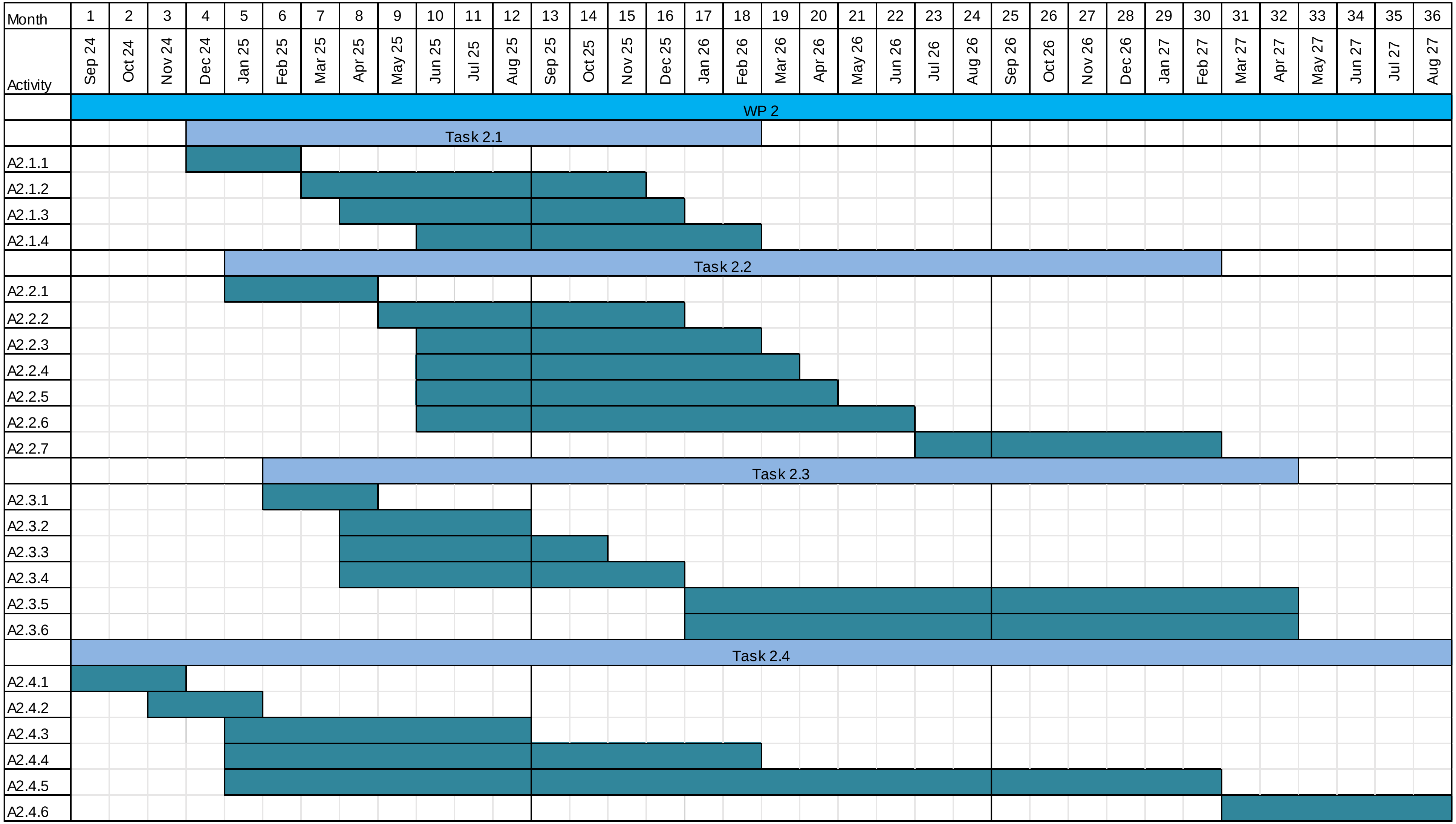
C6.c Task 6.3: Project reporting

Activity number	Activity description	Participants (Lead in bold)
A6.3.1 M01	One month after the start of the project a publishable summary will be produced and submitted to EURAMET.	**CEA**, all participants
A6.3.2 M06	Six months after the start of the project a data management plan (DMP) and a dissemination, communication and exploitation plan (DCE) will be produced and submitted to EURAMET.	**CEA**, all participants
A6.3.3 M36 +60 days	Following Articles 19 and 21 and the data sheet of the grant agreement, information will be submitted to EURAMET, in accordance with the procedures issued by them to enable EURAMET to comply with its obligations to report on the programme to the European Commission. • Progress reports will be submitted at months 9, 27 (May 2025, November 2026 + 45 days), 18, 36 (February 2026, August 2027 + 60 days). • Outcomes and Impact reports and updated publishable summaries will be submitted at the same times. All participants will provide input to these reports and the coordinator will provide these and updated publishable summaries to EURAMET. Where necessary, additional reports and / or information may be requested to enable EURAMET to comply with its obligations to the European Commission.	**CEA**, all participants
A6.3.4 M36 +60 days	Periodic Reports (including financial reports, updated data management plan, and updated dissemination, communication and exploitation plan) will be delivered at months 18 and 36 (February 2026, August 2027 + 60 days) in accordance with Articles 19 and 21 and the data sheet of the grant agreement. All participants will provide input to these reports and the coordinator will provide these to EURAMET.	**CEA**, all participants
A6.3.5 M36 +60 days	Final Reports will be delivered at month 36 (August 2027 + 60 days) in accordance with Articles 19 and 21 and the data sheet of the grant agreement. All participants will provide input to these reports and the coordinator will provide these to EURAMET.	**CEA**, all participants
A6.3.6 M20	Some projects will be subject to a midterm review in Spring 2026. Where projects are selected for a midterm review, reports (project self-assessment, updated publishable summary and presentation) will be delivered prior to the midterm reviews for Call 2023, following the schedule detailed by EURAMET for the specific review. All participants will provide input to these reporting documents and the coordinator will provide the documents to EURAMET.	**CEA**, all participants

Formal reporting will be in line with EURAMET's requirements and will be submitted in accordance with the Reporting Guidelines.

C7 Gantt chart

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WP 2
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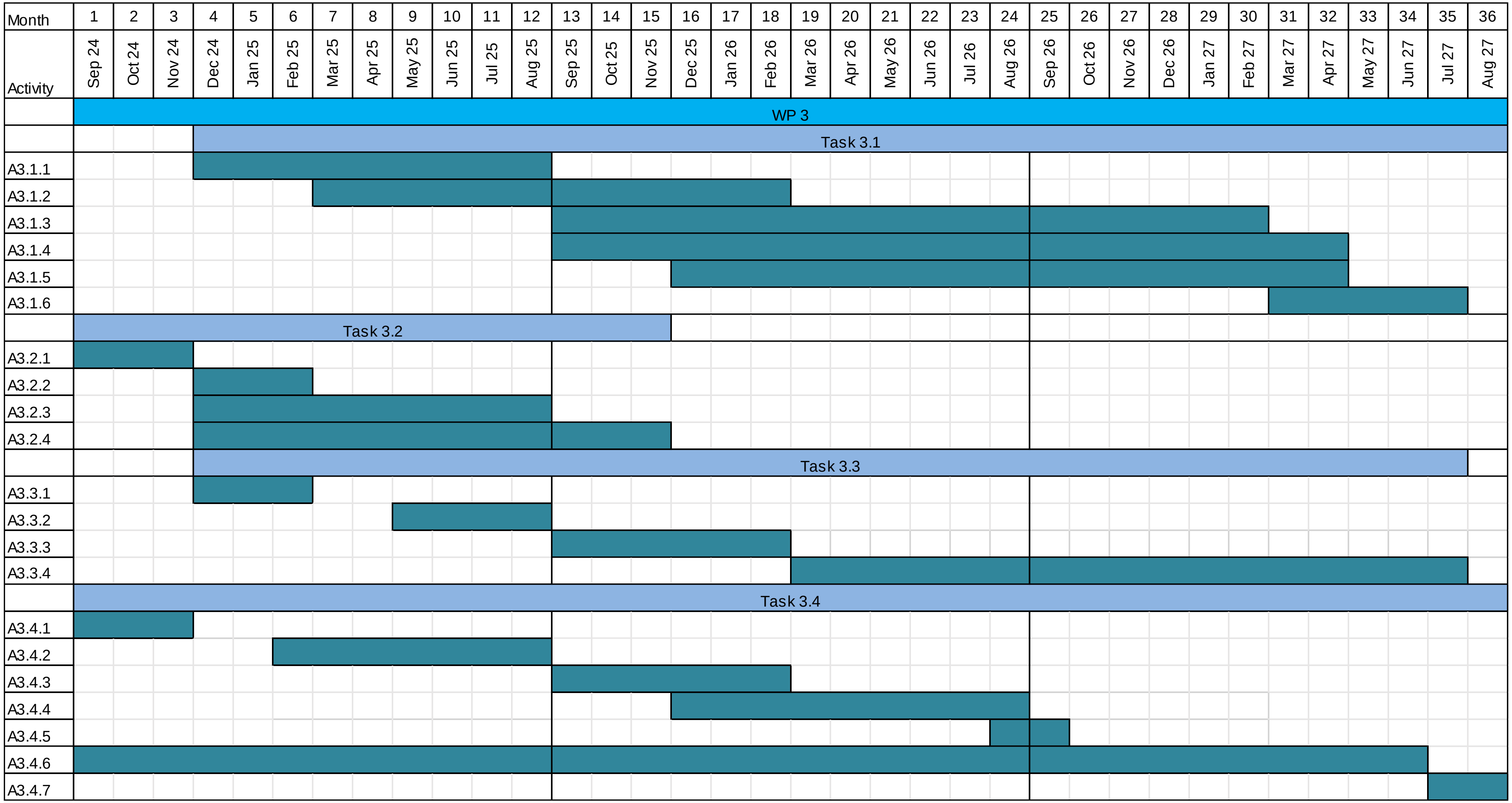
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WP 3
Task 3.1
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A3.1.5
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Task 3.2
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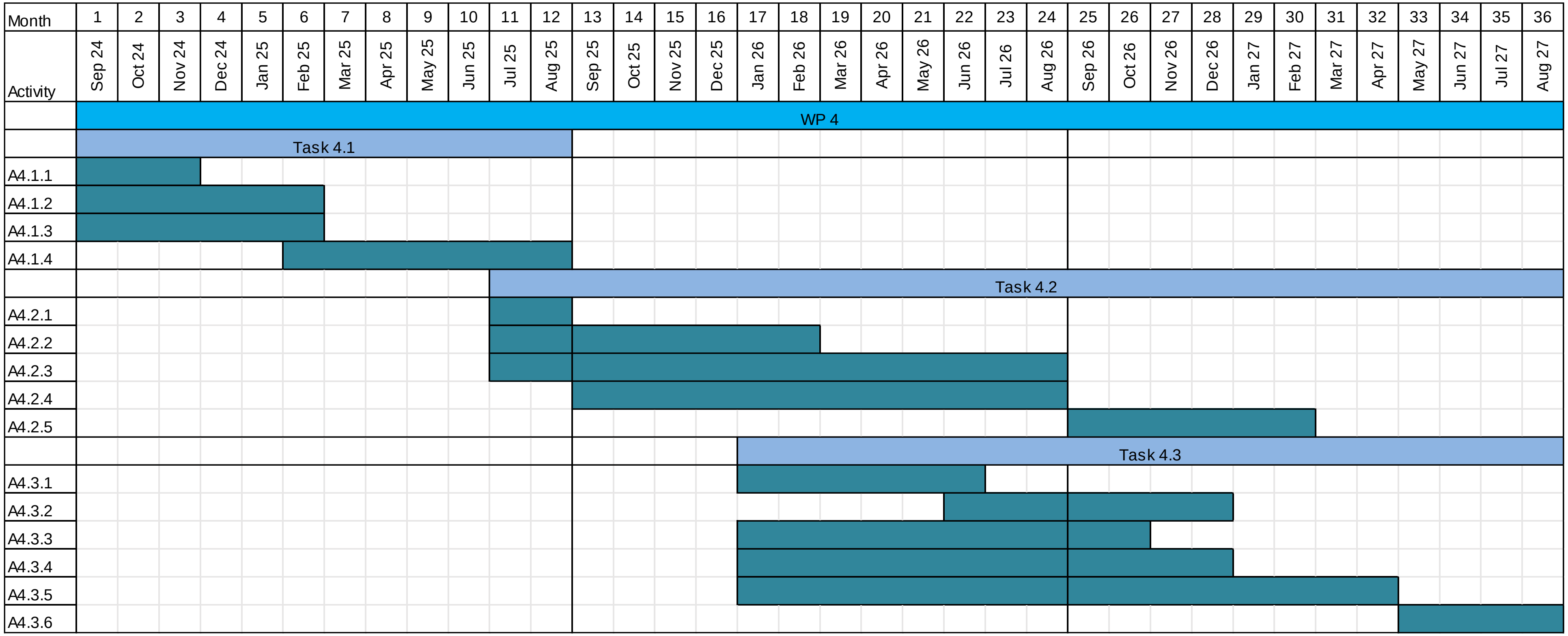
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WP 4
Task 4.1
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Section D: Risk and risk mitigation

D1 Scientific/technical risks

Risk (description)	**Likelihood, impact and severity of occurrence**	**Mitigation** i.e. what the consortium will do to decrease the likelihood of the risk occurring	**Contingency** i.e. what the consortium will do if despite the mitigation the risk still occurs
Task 1.1: The deviation between experimental and calculated data for sensitivity of semiconductor sensors is not as the target and cannot be used for further development	Likelihood after mitigation: Low Impact: Delay in A1.1.4 delivery. Level of severity: Medium	CMI will check MC models for calculated data and perform additional measurements to reach the target values.	CMI will ask other project participants for their assistance and also collaborators (e.g., CIEMAT, CTU) for creation of another MC model(s) and data calculation.
Task 1.2: Microphonics (i.e., electronic noise caused by mechanical vibrations) degrade the in-situ performance of ionisation chambers	Likelihood after mitigation: Low Impact: The ionisation chambers might not be suitable for implementation as transfer standards. Level of severity: High	USIEG with support of PTB are developing and testing ionisation chambers with active and passive noise reduction, based on mechanical springs, coaxial construction of the detector, and active electronic filters as well as self-stabilising chamber geometries that are less susceptible to microphonics.	The aim of the project is to develop different approaches to select the best one. Even if one of the approaches fails, the project is capable of reaching the objectives.
Task 1.3: Gas and pollutant up-take by the scintillating porous material leads to aging/ degrading performances along its uses	Likelihood after mitigation: Low Impact: The material loses its properties with time and cannot be used over a long time period Level of severity: High	The project aims to develop mass-manufactured sensors. In case of degradation, the sensor can easily be replaced. The aim of the project is to obtain scintillating porous material as reliable detector. One option is that for onsite measurements a protective layer will be applied to the material that will avoid degrading but reduce performance. Continuous on-site calibration is also a way to mitigate this risk and is one of the goals of the project.	The aim of the project is to develop different approach so that the riskiest one can be mitigated with another technique that is less challenging and relatively less innovative but still capable of reaching the objectives.
Task 1.3: Delay in testing a method/technique	Likelihood after mitigation: Medium Impact: Failure to address the assessment tests for the particular method/technique. Level of severity: Low	A reasonable distribution of duties will be done to avoid work overload and prevent that participants might not deliver. Several participants such as CEA, PTB, CMI, SUBG, INFIN-HH, SMU and UH can propose alternative testing solution in the consortium.	The consortium will redistribute the work among the participants that have availability.
Task 1.4: Delays or complications in the transfer process due to large cost of production	Likelihood after mitigation: Medium Impact: Failure to prepare a transfer of the technology to the industry. Level of severity: Low	CMI, CEA, SUBG, UCBL, PTB, USIEG, with the involvement of SMEs such as LivAir and Radonova and with the assistance of a large company such as NUVIA, will streamline the process, facilitating a smoother transfer to industrial organisations.	If the manufacturing cost is too high, the industrial goal will be redirected towards a more efficient device, thus less burdensome. On the other end, external assistance to the consortium, particularly through stakeholders, will facilitate the establishment of one or more large-scale manufacturing setups to meet the demand for low-cost production.

Task 2.1: Problems during the development of a new standard of radon gas due to a lack of the necessary sensitive measurement devices	Likelihood after mitigation: Low Impact: Calibration activities cannot be carried out. Level of severity: Low	CEA, PTB, IFIN-HH, SUBG and SMU will be contacted by CEA with a request to use their facilities (existing high activity radon gas standard).	CEA will contact stakeholders with such facilities such as BfS in Germany.
Task 2.2: The sensors' energy resolution or sensitivity show degradation with humidity, temperature, CO_2, or pressure	Likelihood after mitigation: Low Impact: The measurement uncertainty will be higher. Level of severity: Low	To prevent that the sensors are affected by humidity, temperature, CO_2, or pressure the project participant PTB, NPL and LivAir will provide state of the art monitors that will alert of any variation of these parameters. All three devices developed in WP1 will be monitored to prevent this degradation.	On the WP2 leader's request (PTB), the coordinator, calls a meeting with all participants to help solving the problem.
Task 2.3: Radon sensors show complex dependency on time-dependent environmental conditions (hysteresis effects)	Likelihood after mitigation: Low Impact: Increased uncertainty or biased measurements. Level of severity: Medium	CEA and SUBG will measure the behaviour of the radon sensor and quantify it in cooperation with WP4 participants, to match calibration constants, not just to current values of environmental parameters, but to their history as well.	The consortium will identify safe ranges of rate of change of environmental parameters within which sensors can be trusted, and flag sensor data as possibly compromised if rate of change of environmental parameters exceeds these bounds.
Task 2.4: The decision criteria may be too complex to be met for the instruments selected as measurement sensors or transfer standards	Likelihood after mitigation: Low Impact: May change the criteria to the instruments developed in WP1. Level of severity: Medium	PTB with support from all participants will revisit all the developed detectors and try to improve performance to match the decision criteria.	If some of the detectors do not pass the decision criteria even after the mitigation, the consortium will continue with a smaller set of detectors in WP3 and WP4.
Task 3.1: No suitable testbed facility is found	Likelihood after mitigation: Low Impact: It would be impossible to test the radon network under field conditions. Level of severity: High	Talks between the participants and potential building owners have already started during the writing of the Grant Agreement. UH has the facilities for the test bed with the necessary authorisations.	The network will be installed in the facilities of some of the participants (Such as CEA, SUBG and PTB building already presenting 3 very different natural level of radon). If the sensors required for expanding the network for measurements other than radon are not already installed, they will be purchased and implemented accordingly.
Task 3.1: Technical difficulties may arise while establishing the testbed and the test network within the testbed developed within A3.1.2	Likelihood after mitigation: Low Impact: It would be impossible to test some of the radon sensors under field conditions. Level of severity: Medium	To mitigate this the consortium will start with tests of the installations of more types of the sensors developed in A1.1.2, A1.2.5, A1.3.2 and A1.3.3. This will increase the probability to overcome technical difficulties. Also, commercial instruments in the testing will be added by PTB and other participants.	If some of the detectors do not pass the decision criteria even after the mitigation, the consortium will continue with smaller set of detectors in WP3 and WP4. Also, commercial detectors for the future tests in WP3 and WP4 will be added.
Task 3.2: The data and calibration methods from existing gamma dose/spectrometry networks may not be found suitable for application to calibrate the radon monitoring networks	Likelihood after mitigation: Low Impact: Knowledge and good practices from other networks may not be applicable to radon sensor networks. Level of severity: Medium	The consortium (PTB, UH and other participants) will develop procedures dedicated to radon sensor networks specifically.	The consortium will implement and will work with the procedures developed specifically for the radon sensor networks.

Task 3.2: The UK 'Sigma' network does not provide sufficient information to establish calibration methods	Likelihood after mitigation: Low Impact: It would be impossible to develop and test calibration methods for radon network. Level of severity: High	UH can also provide data from the Finnish network, thereby increasing the amount of information available to conduct the work. Additionally, LivAir can supply data from its deployed radon sensor network.	If the data are insufficient, other members of the consortium will request necessary information from other participants, such as the military department of CEA or the existing infrastructure of CLOR. If this information proves inadequate, additional data will be collected from stakeholders, such as those who already pledged to support the project (e.g., AGES and Bfs).
Task 3.3: Some of the commercially available sensors for radon measurements may have difficulties to connect to the developed network by the interface based on Message Queuing Telemetry Transport (MQTT)	Likelihood after mitigation: Low Impact: Not all of the commercial sensors may be connectable to the testbed network via the envisioned protocol, mainly due to "know-how" saving policy. Level of severity: Medium	The consortium (PTB, UH and other participants) will develop parallel network, for which the sensors in question are known to connect without problems.	If the mitigation does not work, the consortium will continue without these commercial detectors.
Task 3.4: The methods/models that will be developed for proper background estimation prove to be unreliable when implemented	Likelihood after mitigation: Low Impact: Increased uncertainty or biased measurements. Level of severity: Medium	Conventional methods for background estimation will be used in WP2 and complemented by the new methods in WP3.	Conventional methods will be used for background estimations.
Task 4.1: Inaccurate or incomplete technical information gathered about sensors and environmental monitoring technologies could lead to suboptimal selection and implementation of monitoring solution	Likelihood after mitigation: Low Impact: ineffective monitoring of indoor air quality and radon levels in large buildings. Level of severity: Low	CLOR will ensure thorough validation and cross-referencing of technical information gathered from various sources to verify accuracy and completeness.	CLOR with support of all participants will consult experts from relevant fields (such as IRSN and BfS) to provide guidance and validation of collected information.
Task 4.2: Air quality parameters (such as CO_2 concentration, pollution in the building, volatile organic compounds, aerosols) may have little synergy with radon i.e. they may not have high correlation with indoor radon concentrations	Likelihood after mitigation: Low Impact: It will become more difficult to connect radon readings with those of the other sensors. Level of severity: Medium	A broader approach, including non-parametric analysis may be tested by NPL, PTB and CLOR and other participants to describe the synergy between radon and the other parameters.	The radon sensor may appear to be a separate system for the air quality networks, not correlated with the other parameters. The consortium will provide evidence in this case that the data from the radon sensors have to be considered separately from the data from the other sensors.
Task 4.3: Automated coupling of radon data analysis to the facilities ventilation system fails	Likelihood after mitigation: Medium Impact: Too much or too little ventilation. Level of severity: Medium	WP4 includes several tests of the radon data analysis. A clear relationship between radon activity concentration levels and ventilation will be established.	The ventilation system and the radon activity concentration will be decoupled, and a manual adjustment of the ventilation will be necessary until the problem is solved.

D2 Management risks

Risk (description)	**Likelihood, impact and severity of occurrence**	**Mitigation** i.e. what the consortium will do to decrease the likelihood of the risk occurring	**Contingency** i.e. what the consortium will do if despite the mitigation the risk still occurs
Key personnel are lost to the project	Likelihood after mitigation: Very low Impact: The loss of key team members would create difficulties in delivering the project, or specific tasks or deliverables. Level of severity: Medium	None of the team members are planning to leave or retire within the project. The grouping of experts within the consortium will minimise the areas where knowledge is held by a single person. All the participants will identify backups for key workers wherever possible to reduce the overall risk to the project. Project plans and software will be shared within the consortium and results and methodology will be documented.	If a key member leaves the project, then the participant concerned will be responsible for appointing a replacement. WP leaders will be notified in advance of upcoming key members' departures. However, this may still lead to a delay in delivery.
Complexity of managing a large consortium	Likelihood after mitigation: Low Impact: Failure to fully cooperate or communicate effectively within the consortium could endanger efficient delivery of the project. Level of severity: Low	The participants are all experienced with complex multinational projects. Many have previously developed close relationships through collaborating within other European consortia. One representative from each participant (generally the member of the project management board) and one deputy will be the interlocutors for management issues. Regular communication and feedback will ensure that potential problems are identified early and that all participants are clear on their roles.	WP leaders will play an important role in flagging up potential problems to the coordinator and the project management board, who will then decide on the best course of action to take. If necessary, work will be reassigned to an alternative participant, or parts of the work re-scoped in agreement with EURAMET.
Inter-dependencies between technical activities and tasks are too complex	Likelihood after mitigation: Low Impact: Tasks are delayed, or it is not possible to deliver them. Level of severity: Low	Technical meetings run by WP leaders have been scheduled to ensure proper sharing of knowledge. The interdependencies between tasks will be considered at meetings to ensure that this is addressed properly in the planning of the work. The technical WPs will be closely managed by their WP leaders to ensure that they deliver their own outputs.	In most cases, activities on the critical path have some overlap in time and thus a delay in the output of one deliverable does not necessarily cause an immediate delay in another.
The onsite facilities of participants, and/or access to public/commercial services or sites is restricted for a period of time during the project due to an extraordinary event or situation that is beyond the participants' control e.g. COVID-19	Likelihood after mitigation: High Impact: Activities and deliverables are delayed, or no longer able to be completed. Level of severity: High	In most cases, activities on the critical path have been scheduled to have some overlap in time and thus a delay in the output of one activity will not necessarily cause an immediate delay in another.	Where possible, work will be reassigned to an alternative participant, or rephased, therefore minimising delays and technical deviations that would have a negative impact on the project. If necessary, the consortium will contact EURAMET to discuss options according to the grant agreement.

Organisation of workshops and joint demonstrator activities in a post- or trans-COVID world	Likelihood after mitigation: Medium. Impact: Failure to show the outputs at workshops or through joint demonstrator activities risks reducing the knowledge transfer and impact from the project. Level of severity: Low	Although most COVID travel restrictions have been removed, there is the possibility that some restrictions may be re-introduced nationally or internationally, or organisations may apply their own restrictions. Some flexibility is built into the tasks and activities with nominal locations and dates, but these will be reviewed nearer the time and the consortium will decide on the appropriate locations of such activities e.g. to take advantage of/cope with moved external events.	Alternatives such as webinars or online meetings can be used.
Problems dealing with Intellectual Property (IP) ownership and/or exploitation might occur and could be a source of potential conflict	Likelihood after mitigation: Low Impact: Disagreement between the participants could delay the project (in implementing the work and publishing results). Level of severity: Low	All beneficiaries will sign the grant agreement and all participants will sign the consortium agreement, which includes IP clauses. IP will be handled accordingly.	Independent arbitrators will be used in the event of disagreement between participants.
A collaborator fails to provide access to facilities or equipment	Likelihood after mitigation: Very low Impact: The consortium may not be able to complete the planned work, or the work might need to be delayed until another collaborator or alternative access to facilities or equipment is found. Level of severity: Medium	The coordinator or relevant participant will liaise with the collaborator early in the project regarding access to the facilities / equipment. All collaborators are professional organisations and experienced in working in projects. Each WP leader will work closely with each associated collaborator to report any issues back to the coordinator. Project meetings are held every 9 months, so any issues will be discussed at these meetings.	The WP leader will work with the coordinator to find an alternative collaborator or alternative access to facilities or equipment. If necessary, parts of the work will be re-scoped in agreement with EURAMET

D3 Ethics

The Partnership Ethics Review 2023 has given JRP 23IND07 RadonNET “Ethics clearance”.

Ethical integrity

The participants will ensure that all ethics issues related to activities in the project are addressed in compliance with ethical principles (including the highest standards of research integrity as set out in the ALLEA European Code of Conduct for Research Integrity https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/european-code-of-conduct-for-research-integrity_horizon_en.pdf), the applicable international and national law, and the provisions set out in the grant agreement. This includes the ethics issues identified in the ethics screening and the submitted documents, and any additional ethics issues that may emerge in the course of the project. In the case where any substantial new ethics issues arise, participants will inform the granting authority EURAMET e.V, and for each ethics issue applicable, participants will follow the guidance provided in the Horizon Europe *'How to complete your ethics self-assessment' guide'*.

The consortium will ensure that appropriate procedures, policies and structures (https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/guideline-for-promoting-research-integrity-in-research-performing-organisations_horizon_en.pdf) are in place to foster responsible research practices, to prevent questionable research practices and research misconduct, and to handle allegations of breaches of the principles and standards in the Code of Conduct.

Data protection

By signing or acceding to this grant agreement and / or consortium agreement each participant asserts that the requirements of the General Data Protection Regulation (GDPR) 2016/679 which entered into force on 25

May 2018 will be met. Under the regulation, the data controllers and processors are fully accountable for the data processing operations. Any violation of the data subject rights may lead to sanctions as described in Chapter VIII, art.77-84 of the GDPR.

If personal data are transferred from the EU to a non-EU country or international organisation, such transfers will be in accordance with Chapter V of the GDPR 2016/679. If personal data are transferred from a non-EU country to the EU (or another third state), such transfers will comply with the laws of the country in which the data was collected.

Non-EU countries

The consortium will ensure that participants and collaborators, including those from non-EU countries, fully adhere to Horizon Europe ethics standards and guidelines, no matter where the research or activities are carried out and that research or activities performed outside the European Union are compatible with EU, national and international legislation and can be legally conducted in one of the EU Member States. If applicable, details on the material, samples and/or equipment which will be imported to/exported from EU must be provided and the adequate authorisations granted by the relevant authorities have been or will be obtained and kept on file by the consortium. The consortium will also, in the case of dual use applications, clarify whether any export licence is required for the transfer of knowledge, equipment or material.

Environmental and Health and Safety

The ethics screening identified that there are potential environmental and health and safety issues arising from this project, related to the use of radioactive materials.

By signing or acceding to this grant agreement and / or the consortium agreement each participant asserts that appropriate health and safety procedures conforming to relevant local and national guidelines and/or legislation (including national nuclear laws and standards and international recommendations), are followed by staff involved in this project. Only staff certified by national nuclear regulators will handle radioactive substances. Any risks and precautions will be clearly stated and understood by all staff involved in the project, and the risks minimised where appropriate. The radiation protection principle ALARA (As Low As Reasonably Available) will always be applied for dealing with any radioactive material. Rules and principles given by national and international radiation protection bodies will be followed. Radioactive materials will always be dealt with in control zones with permission from national nuclear regulators. The transport of radioactive substance within a country, or between countries will always be performed by certified companies and permission will be obtained from relevant national nuclear regulators. Moreover, principles of the EU Council Directive 2013/59/EURATOM, laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and International Atomic Energy Agency (IAEA) basic safety standards (BSS) will be followed. For safety purposes, authorisations for the use of facilities and materials will be obtained, where appropriate, and kept on file by the consortium (e.g. approval of safe working practices in the laboratory, security classification of the laboratory). Where applicable, further information on the possible harm to the environment and environmental risks due to the research, and the precautions and measures taken to mitigate the risks will be kept on file by the consortium.

Artificial intelligence

The ethics screening identified that there are issues arising from project work involving artificial intelligence.

By signing or acceding to this grant agreement each participant asserts that any work involving artificial intelligence is carried out in agreement with ethical principles and relevant legislations. Any AI used in the project, as well as its type and state, must be clarified and dealt with appropriately.

The consortium will ensure that any AI methods used and/or developed in the project comply with the prerequisites for ethically sound AI systems in accordance with the '*Ethics Guidelines for Trustworthy AI*'.

Section E: References

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